GEOSPATIAL MODELING FOR AGRICULTURAL DROUGHT VULNERABILITY ASSESSMENT IN NAKHON RATCHASIMA, THAILAND

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

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แบบจำลองเชิงพื้นที่สำหรับการประเมินความเปราะบาง ภัยแล้งด้านเกษตรกรรม นครราชสีมา ประเทศไทย

นายคชา เชษฐบุตร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต

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

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คชา เชษฐบุตร : แบบจำลองเชิงพื้นที่สำหรับการประเมินความเปราะบางภัยแล้งด้านเกษตรกรรม นครราชสีมา ประเทศไทย (GEOSPATIAL MODELING FOR AGRICULTURAL DROUGHT VULNERABILITY ASSESSMENT IN NAKHON RATCHASIMA, THAILAND) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.ทรงกต ทศานนท์, 331 หน้า.

จังหวัดนครราชสีมาตั้งอยู่ในพื้นที่เสี่ยงภัยแล้งและภาวะแล้งซ้ำซากซึ่งส่งผลกระทบต่อการดำรงชีวิตของประชาชน ภาคเกษตรกรรมและความมั่นคงทางอาหาร วัตถุประสงค์ของการศึกษา คือ (1) เพื่อวิเคราะห์และจัดทำแผนที่ภัยแล้งด้านอุตุนิยมวิทยา (การเปิดเผยของความเสี่ยงภัยแล้ง) ความอ่อนไหวของภัยแล้งด้านเกษตรกรรม และความสามารถในการปรับตัว สำหรับการประเมินความเปราะบางภัยแล้งด้านเกษตรกรรม และ (2) เพื่อสร้างและจัดทำดัชนีความเปราะบางภัยแล้งด้านเกษตรกรรม โดยอ้างอิงจากดัชนีที่สำคัญ ได้แก่ ดัชนีการเปิดเผยของความเสี่ยงภัยแล้ง ดัชนีอ่อนไหวของภัยแล้งด้านเกษตรกรรม และดัชนีความสามารถในการปรับตัว ในการศึกษาครั้งนี้ การเปิดเผยของความเสี่ยงภัยแล้ง เป็นการพิจารณาร่วมกันระหว่าง ความถี่และความเข้มของภัยแล้งด้านอุตุนิยมวิทยา ซึ่งมี 3 ช่วงเวลา (SPI-3m7 SPI-3m10 และ SPI-6m10) ความอ่อนไหวของภัยแล้งด้านเกษตรกรรมแบบภาพรวม เป็นการพิจารณาร่วมกันของปัจจัยทางด้านสภาพอากาศ พืชพรรณ กายภาพ และปัจจัยด้านเศรษฐกิจและสังคม โดยพิจารณา 3 ช่วงเวลา (3m7 3m10 และ 6m10) และการศึกษาความสามารถในการปรับตัว เป็นการ ใช้ข้อมูลเศรษฐกิจและสังคม ซึ่งแบ่งข้อมูลโดยใช้เทคนิค natural break เป็น 5 ระดับ (ต่ำมาก ต่ำ ปานกลาง สูง และสูงมาก) และนำปัจจัยหลักทั้งสามมาพิจารณาร่วมกัน เพื่อการวิเคราะห์และจำแนกพื้นที่เปราะบางภัยแล้งด้านเกษตรกรรมของจังหวัดนครราชสีมา

ผลการศึกษา พบว่า การจำแนกการเปิดเผยของความเสี่ยงภัยแล้งใน 3 ช่วงเวลา (3m7 3m10 และ6m10) มีระดับของการจำแนกที่พบมากที่สุด คือ สูงและสูงมาก ครอบคลุมพื้นที่คิดเป็น 43.60 39.20 และ49.50 เปอร์เซ็นต์ของพื้นที่ทั้งจังหวัด เรียงตามลำดับ การจำแนกความเปราะบางภัยแล้งด้านเกษตรกรรมใน 3 ช่วงเวลา พบว่า ระดับของการจำแนกที่พบมากที่สุด คือ ต่ำมาก และต่ำ โดยครอบคลุมพื้นที่คิดเป็น 36.55 40.43 และ 40.62 เปอร์เซ็นต์ของพื้นที่ทั้งจังหวัด เรียงตามลำดับ การจำแนกความสามารถในการปรับตัวต่อผลกระทบจากภัยแล้ง พบว่า ระดับของการจำแนกที่พบมากที่สุด คือ ต่ำมาก และต่ำ โดยครอบคลุมพื้นที่คิดเป็น 38.73 เปอร์เซ็นต์ ของพื้นที่ทั้งจังหวัด และการจำแนกความเปราะบางภัยแล้งด้านเกษตรกรรมระดับจังหวัดในช่วงเวลา 3m7 พบว่า ระดับของการ

จำแนกที่พบมากที่สุด คือ ต่ำมาก และต่ำ โดยครอบคลุมพื้นที่คิดเป็น 35.83 เปอร์เซ็นต์ ของพื้นที่ทั้งจังหวัด การจำแนกความเปราะบางภัยแล้งด้านเกษตรกรรมระดับจังหวัดในช่วงเวลา 6m10 พบว่า ระดับของการจำแนกที่พบมากที่สุด คือ ต่ำมาก และต่ำ โดยครอบคลุมพื้นที่คิดเป็น 37.91 เปอร์เซ็นต์ ของพื้นที่ทั้งจังหวัด และ การจำแนกความเปราะบางภัยแล้งด้านเกษตรกรรมระดับจังหวัดในช่วงเวลา 3m10 พบว่า ระดับของการจำแนกที่พบมากที่สุด คือ สูง และสูงมาก โดยครอบคลุมพื้นที่คิดเป็น 42.35 เปอร์เซ็นต์ ของพื้นที่ทั้งจังหวัด

จากผลการศึกษาสรุปได้ว่า แบบจำลองเชิงพื้นที่เป็นเครื่องมือที่มีประสิทธิภาพในการประเมินการเปิดเผยของความเสี่ยงภัยแล้ง ความอ่อนไหวของภัยแล้งด้านเกษตรกรรม และความสามารถในการปรับตัวสำหรับประเมินความเปราะบางภัยแล้งด้านเกษตรกรรม จังหวัดนครราชสีมา

สาขาวิชาภูมิสารสนเทศ
ปีการศึกษา 2560

ลายมือชื่อนักศึกษา______
ลายมือชื่ออาจารย์ที่ปรึกษา______
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม______

KACHA CHEDTABUD : GEOSPATIAL MODELING FOR AGRICULTURAL DOUGHT VULNERABILITY ASSESSMENT IN NAKHON RATCHASIMA, THAILAND. THESIS ADVISOR : ASSOC. PROF. SONGKOT DASANANDA, Ph.D. 331 PP.

EXPOSURE DROUGHT HAZARD/OVERALL AGRICULTURAL DROUGHT SENSITIVITY/ ANNUAL AGRICULTURAL DROUGHT SENSITIVITY / ADAPTIVE CAPACITY / AGRICULTURAL DROUGHT VULNERABILITY

Nakhon Ratchasima province is drought prone areas, recurrent of drought that effected to human life, agricultural sector and food security. The main objectives were (1) to analyze and map meteorological drought (exposure hazard), agricultural drought sensitivity and adaptive capacity for agricultural drought vulnerability assessment, and (2) to create and map agricultural drought vulnerability index based on prominent exposure, sensitivity and adaptive capacity indices. In this study, exposure drought hazard based on combination of meteorological drought hazard frequency and intensity of 3 periods (SPI-3m7, SPI-6m10, and SPI-6m10), overall agricultural drought sensitivity based on integration of climate, vegetation, physical and socio-economic factors of 3 periods (3m7, 6m10, and 6m10) and adaptive capacity based on socio-economic data were separately analyzed and classified into 5 levels (very low, low, moderate high, and very high) by natural break method. Then, their classifications were combined to analyze and classify agricultural drought vulnerability of Nakhon Ratchasima province.

As results, the most dominant class of exposure drought hazard classification of 3 periods at province level was high and very high exposure drought hazard and covered area of 43.60%, 39.20%, and 49.50%, respectively. Likewise, the most dominant class of overall agricultural drought sensitivity classification of 3 periods at province level was very low and low and covered area of 36.55%, 40.43%, and 40.62%, respectively. Similarly, the most dominant class of adaptive capacity to agricultural drought effect at provincial level was very low and low adaptive capacity and covered area of 38.73%. Subsequently, the most dominant class of agricultural drought vulnerability assessment at province level of 3m7 period was very low and low agricultural drought vulnerability and covered area of 35.83%. Likewise, the most dominant class of 6m10 period was very low and low agricultural drought vulnerability and covered area of 37.91%. In contrast, the most dominant class of 3m10 period was high and very high agricultural drought vulnerability and covered area of 42.35%.

In conclusion, it appears that geospatial modeling can be efficiently used as tools to assess exposure drought hazard, agricultural drought sensitivity, and adaptive capacity for agricultural drought vulnerability assessment.

School of Geoinformatics

Academic Year 2017

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Kacha Chedtabud

CONTENTS

CONTENTS (Continued)

Page

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

Page

CONTENTS (Continued)

CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF ABBREVIATION

3m7	=	May, June and July
3m10	=	August, September and October
6m10	=	May, June, July, August, September and October
AADS	=	Annual Agricultural Drought Sensitivity
ACI	=	Adaptive Capacity Index
AUC	=	Area under Curve
AVHRR	=	Advanced Very High Resolution Radiometer
AWC	=	Available water capacity
CART	=	Classification and Regression Tree
CDF	=	Cumulative Distribution Function
CV	=	Coefficient Variation
CWSI	=	Crop Water Stress Index
CZI	=	China-Z index
DDPM	=	Department of Disaster Prevention and Mitigation
DEM	=	Digital Elevation Model
DEQP	=	Department of Environmental Quality Promotion
DHI_{Met}	=	Meteorological Drought Hazard Frequency Index
DVI	=	Drought Vulnerability Index
ED	=	Extreme Drought
EDII	=	European Drought Report Inventory

LIST OF ABBREVIATION (Continued)

EOST	=	End Of Season Time
ET	=	Evapotranspiration
EVI	=	Enhanced Vegetation Index
GAMs	=	Generalized Additive Models
GDP	=	Gross Domestic Product
HH	=	Household
HRU	=	Hydrologic Response Units
IDVI	=	Integrated Drought Vulnerability Index
IDW	=	Inverse Distance Weighting
JERS-1	=	Japanese Earth Resources Satellite 1
KG	=	Kilogram
LCWS	=	Linear Combination Weighting System
LDD	=	Land Development Department
LMB	=	Lower Mekong Basin
LST	=	Land Surface Temperature
LU	=	Land Use
LULC	=	Land Use and Land Cover
MCE	=	Multi-Criteria Evaluation
MD	=	Moderate Drought
MODIS	=	Moderate Resolution Imaging Spectroradiometer
MOSTE	=	Ministry of Science, Technology and Environment
NADM	=	North American Drought Monitor

LIST OF ABBREVIATION (Continued)

NDVI	=	Normalized Different Vegetation Index
NDWI	=	Normalized Difference Water Index
NMDI	=	Normalized Multi-band Drought Index
NND	=	Near Normal Drought
NRD2C	=	National Economic and Social Development Board
NOAA	=	National Oceanic and Atmospheric Administration
OADS	=	Overall Agricultural Drought Sensitivity
OP	=	Occurrence Probability
PASG	=	Percent Annual Seasonal Greenness
PCI	=	Precipitation Condition Index
PDF	=	Probability Distribution Function
PDSI	=	Palmer Drought Severity Index
PET	=	Potential Evapotranspiration
PSA	=	Potential Surface Analysis
R	=	Correlation coefficient
R^2	=	Coefficient of determination
RDI	=	Reconnaissance Drought Index
RMSE	=	Root Mean Square Error
ROC	=	Receiver Operating Characteristic
SAW	=	Simple Additive Weighting
SAWC	=	Soil Available Water Content
SD	=	Severe Drought

LIST OF ABBREVIATION (Continued)

SDI	=	Streamflow Drought Index
SG	=	Savitsky-Golay
SG	=	Seasonal Greenness
SMCI	=	Soil Moisture Condition Index
SMDI	=	Soil Moisture Deficit Index
SOSA	=	Start of Season Anomaly
SOST	=	Start Of Season Time
SPAEI	=	Standardized Precipitation Actual Evapotranspiration Index
SPEI	=	Standardized Precipitation Evapotranspiration Index
SPI	=	Standardized Precipitation Index
SWSI	=	Surface Water Supply Index
TCI	=	Temperature Condition Index
TDS	=	Total dissolved solids
TMD	=	Thai Meteorological Department
TRMM	=	Tropical Rainfall Measuring Mission
TVDI	=	Temperature Vegetation Dryness Index
USDM	=	U.S. Drought Monitor
VAM	=	Vulnerability Assessment Method
VCI	=	Vegetation Condition Index
VegDRI	=	Vegetation Drought Response Index
VegOut	=	Vegetation Outlook
VHI	=	Vegetation Health Index

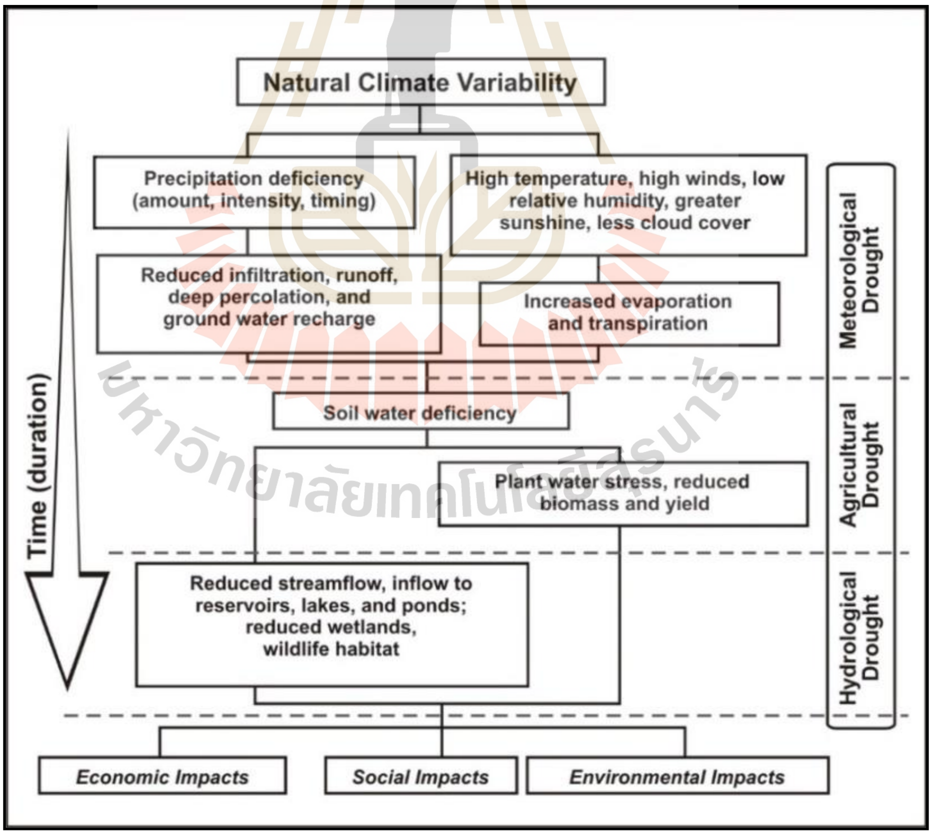
CHAPTER I

INTRODUCTION

1.1 Background problem and significance of the study

Natural disaster is a common threat that shall have huge negative effect on people or environment like flood, drought, landslide, earthquake, tornado, volcanic eruption, or tsunami (Mishra and Singh, 2010). Impact of each disaster is different depending on characteristics of the disaster itself, for examples, duration of time (start and end event), intensity, frequency, spatial extent, specific geography, or severity. For instance, when considered geographic aspect, most natural disasters usually appear in the unique areas such as volcanic eruptions and earthquakes mostly happen along the ring of fire region (i.e. the boundaries of tectonic plates over the Pacific Ocean); tornados typically occur over the vast lowland of the North American continent. While, regarding spatial extent aspect, spatial scale of the affected area could be defined as slightly, small, moderately, large, or largest under the referred criteria.

Drought is a complex phenomenon with no accepted universal definition because of its unpredicted started and ended point time, or how long the event would happen, as well as the non-specific spatial extent or geography for the observed incidence such as plateau areas, river basin or mountain, and the very uncertain frequency and intensity. In general, Park et al. (2016) explained that drought, unlike other natural disasters such as floods and earthquakes, is a slow developing event and it is hard to define its spatial extent and temporal starting and ending point. Its severity typically depends on duration, intensity, spatial extent, and local socioeconomic conditions (Son et al., 2012). There is no single indicator that can fully explain complexity and diversity of drought because it usually has multiple factors as a cause. Conventionally, drought can be classified into four types: meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought (Figure 1.1). However, all droughts originate from a deficiency of precipitation, or from meteorological drought, but other types of drought and impacts shall cascade from this stated deficiency.



Source: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.

Figure 1.1 Common types of drought along with their relation and relevant impacts.

Main occupation of Thailand is agriculture whose productivity crucially relies on amount of rainfall as effective irrigation system for farms is still limited (Punprasit, 2006). Homdee et al. (2016) described that Thailand region is characterized by a monsoon tropical climate with distinctive dry and rainy seasons causing droughts and floods to repeat alternatively. Consequently, impact of climate change, particularly drought occurrence, has become important issue for the country for a long time (Prathumchai et al., 2001; Jamphon, 2004), particularly in the northeast region of Thailand. During the past decades, most parts of this region have experienced several wide and prolonged severe drought events which led to huge loss of main agricultural products, especially rice and several economic crops (Department of Disaster Prevention and Mitigation, 2007). In addition, period of rainfall data (35 years) illustrated that the western of the northeast region including Nakhon Ratchasima province has the least of rainfall (Sompit Nithiyanan, 2003).

Furthermore, Nakhon Ratchasima province is a large province that locates in the middle of the country. So, it is often slightly influenced by winds of the Indian and Pacific Ocean. From the historical of drought areas (Table 1.1) and the historical of drought and dry-spell that effected to agricultural areas (Table 1.2) demonstrates that Nakhon Ratchasima province is drought prone areas, recurrent of drought that effected to human life, agricultural sector and food security.

Refer to Table 1.2, it can be observed that the area of agricultural drought in 2010 is rather low when it compares with other years because this year is wet year, an average rainfall (1,265.6 mm) is higher than an average 42 year records (1,051.4 mm). In addition, severe flood taken place in many districts of Nakhon Ratchasima province, particularly Mueang Nakhon Ratchasima, and Pak Thong Chai districts.

Table 1.1 The historical of drought areas in Nakhon Ratchasima province.

Years	**Number of drought areas**			
	District	**Sub-district**	**Villages**	**Household**
1988	21	97	524	51,280
1990	17	163	836	82,484
1991	24	194	600	58,594
1992	25	215	1,058	91,389
1993	25	409	1,301	137,644
1994	25	241	1,229	126,655
1996	23	204	920	95,113
1997	28	210	956	114,046
1998	32	237	1,320	128,910
1999	9	58	270	23,501
2004	31	268	2,943	34,870
2007	28	198	996	n.a

Source: Department of Disaster Prevention and Mitigation (2007)

Table 1.2 The historical data of drought and dry-spell effected to agricultural areas in Nakhon Ratchasima province.

Years	**Areas of agricultural drought (km2)**
2005	1,575.04
2007	539.52
2009	202.95
2010	4.80
2012	507.18
2013	1,061.39
2014	1,179.66

Source: Nakhon Ratchasima provincial agriculture office (2017)

Therefore, knowledge of the drought vulnerability along with its potential impact to farmers and local people is very essential for effective planning of drought warning and mitigation policy. This need can be systematically fulfilled by application of geospatial models for agricultural drought vulnerability analysis using relevant GIS-based and satellite-based data, from which the drought zone of the study area in Nakhon Ratchasima Province can be classified and mapped to aid agricultural drought vulnerability identification and mitigation purposes in the future. All these aforementioned tasks are carried out in this thesis as a pilot work for Thailand, in which three main aspects of agricultural drought vulnerability including exposure, sensitivity and adaptive capacity are thoroughly investigated for the examined area.

1.2 Research objective

Main purpose of this research is to investigate agricultural drought vulnerability of the chosen study area in Nakhon Ratchasima Province of Thailand with great prone to strong drought impact, in which two specific topics of the analysis are fulfilled as follows:

(1) To analyze and map meteorological drought (exposure hazard), agricultural drought sensitivity and adaptive capacity for agricultural drought vulnerability assessment,

(2) To create and map agricultural drought vulnerability index based on prominent exposure, sensitivity and adaptive capacity indices.

1.3 Scope and limitation of the study

1.3.1 Scope of the study

(1) For exposure hazard assessment, two components of exposure include meteorological drought hazard frequency and intensity are assessed using number of SPI values and average of SPI values, respectively.

(2) For agricultural drought sensitivity assessment and mapping, four influential factors include vegetation, climate, physical and socioeconomic condition are assessed to determine both annual agricultural drought sensitivity using Classification and Regression Tree (CART) and overall agricultural drought sensitivity based on average historical data using Simple Additive Weighting method with questionnaire. For agricultural drought sensitivity assessment, it considers significant factors at local scale that consists of agricultural drought frequency, agricultural drought intensity, PASG, SOSA, SPI, SPEI, land use, soil drainages, agricultural irrigation area, slope, elevation, distance to river, drainage density, agricultural occupation, economic crop production and population density.

(3) For adaptive capacity assessment and mapping, the selected factors include proportion of people below poverty line, farm holding size, income from agricultural sector, income from non-agricultural sector, illiteracy and information accessibility are here used to create adaptive capacity map using adaptive capacity index.

(4) For agricultural drought vulnerability assessment and mapping, two main indices include (1) exposure hazard (meteorological drought) and (2) agricultural drought sensitivity are firstly apply to classify five classes of potential impact (very low, low, moderate, high, and very high) and then all are combined

using additive operation. Meanwhile, adaptive capacity index is classified into five level of adaptive capacity (very low, low, moderate, high, and very high) using natural break method. After that potential impact index that is derived by combination of exposure and sensitivity is combined with adaptive capacity index using subtractive operation for final agricultural drought vulnerability map.

1.3.2 Limitation of the study

(1) Due to limitation of data accessibility from various concerned agencies, the applied input data in this study have different time-scale. For instance, MODIS data can be downloadable since 2000 while long-term records of precipitation are 41 years.

1.4 Study area

1.4.1 Location and administration

The study area is Nakhon Ratchasima province that is part of Northeastern of Thailand which settles in the high plateau of Korat between longitudes 101 degree 10.8 minute east and 103 degrees 0.77 minute east and between latitude 14 degree 7.2 minute north and 1 degree 48.6 minute north (Office of Agricultural Economics, 2010). Nakhon Ratchasima province consists of 32 districts (289 sub-district) with total area of 20,784.46 km^2 (Figure 1.2).

Figure 1.2 Location and administration boundaries of the study area.

1.4.2 Topography

The main characteristics of topography can be divided into 4 areas that consist of (1) the hill and high areas at the southern part, (2) the high areas at central part, (3) the uneven or wave areas at the northern part and (4) the lowland at the northern part (Office of Agricultural Economics, 2010). The elevation in the study area varies between 74 and 1,328 m above mean sea level (Figure 1.3). Most of the study area is flat to slightly undulating (0-5%) that covers area of 83.91 percent of the province (Department of Environmental Quality Promotion, 2004).

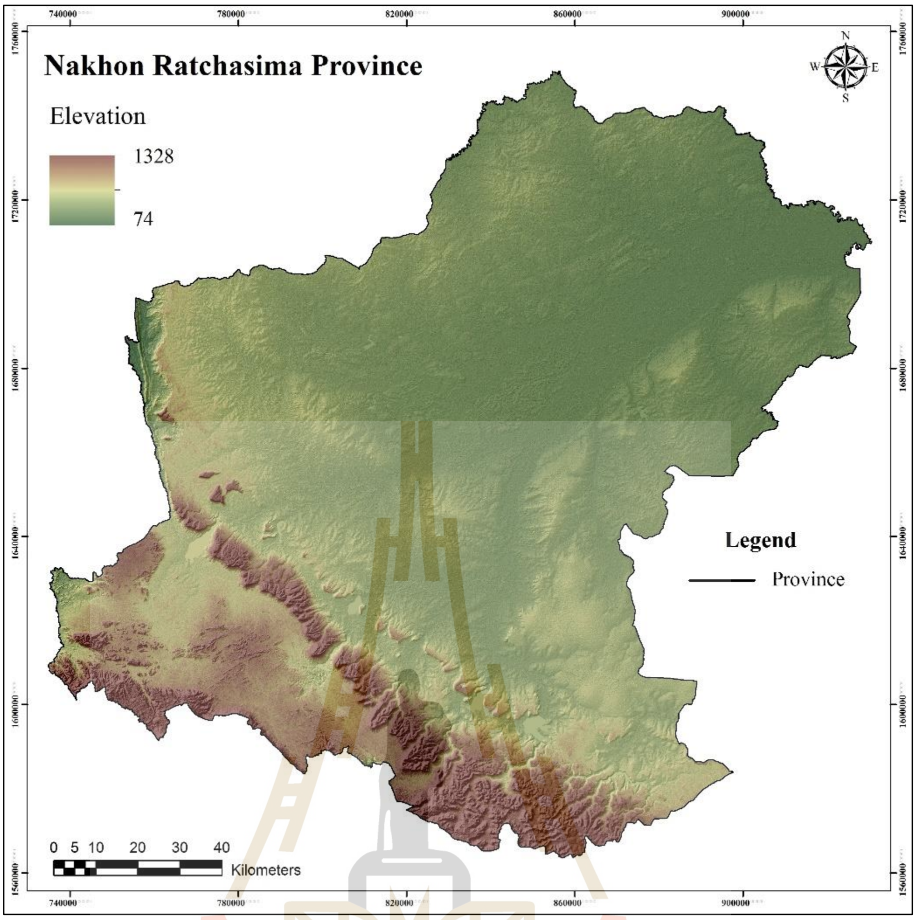


Figure 1.3 Topography of the study area.

1.4.3 Climate

In general, there are three seasons in the northeastern: hot season (mid February to mid May), rainy season (mid May to mid October) and cool dry season (mid October to mid February). The characteristics climate of Nakhon Ratchasima province consist of the annual mean temperature is 27 degree Celsius, the annual mean maximum temperature is 32.9 degree Celsius and the annual mean minimum temperature is 22.3 degree Celsius. While, the annual mean humid relative is 70%, annual mean maximum humid relative is 87% and annual mean minimum humid relative is 49%. The annual rainfall is 1,151.4 mm (1975 to 2016), and annual mean rainy day is 108.2 days, and the annual daily maximum of rainfall is 104.3 mm (TMD, 2003).

Nakhon Ratchasima province is a largest province of Thailand and locates in the middle of the country and it is far from coastal zone. Thus, the influence of rain from the India Ocean and Typhoon from Pacific Ocean leads to less rainfall in the area. The main influence of rain in the area consists of (1) the southwest monsoon that occurs more rainfall in rainy season (which starts in May and ends in October), (2) the monsoon trough or the Intertropical Convergence Zone (ITCZ) that moves up north from the equator passing this area around May to June towards southern China and then moves back south trough the country again from August to October (TMD, 2018). Therefore, the distribution of average rainfall is double-bell shape (Figure 1.4) that provides the maximum rainfall in September and May, respectively.

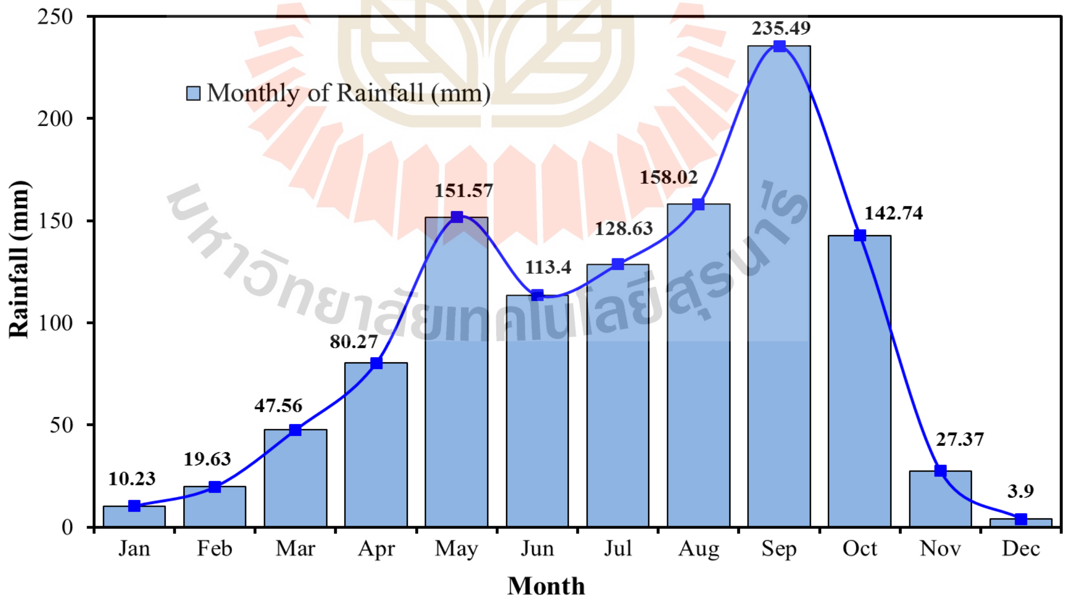


Figure 1.4 The distribution of monthly rainfall of Nakhon Ratchasima province in double-bell shape pattern during 1975 to 2016.

According to rainfall distribution, rainy season period that covers 6 months (May, June, July, August, September and October) and two inter-rainy seasons: (1) the first 3 months period (May, June and July) and (2) the second 3 months period (August, September and October) are here identified for SPI periods, namely 6m10, 3m7, and 3m10, respectively.

1.5 Benefits of the study

Generally, the research will be provided a useful means for more understand drought hazard and vulnerability drought based on exposure, sensitivity, adaptive capacity factors of the study area. The expected research results are as follows:

(1) Meteorological drought hazard frequency and intensity indices and exposure hazard index and Map,

(2) Overall agricultural drought sensitivity index and map,

(3) Annual agricultural drought sensitivity index and maps,

(4) Adaptive capacity index and map,

(5) Agricultural drought vulnerability index and map.

1.6 Outline of the thesis

The thesis is structured in two parts and follows a hierarchical organization as shown in Figure 1.5. Key information of each chapter in each part is summarized in the following section.

The first part includes Chapter I "Introduction", Chapter II "Basic Concepts and Literature Reviews", Chapter III "Data and Methodology" and Chapter IV

"Preprocessing Data for Agricultural Drought Sensitivity Analysis". Chapter I contains background problem and significance of the study, research objectives, scope and limitations of the study, study area, benefits of the study and outline of the thesis. Chapter II consists of (1) basics of definition and characteristics of drought, (2) drought detection techniques, (3) type of drought, (4) drought vulnerability assessment, (5) agricultural drought vulnerability, and (6) relevant literature reviews. Meanwhile, Chapter III presents data and explains details of research methodology including (1) data collection and preparation, (2) exposure drought hazard assessment, (3) agricultural drought sensitivity assessment (4) adaptive capacity analysis and (5) agricultural drought vulnerability analysis. Chapter IV "Preprocessing Data for Agricultural Drought Sensitivity Analysis" consists of preprocessing data of 4 conditions of agricultural drought include (1) vegetation (2) climate (3) physical and (4) socioeconomic conditions.

The second part consists of five chapters of the results with discussion, which separately describe according to objectives and one chapter presents conclusion and recommendation. Chapter V "Drought Exposure Hazard Assessment" contains (1) SPI calculation for meteorological drought assessment, (2) drought occurrence probability by SPI, (3) meteorological drought hazard frequency assessment, (4) meteorological drought hazard intensity assessment, (5) drought exposure hazard assessment and (6) validation of drought exposure hazard assessment. Chapter VI "Agricultural Drought Sensitivity Assessment" consists of (1) overall agricultural drought sensitivity assessment and its validation and (2) annual agricultural drought sensitivity assessment and its validation. Meanwhile, Chapter VII "Adaptive Capacity Assessment" contains (1) characteristics of adaptive capacity factor and (2) adaptive capacity assessment. Chapter VIII "Agricultural Drought Vulnerability Assessment" comprises of (1) component of agricultural drought vulnerability analysis and (2) agricultural drought vulnerability assessment. Chapter IX "Conclusion and Recommendation" comprises of conclusion of the study and recommendation.

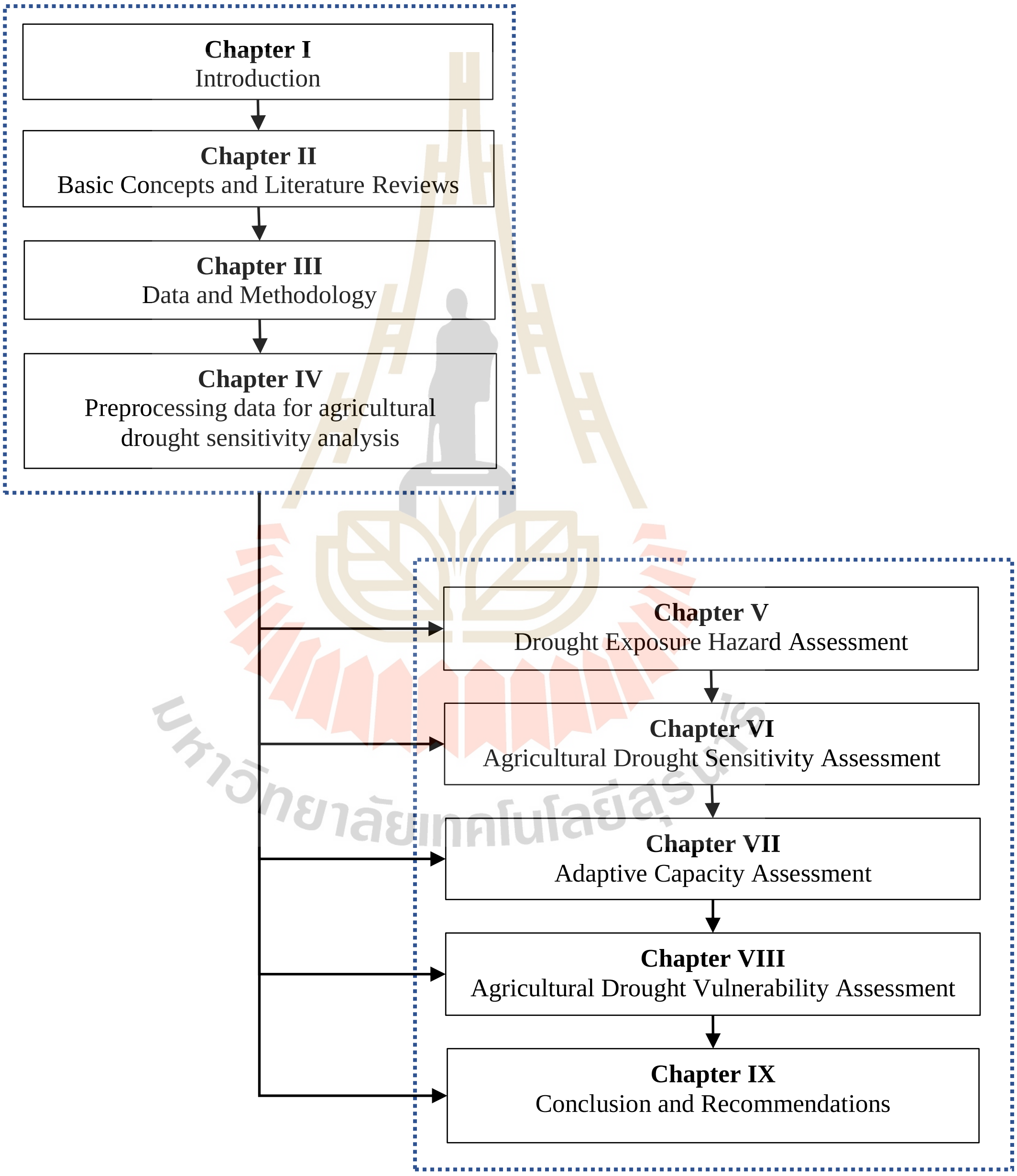


Figure 1.5 Structure of the thesis.

CHAPTER II

BASIC CONCEPTS AND LITERATURE REVIEWS

Basic concepts including (1) definition and characteristics of drought, (2) drought detection techniques, (3) type of drought, (4) drought vulnerability assessment, (5) agricultural drought vulnerability, and (6) relevant literature reviews are here reviewed in this chapter.

2.1 Definition and characteristics of drought

A natural hazard can be defined as a threat of a naturally occurring event that will have a negative effect on people or the environment (Mishra and Singh, 2010). Nelson (2014) defined "natural hazard is a threat of a naturally occurring event will have a negative effect on humans". It consists of earthquakes, volcanic eruptions, tsunami, landslides, floods, hurricanes, tornado, asteroid impact and drought. Table 2.1 showed that famines and drought are most serious impact to percentage of deaths population more than other natural hazard that consistent with a number of disasters occurrence. Besides, impact of natural hazard is a significant loss of life, property, economic, environmental, and social that is obstructed to development (Wilhite, 2000).

From above mention, drought is a significant problem at all regions in the world. The characteristics of drought differ from others natural hazard because drought condition is much more difficult to identify and it is derived from relevant various factors (Vicente-Serrano et al., 2012).

Table 2.1 Hazard types and their contribution to deaths, 1990-1999.

Hazard type in rang order	Percentage of deaths
Slow onset:	
Famines – Drought	86.9
Rapid onset:	
Floods	9.2
Earthquakes and tsunami	2.2
Storms	1.5
Volcanic eruptions	0.1
Landslides	<0.1
Avalanches	Negligible
Wildfires	Negligible

Source: Wisner et al. (2003) refer to DRED at www.cred.be/emdat

Drought can classify drought different from other natural hazards in several aspects (Wilhite and Buchanan-Smith, 2005; Mishra and Singh, 2010) included: onset and end of drought, duration of drought event, affected areas and pattern/structural of drought, triggering factors of drought and definition of drought.

2.1.1 Definition of drought

Definition of drought is considerable both of conceptual and operational definitions. Conceptual definition is considered duration of drought event as relative term such as extension of drought and dry period. While, operational definition is considered to find out characterization of drought such as onset and end of duration, severity or intensity and spatial coverage of drought which can be used analyze frequency, severity and duration of drought from historical period data. Besides, it can be find the probability change of drought in term intensity, duration, and spatial characteristics (Wilhite and Glantz, 1985; Mishra and Singh, 2010).

2.1.2 Characteristics of drought

From the literature reviews, it can be concluded that the characteristics of drought can be mainly categorized into four categories consists of duration, frequency, intensity, and spatial extent. Drought can be defined as complex natural hazard due to variety characteristics that cause a negative impact or damage on many sectors such as agricultural, social, economic and environmental. Therefore, characteristics of drought is important to understand for drought definition lead to determination or classification types of drought by using those characteristics or relevant factors that consist of duration, frequency, intensity and spatial extent.

2.2 Drought detection techniques

Generally, drought can be detected using two techniques: (1) drought indices and (2) drought indices with corporate drought factors.

2.2.1 Drought indices

Drought indices can be derived from two major data sources, namely stationary based and satellite based data. The details of each data source are briefly summarized as follows:

2.2.1.1 Stationary based data

Drought can be effectively monitored by drought indices derived from stationary based meteorological data (Zhang and Jia, 2013), such as the percent of normal precipitation, deciles (Gibbs and Maher, 1967), Standardized Precipitation Index, SPI (McKee et al., 1993; 1995), the Palmer Drought Severity Index, PDSI (Palmer, 1965), Palmer Moisture Anomaly Index, z-index (Palmer, 1965), Standardized Precipitation Evapotranspiration Index, SPEI (Vicente-Serrano et al., 2010), China-Z index, CZI (Wu et al., 2001).

2.2.1.2 Satellite based data

Because of stationary-based drought indices can effectively estimate drought conditions around meteorological station, but they lack of continuous spatial coverage and limit the ability of characterizing and monitoring detailed spatial pattern of drought conditions at regional scale, especially in areas with sparse meteorological stations or high degree of spatial variability (Zhang and Jia, 2013). Moreover, Park et al. (2016) described that the stationary-based indices are point-based and limited in covering vast areas to show the spatial distribution of drought. Spatial interpolation is required to estimate spatial distribution of drought from stationary-based data, which often produces high uncertainty in interpolated areas (Brown et al., 2008). Whereas, satellite-based data is predominant in spatial and temporal pattern, namely the various of spatial resolution is several levels such as low, moderate, and high resolution that can be selected for suitable application in drought monitoring and level of interest areas at local, country, regional, continental, and global levels. Particularly, temporal pattern is high frequency data that proper to time-series indices. In order to understand and monitor of drought effectively, thus, the use of satellite-based data for application in drought is more essential.

2.2.2 Drought indices with cooperated drought factors

There is no single indicator that can fully explain the complexity and diversity of drought, because drought is caused by multiple factors. Some drought indices are not only used satellite data but also climatic, biophysical and oceanic data for more accurately drought monitoring such as Vegetation Drought Response Index, VegDRI (Brown et al., 2008; Wardlow et al., 2012), Vegetation Outlook, VegOut (Tadesse et al., 2010), North American Drought Monitor, NADM (Lawrimore et al., 2002) and U.S. Drought Monitor, USDM (Svoboda et al., 2002).

2.3 Type of drought

Most of drought definition identified drought into four types include meteorological, agricultural, hydrological, and socioeconomic drought (Wilhite and Glantz, 1985; Wilhite and Buchanan-Smith, 2005; Whitmore, 2000) (See Figure 1.1). Besides, Subrahmanyam (1967) has identified drought into six types that consist of meteorological, climatological, atmospheric, agricultural, hydrologic, and water-management. Drought types may correlate or uncorrelated among them. For example, several weeks of dryness may cause agricultural drought and leads vegetation stress but this drought has little effect on streamflow and groundwater, which would not result as hydrological drought for the same event (Hayes et al., 2012).

2.3.1 Meteorological drought

Monitoring meteorological drought is essentially important for early warning and risk management of water resources and agricultural production (Zhang and Jia, 2013). Main component in this section consists of definition and indices, which here presented in details as follows:

2.3.1.1 Definition

Wilhite and Glantz (1985) stated that meteorological drought was defined solely on the basis of degree of dryness and the duration of the dry period.

Whitmore (2000) described that meteorological drought is usually defined as a period of rainfall significantly less than the long-term average or some designated percentage less than some fixed value.

Park et al. (2016) stated that meteorological drought occurs due to a lack of precipitation.

In summary, meteorological drought is compared between normal precipitation and average precipitation of region in the same time. The dominant characteristics frequently apply to describe meteorological drought include amount of precipitation (that is the original resource of water) and its frequency that identify to probability or a number of occurrence drought, severity or intensity that demonstrated level of precipitation more than normal condition or average precipitation in the same period. The most significant factor of meteorological drought is climate variable or atmospheric hazard, which influence to occur rainy in season or out of season. In general, meteorological drought both directly or indirectly effects to agricultural, hydrological and socioeconomic drought.

2.3.1.2 Indicators

Meteorological drought indicators are almost associated with climatological variables such as precipitation, temperature and evapotranspiration (Steinemann et al., 2005) which is here described in details as follows:

1) Standardized Precipitation Index (SPI)

Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) at Colorado State University to quantify the precipitation deficit for multiple time scales such as 1, 3, 6, 9, 12, 24, and 48 months (Rahmat et al., 2015). Generally, the original precipitation data is not completely normal distribution that essential to transformation of precipitation time series into a standardized normal distribution. This index can be calculated by fitting Gamma probability function to a given frequency of total precipitation (Sayari et al., 2013).

The SPI with different time scale can apply to each drought types. Herein, SPI with short-time scale (weeks and months) is suitable to apply for meteorological or agricultural drought, while SPI with long-time scale (years) is suitable to apply for hydrological drought and water management (Guttman, 1999; Quiring and Ganesh, 2010). Sayari et al. (2013) described that the longer time scales of SPI relate with hydrological drought and shorter time scales may represent agricultural drought. Stagge et al. (2015) recommended that SPI is predominant meteorological drought indices used in Europe.

Tan et al. (2015) described that SPI calculation requires data at least 20 to 30 years of monthly precipitation. Moreover, Guttman (1999) recommended that SPI calculation require data at least 50 years for drought periods of 1 years or less and more for multiyear droughts in order to more detail and ideal. For instance, Tan et al. (2015) used monthly precipitation data during years 1972 to 2011 (41 years) to calculate the monthly SPI value for Ningxia, China. Zhang and Jia (2013) used to the long term monthly precipitation data from 1960 to 2010 (51 years) to construct SPI series at 1, 3, 6, 9, and 12-month time scales for each weather station. While, Quiring and Ganesh (2010) stated that the SPI requires a long-term precipitation record (1895 to 2005 years) because it fits a probability distribution function (PDF) to the observed data and then transforms it using an inverse normal (Gaussian) function.

The computation of the SPI index requires the following steps (Makee et at., 1993; Rahmat et al., 2015; Sonmez et al., 2005):

1) Fit a cumulative probability distribution function (PDF) (usually gamma distribution) on aggregated monthly (k) precipitation series (namely, k = 3, 6, and 12 months). The gamma PDF, g(x) is defined as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \tag{2.1}$$

$\alpha > 0$, $\beta > 0$, and $x > 0$

where β is a scale parameter, α is a shape parameter, which can be estimated using method of maximum likelihood, x is the precipitation amount and is the gamma function at α. $\Gamma(\alpha)$ is gamma distribution function.

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \tag{2.2}$$

The estimated parameters can be used to find the cumulative PDF of observed precipitation events for the given month and particular time scale. The cumulative distribution function (CDF) is obtained by integrating Equation 2.3.

$$G(x) = \int_0^x g(x)dx = \int_0^x \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} x^{\hat{\alpha}-1} e^{-\frac{x}{\hat{\beta}}} dx \tag{2.3}$$

$$\text{where } \hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2.4}$$

$$\hat{\beta} = \frac{\hat{x}}{\hat{a}} \tag{2.5}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{2.6}$$

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1}e^{-t}dt\ ,\ t = \frac{x}{\hat{\beta}} \qquad (2.7)$$

n is a number of precipitation observation and refer to the sample mean of the data.

2) Since the gamma distribution is undefined for x = 0 and q = P (x = 0) > 0 where P (x = 0) is the probability of zero precipitation, CDF becomes as follow:

$$H(x) = q + (1\text{-}q)\ G(x) \qquad (2.8)$$

where q is the probability of zero precipitation

The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI and classified SPI categories (Table 2.2).

In addition, magnitude of SPI is calculated by the sum of the SPI for every month from the initiation to the end of each drought event, the intensity is the ratio between the magnitude and the duration of the event (Rahmat et al., 2015).

Two important factors should be carefully considered when applying SPI include adequate the length of precipitation record and natural of probability distribution (Mishra and Singh, 2010).

Table 2.2 The SPI drought classification.

Values of SPI	**SPI category**
2.00 and above	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Normal
-1.49 to -1.00	Moderately drought
-1.99 to -1.5	Severely drought
less and -2.00	Extremely drought

Source: Mckee et al. (1993)

2) Standardized Precipitation Evapotranspiration Index

The Standardized Precipitation Evapotranspiration Index (SPEI) uses a similar methodology as SPI, but it includes additive water balance (Stagge et al., 2015). The variables of the SPEI consist of a time-series of total monthly precipitation (P) and monthly potential evapotranspiration (PET) (Tan et al., 2015). The popularities of this index are its simple interpretation, responsible to vegetation by applying temperature or PET like PDSI and its flexibility similar on multiscale like SPI. The multiscale characteristic of SPEI for short or long accumulated anomalies allows the user to approximate agricultural, hydrological, and socioeconomic drought by adjusting the accumulation period of the index (Vicente-Serrano et al., 2012). The formula of SPEI (Tan et al., 2015) is as follows:

2.1) Climate Water Balance

A simple climate water balance was calculated as the differences between precipitation P and PET for month j according to:

$$D_j = P_j - PET_j \tag{2.9}$$

where monthly PET is calculated by:

$$PET = 16K\left[\frac{10T}{I}\right]^{m} \tag{2.10}$$

where T is monthly mean temperature (°C); I is heat index calculated as the sum of 12 monthly index values; m is the coefficient dependent on

$$I: m = 6.75 \times 10^{-7} \cdot I^{3} - 7.71 \times 10^{-7} \cdot I^{2} + 1.79 \times 10^{-7} \cdot I + 0.492; \tag{2.11}$$

and K is a correction coefficient computed as a function of the latitude and month.

The calculated D_i values are aggregated at different time scales, following the same procedure as used for the SPI. The difference k, $D^{k}_{i,j}$ in month j and year i depends on the chosen time scale k. For example, the accumulated difference for one month in a particular year i with a 12-month time scale is calculated using:

$$X^{k_{i,j}} = \sum_{l=13-k-j}^{12} D_{i-1,l} + \sum_{l=13-k-j}^{j} D_{i,l}\ ,\ j < k \tag{2.12}$$

$$X^{k_{i,j}} = \sum_{l=j-k+1}^{j} D_{i,l}\ ,\ \text{if } j \geq k \tag{2.13}$$

where $D_{i,j}$ is the P – PET difference in month l and year i, in millimeters.

2.2) Normalize the Water Balance

The log-logistic distribution was used for normalizing the D series to obtain the SPEI. The probability density function of a three-parameter log-logistic distributed variable is expressed as:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \tag{2.14}$$

where α, β, and γ are scale, shape, and origin parameters respectively, for D values in the range ($\gamma > D > \infty$). The parameters of the Pearson III distribution can be obtained from Singh et al. (1993).

Thus, the probability distribution function of the D series, according to the log-logistic distribution, is given by:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{2.15}$$

2.3) Calculate the SPEI Series

The SPEI can easily be obtained as the standardized values of F(x). Following the classical approximation of Abramowitz and Stegun (1965):

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W^1 + d_2 W^2 + d_3 W^3} \tag{2.16}$$

$$\text{where} \quad W = \sqrt{-2\ln(P)} \text{ , for } P \leq 0.5 \tag{2.17}$$

and P is the probability of exceeding a determined D value, P = 1 – F(x). If P > 0.5, then P is replaced by 1 − P and the sign of the resultant SPEI is reversed. The constants are C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308.

2.3.2 Agricultural drought

2.3.2.1 Definition

Wang et al. (2015) defined agricultural drought is a period with declining soil moisture and consequent crop failure without any reference of surface water resource.

Park et al. (2016) described that prolongation of meteorological drought leads to the decrease soil moisture content that trigger agricultural drought.

Van Loon (2015) described that agricultural drought refers to a deficit of soil moisture in mostly the root zone level, reducing the supply of moisture vegetation.

In summary, agricultural drought is directly relevant to soil moisture that is important factor for supported vegetation growth and directly impacted to human. Generally, it is directly impacted from meteorological and hydrological drought because they are importance resources that indicate capability water availability of vegetation or soil moisture condition.

2.3.2.2 Indicators

1) Normalized Different Vegetation Index (NDVI)

NDVI is the most popular vegetation index because of simple algorithms, easy interpretation, the most satellite data have product for calculate this index. NDVI can indicate situation, healthy, or greenness of vegetation by calculation ratio between the subtraction of Near Infrared and Red bands and addition of Near Infrared and Red band as shown Eq. 2.18. NDVI values range from -1 to + 1, with values near zero indicating no or less green vegetation, and values near

+1 indicating high greenness vegetation, density, or healthy of vegetation. Kogan (1995) mentioned that NDVI can apply to monitor drought in the short-term period but it is fluctuating in the long-term period.

$$\text{NDVI} = \frac{(\rho_{\text{NIR}} - \rho_{\text{red}})}{(\rho_{\text{NIR}} + \rho_{\text{red}})} \tag{2.18}$$

where ρ_{NIR} is near infrared reflectance; ρ_{red} is red reflectance

2) Vegetation Condition Index (VCI)

Kogan (1995) stated that the VCI is an efficiently tool to detect drought and to measure time of its onset, intensity, duration, dynamics, and impacts on vegetation. However, the VCI is based on vegetation and used almost primarily advantage for the summer growing season (Mishra and Singh, 2010). Quiring and Ganesh (2010) described that VCI can provide near real-time data over the globe at a relatively high spatial resolution because it is a satellite-based drought product. Moreover, VCI was high correlation with agricultural production or yield during crop growth in South America, Africa, Asia, North America and Europe (Kogan, 1997). Quiring and Ganesh (2010) evaluated the suitability of the VCI for monitoring meteorological drought in Texas and they founded that the VCI is most strongly correlated with the SPI-6M, SPI-9M, and PDSI. This indicated the VCI is the strongest response to long-term drought whereas it the less sensitive to short-term drought.

Furthermore, the VCI used as a completely independent methodology for monitoring drought, while all of the other meteorological indices rely, to some extent on station-based meteorological data (Quiring and Ganesh, 2010).

The VCI is a pixel-wised normalization of NDVI that is useful for making relative assessments of changes in the NDVI signal by filtering out the contribution of local geographic resources to the spatial variability of NDVI. VCI was defined by the following expression:

$$VCI = 100 * \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}} \right) \quad (2.19)$$

where the minimum of VCI value such as less than 30 percentage demonstrated that high severity of drought while more VCI value meaning to the highly health of vegetation or indicate problem occurs of drought is less.

3) Vegetation Health Index (VHI)

The VHI concept assumes an inverse relationship between NDVI and BT because higher land surface temperatures (LSTs) lead to negatively impact on vegetation vigor (and decrease NDVI), which can be used as indicator of a drought stress signal because of reduced evapotranspiration (ET) (Wardlow et al., 2012).

$$VHI = \alpha * VCI + (1-\alpha) * TCI \quad (2.20)$$

Besides, Kogan (1995) determined some weight for indices because VCI was created by NDVI that reflects temperature and precipitation for estimate drought condition. Sum weight of indices values is 1 (0.7 and 0.3 values). The higher weight was assigned to the VCI (Kogan, 1995).

$$VHI = 0.70 * VCI + 0.30 * TCI \quad (2.21)$$

2.3.3 Hydrological drought

2.3.3.1 Definition

Wilhite (1992) stated that "hydrological droughts are concerned more with the effects of periods of precipitation shortfalls on surface or subsurface water supply (streamflow, reservoir, lake levels and ground water) rather than with precipitation shortfalls."

Mishra et al. (2010) described that hydrological drought related to a period of scarcity surface and subsurface water resource for established water use of a given water resource s management system. The data was widely used for hydrological drought analysis is streamflow data.

Van Loon (2015) stated that hydrological drought is negative anomalies or a lack of water in the hydrological system (surface and subsurface water) such as anomalous low streamflow in the rivers, abnormally low levels in lakes, reservoirs, and groundwater.

In conclusion, hydrological drought is phenomenon relevant with deficit of surface water and subsurface water supplies because of are significantly lower level than average condition of water for each area. Trigger factors of hydrological drought have various relevant factors both direct and indirect. The main factors of trigger are deficit precipitation (meteorological drought). Besides, hydrological drought significant effected to agricultural drought and socioeconomic drought that bring to consecutive and serious problems.

4.3.3.2 Indicators

Mostly, standardized indices for the characteristics of hydrological drought use different hydrological variables (from observed of stimulated data) as input (Van Loon, 2015) such as streamflow, groundwater levels and lake levels others data. Nalbantis (2008) stated that streamflow is the most significant variable from the viewpoint of quantity of water and represents surface water resources. Moreover, Nalbantis and Tsakiris (2009) described that the use of streamflow as the key variable for assessing hydrological droughts is not new since many authors have used it in their studies. Thus, hydrological drought events are related to streamflow deficit that deviated from normal condition.

1) Surface Water Supply Index (SWSI)

SWSI is developed by Shafer and Dezman (1982) in order to monitoring the anomalous condition of surface water supply sources that consist of precipitation, reservoir water storage, streamflow (for summer months) and snowpack (for winter months). Normalization of the components data to one scale-the non-exceedance probability (study drought) used frequency analysis. Each of components is determined weight of each basin in areas. It is expressed as (Shafer and Dezman, 1982):

$$SWSI = \frac{(a \times PN_{SF}) + (b \times PN_{PCP}) + (c \times PN_{RS}) + (d \times PN_{SP}) - 50}{12} \quad (2.22)$$

where a, b, c and d are weights for each component by summation is 1, PN is probability of non-exceedance (%), and SF, PCP, RS and SP refer to streamflow, precipitation, reservoir storage and snowpack component, respectively. Subtracting 50 centers the SWSI values around zero, and dividing by 12 compresses the range of values between -4.17 and +4.17 (Garen, 1993). The intensity of hydrological drought can be classified according SWSI level as shown in Table 2.3.

Table 2.3 The categories of classify the SWSI level by using hydrological drought intensity.

SWSI value	Classification
+2 or above	abundant supply
-2 to +2	near normal
-3 to -2	Moderate drought
-4 to -3	severe drought
-4 or below	extreme drought

Source: Garen (1993).

2) Streamflow Drought Index (**SDI**)

The SDI used streamflow that usually derive from observed data and can also be model simulated. SDI is defined for each reference period k of the i-th hydrological year that based on the cumulative streamflow volumes ($V_{i,k}$) as follows (Nalbantis, 2008):

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{s_k} \quad i = 1, 2, \ldots \quad k = 1, 2, 3, 4 \qquad (2.23)$$

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad i = 1, 2, \ldots \quad j = 1, 2, \ldots, 12 \quad k = 1, 2, 3, 4 \qquad (2.24)$$

where Vi, k is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, i is the hydrological year, j is the month in the hydrological year that j = 1 for October and j = 12 for September, and k is the reference of hydrological period that consist of 4 periods such as k = 1 for October-December, k = 2 for October-March, k = 3 for October-June, and, k = 4 for October-September. $Q_{i,j}$ is available where i denotes the hydrological year and j the month within hydrological year.

where $\overline{V}_k$ and s_k are respectively the mean and the standard deviation of cumulative streamflow volumes of the reference period k as these are estimated over a long period of time. In this definition, the truncation level is set to $\overline{V}_k$ although other values based on rational criteria could be also used.

Generally, for small basins, streamflow may follow a skewed probability distribution which can well be approximated by the family of the gamma distribution functions. The distribution is then transformed into normal. Using the two-parameter log-normal distribution (for which the normalization is simply reclaiming the natural logarithms of streamflow), the SDI index is defined.

$$SDI_{i,k} = \frac{y_{i,k} - \bar{y}_k}{s_{y,k}} \quad i = 1, 2, \ldots \quad k = 1, 2, 3, 4 \tag{2.25}$$

$$y_{i,k} = \ln(V_{i,k}),\ i = 1, 2, \ldots, k = 1, 2, 3, 4 \tag{2.26}$$

where $y_{i,k}$ is the natural logarithms of cumulative streamflow with mean ($\overline{y}_k$) and standard deviation ($s_{y,k}$) as these statistics are estimated over a long period of time.

The state of hydrological drought can have divided into five state that identify the description of each state and each criterion of SDI (Table 2.4). Besides, the probability of hydrological drought calculated in each state, description, or criterion. Table 2.4 demonstrated that identified of state of hydrological drought, namely the state 0 indicated non-drought events, SDI value is more than 0.0, and probability of hydrological drought events is the most occurrence of events about 50 percent. While, the state order 4 indicated extreme drought events, SDI value is less than -2.0, and the probability of events is slight occurrence of events about 2.3 percent.

Table 2.4 Definition of states of hydrological drought with the aid of SDI.

State	Description	Criterion	Probability (%)
0	Non-drought	SDI ≥ 0.0	50.0
1	Mild drought	- 1.0 ≤ SDI < 0.0	34.1
2	Moderate drought	- 1.5 ≤ SDI < - 1.0	9.2
3	Severe drought	- 2.0 ≤ SDI < - 1.5	4.4
4	Extreme drought	SDI < - 2.0	2.3

Source: Nalbantis and Tsakiris (2009)

2.3.4 Socioeconomic drought

2.3.4.1 Definition

Van Loon (2015) described that "socioeconomic drought is associated with the impacts of the three previously drought types (meteorological, agricultural, and hydrological drought)."

Chopra et al. (2006) described that "socioeconomic drought is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought."

Kiem et al. (2016) defined the socioeconomic drought is "the impact of one or more of the other types of drought on humans, communities and/or the economic, defined based on social expectations, perceptions and other measures such as employment levels, income and debt levels, and mental and physical health."

To summarize, socioeconomic drought is impacted that directly and indirectly occurred from meteorological, agricultural and hydrological drought that effected to decreasing and insufficient supply, on the contrary demand is more than. Therefore, socioeconomic drought occurs from exceed demand more than supply that leads to crucial problems to human, vegetation, animal and others.

2.3.4.2 Indicators

Socioeconomic drought differs markedly from the other types because it associates human activity with elements of meteorological, agricultural, and hydrological drought. Moreover, the factors of the supply or demand for some commodity or economic good that is dependent on precipitation, is affected (Wilhite and Buchanan-Smith, 2005). Wilhite and Buchanan-Smith (2005) described that if development demands exceed the supply of water available, demand may exceed supply even in year of normal precipitation. Eklund and Seaquist (2015) stated that socioeconomic drought occurred from exceeding water demand more than water resource in order to product economic good and suffered livelihood of people. Moreover, Chopra et al. (2009) stated that socioeconomic drought mainly occurred when there the demand for an economic good exceeds its supply due to weather related deficit in water supply.

Almost socioeconomic drought relates to human activity, likelihood, and property namely previously drought impact (meteorological, agricultural, and hydrological drought) effected socioeconomic both directly and indirectly way that occur deficit water, low production crop, and scarcity or food insecurity to human.

2.4 Drought vulnerability assessment

Drought vulnerability assessment can be examined in various aspects or levels. Herein, three drought vulnerability assessments based on exposure, sensitivity and adaptive capacity.

2.4.1 Definition of vulnerability

Knuson et al. (1998) defined that "vulnerability is the characteristics of populations, activities, or the environment that make them susceptible to the effects of drought."

Yusuf and Francisco (2009) stated that vulnerability is defined as: "the degree to which a system is susceptible to, or unable to cope with the adverse effects of climate change, including climate variability and extremes."

Svoboda (2012) stated that "vulnerability is an ability to anticipate, cope with, and recover from drought."

Van Loon (2015) defined that "vulnerability is the lack of capacity to cope with the risk of drought."

Vicente-Serrano et al. (2012) described "drought vulnerability is an index of the inability of a society or an ecosystem to cope with drought, and is the sum of the impacts on the various element of the system such as water resource, crops, etc."

McCarthy et al. (2001) defined that "vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed as well as the system's sensitivity and adaptive capacity."

2.4.2 Components of vulnerability

Svoboda (2012) described that vulnerability factors consist of population growth, population shifts, urbanization, technology, land use practices, environmental degradation, water use trends, government policies and environmental awareness. Besides, the symptoms of underlying vulnerability can have divided into three categories: economic, social, and environmental category. Economic category consists of agricultural industry, tourism and recreation, energy, financial and transportation. Social category consists of stress and health, nutrition, recreation, public safety, cultural values and aesthetic values. Finally, environmental category consists of animal or plant, wetland and water quality.

Knuson et al. (1998) and Van Loon (2015) described that "the degree of vulnerability depends on the environmental and social characteristics of the region and is measured by the ability to anticipate, cope with, and recover from drought."

Eklund and Seaquist (2015) stated that vulnerability classified by using a function that comprised of two variables: 1) exposure to hazard that is consideration the characteristics of drought that consist of three mainly components: frequency, longevity, and spatial extent. 2) Adaptive capacity is ability of adaptation of community, household, or individual that affected from socioeconomic drought.

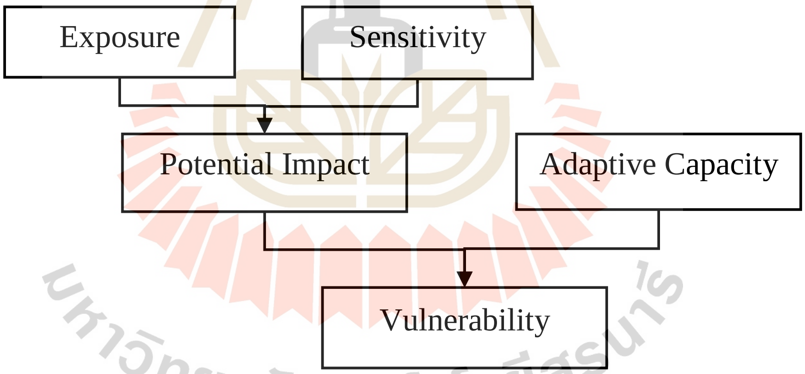
Fontaine and Steinemann (2009) presented a vulnerability assessment method (VAM) that is based on three mainly variables consist of exposure, sensitivity and adaptive capacity. Exposure and sensitivity determined the potential impact. Adaptive capacity determines the portion of the potential impact that becomes an actual impact. The combination of the three components results in a net impact or vulnerability to the drought (Figure 2.1). Moreover, Gbetibouo and Ringler (2009) described that the vulnerability of system depends on exposure and sensitivity, which combined provides the potential impact and the potential for effectively coping with the impacts and associated risks. The vulnerability may be formulated mathematically as follows:

$$V = f\,(I - AC) \tag{2.27}$$

where V is vulnerability, I is potential impact that combined from exposure and sensitivity and AC is adaptive capacity. A higher adaptive capacity is associated with a lower vulnerability, while a higher impact is associated with a higher vulnerability.

The variables of vulnerability are detailed as:

1) Exposure. McCarthy et al. (2001) reported that exposure is defined as “the nature and degree to which a system is exposed to significant climatic variations that have various variables such as temperature, precipitation and extreme weather events. Moreover, exposure incorporated frequency and severity of drought that includes magnitude, duration, and spatial extent.



Source: Fontaine and Steinemann (2009)

Figure 2.1 Conceptual model of vulnerability

2) Sensitivity. It is the susceptibility of a water user or users to the effects of the drought. McCarthy et al. (2001) stated that sensitivity is defined as “the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.” The stimuli are defined the effect that may be direct such as a change in crop yield in response to a change in the mean, range or variability of temperature

or indirect such as damages caused by an increase in the frequency of coastal flooding due to sea level rise. While, Gbetibouo and Ringler (2009) used sensitivity to describe the human-environmental conditions that can either worsen the hazard or trigger an impact. They used five factors that may influence the sensitivity of a farming region: irrigation rate, land degradation index, crop diversification index, percent small-scale and rural population density.

3) Adaptive capacity. It is the ability of a water user to manage or reduce adverse effects of a drought, through actions taken before, during, or after the drought. McCarthy et al. (2001) described adaptive capacity as "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences". Yusuf and Francisco (2009) stated that adaptive capacity is the degree to which adjustments in practices, processes, or structures can moderate or offset potential damage or take advantage of opportunities (from climate change). Moreover, adaptive capacity appeared to play important role in changing the spatial pattern of vulnerability. It can be shown in equation form as follows:

$$\text{Adaptive capacity} = f\,(\text{socioeconomic factors, technology, infrastructure}) \quad (2.28)$$

Fontaine and Steinemann (2009) developed an assessment approach to evaluate exposure, sensitivity, and adaptive capacity using data and evaluations from water users themselves who experiences the vulnerability that examined links between the hazard, the impacts and ways to mitigate the impacts. They performed an in-depth study of water users by using interview questions that investigated factors of vulnerability. They used a five point Likert scale to assess each of the three components for each water user. Each Likert scale ranking: extreme, high, moderate, low and very low corresponds to a score: 5, 4, 3, 2, and 1, respectively. The component scores were combined to generate a vulnerability score (V) as (Fontaine and Steinemann, 2009):

$$V = (E+S)/A \tag{2.29}$$

where E=exposure; S=sensitivity; and A=adaptive capacity. For instance, higher hazard exposure and higher sensitivity lead to higher potential impacts and higher vulnerability; higher adaptive capacity leads to lower vulnerability.

While, Yusuf and Francisco (2009) described that vulnerability can be defined as a function of exposure, sensitivity, and adaptive capacity. Meanwhile, vulnerability related to the degree of natural and social adaptation to drought, in terms of both resistance and resilience. The evaluation of the hydrological, agricultural, and ecological vulnerability to drought are at the root of the social and economic drought (Vicente-Serrano et al., 2012). Svoboda et al. (2002) described that improvement in drought monitoring and forecasting techniques reduced the vulnerability of society to drought and its subsequent impacts.

Vicente-Serrano et al. (2012) stated that assessment of the vulnerability to drought of natural vegetation, cultivation and another key sector are related to the water resources, availability, and quality of the water by using time series of drought indicators with hydrological data records such as river discharge that is a real-time the severity of a hydrological drought.

Vulnerability assessment provides a framework for identifying or predicting the underlying cause of drought-related impacts. Drought may only be one factor along with other adverse social, economic, and environmental conditions that creates vulnerability (Knuson et al., 1998). Jain et al. (2015) used the significance of sub-classes of various physical factors that consists of land use, irrigation support, elevation zones, slope, distance from river reach, soil texture, soil depth and population density. Besides, they used climate and hydrologic factors such as rainfall departure and Soil Moisture Deficit Index (SMDI), respectively.

Jain et al. (2015) described that "vulnerability to drought referred to the degree of exposure to water deficit. Areas that have higher exposure and low coping capability would have the highest risk from a given drought event and vice versa. Thus, vulnerability to drought has dimensions of time and space (Wilhite, 2000)."

2.4.3 Indicators

2.4.3.1 Integrated Drought Vulnerability Index (IDVI)

Jain et al. (2015) proposed Integrated Drought Vulnerability Index (IDVI) that used for assessment of drought vulnerability at spatial and temporal scales. The factors of IDVI consist of physiographic, climatic and hydrologic factors that were integrated relative influence of different factors at the scale of hydrologic response units (HRUs). Because of the climatic, hydrologic and different physiographic factors may not be equally significant in the assessment of relative vulnerability to drought. Therefore, differential weighting scheme of factors depend on their degree of significance in respect of water availability that may provide a more effective tool for appraisal of relative vulnerability to drought. Moreover, the HRUs are technically better spatial units compared to grid cells because a grid cell may encompass heterogeneous areas. For example, soil moisture deficit index (SMDI) and rainfall deficiency have been assigned the highest weight range from 0 to 25 (maximum). Land use and elevation have been considered moderately weight range from 0 to 10. The weights assigned to sub-classes of all factors relate to a particular HRU are integrated using a simple scheme of addition of weights. IDVI is the ratio of sum of assigned weight value of each factor to the sum of the maximum weights of all selected spatial and temporal factors as:

$$IDVI = \frac{\sum_{i=1}^{n} w_i}{\sum_{i=1}^{n} w_{imax}} \quad (2.30)$$

where IDVI is the Integrated Drought Vulnerability Index, w_i is weight scored by HRU for i^{th} factor depending on sub-class of that factor, w_{imax} is maximum weight assigned to i^{th} factor in any sub-class and n is number of factors under consideration.

2.4.3.2 Drought Vulnerability Index (DVI)

Shahid and Behrawan (2008) described that the composite drought vulnerability index (DVI) of the integrated layers calculated by using the following formula:

$$DVI = \frac{PD_r + FMR_r + PL_r + AO_r + IL_r + SWHC_r + FP_r}{\text{Number of indicators}} \quad (2.31)$$

where, PD_r, ratings assigned to population density classes; FMR_r, ratings assigned to female to male ratio classes; PL_r, ratings assigned to poverty level classes; AO_r, ratings assigned to agricultural occupation classes; IL_r, ratings assigned to irrigated land classes; $SWHC_r$, ratings assigned to soil water holding capacity classes; FP_r, ratings assigned to food production per land unit classes.

Kim et al. (2015) described that the vulnerability of drought is a relative measure among regions because it is too complex to objective assessment.

Especially, drought vulnerability is different for different individuals and nations. Therefore, the important selection of vulnerability indicators is directly relevant to the local study context and the particular hazard. They applied the following equation to derive DVI as:

$$DVI = \frac{IL_n + AO_n + CP_n + PD_n + MW_n + IW_n + AW_n}{N} \quad (2.32)$$

where IL_n, AO_n, CP_n, PD_n, MW_n, IW_n, and AW_n are normalized values assigned to irrigated land, agricultural occupation, crop production, population density, municipal water, industrial water, and agricultural water, respectively. N represent number of factors (N = 7). After that, DVI is classified into four classes. Namely, "Low" indicates that the DVI are between 0 and 0.25, "Moderate" between 0.25 and 0.50, "High" between 0.5 and 0.75, "Very High" between 0.75 and 1.0.

2.5 Agricultural drought vulnerability

Most of components of agricultural drought vulnerability consists of exposure, sensitivity and adaptive capacity (Murthy et al., 2014; 2015a; 2015b; Pei et al., 2016; Antwi-Agyei et al., 2012). The detailed of agricultural drought vulnerability components are followed as:

2.5.1 Exposure

Exposure is indicators that indicate characteristics or conditions of drought such as spatial extent, duration frequency and intensity, especially effected vegetation. Murthy et al. (2014; 2015a; 2015b) used meteorological drought as primary cases of agricultural drought. The exposure component consist of rainfall and rainy days. Sehgal and Dhakar (2016) used frequency and intensity of SPI as hazard exposure. Pei et al. (2016) used annual precipitation and forest coverage as exposure indicator. Antwi-Agyei et al. (2012) selected exposure index (monthly rainfall) in order to consider exposure aspect. Moreover, Xiaoqian et al. (2013) used SPI as exposure index for measure the degree of regional drought condition. Gbetibouo and Ringler (2009) described that the higher the frequency, the higher the vulnerability level.

2.5.2 Sensitivity

Murthy et al. (2015a) described that sensitivity is parameters that related to cropping pattern and crop condition. For instance, sorghum crop is less sensitivity to agricultural drought compared to groundnut crop. Murthy et al. (2014; 2015a) used season's integrated NDVI (CV and drought frequency), season's maximum NDVI (CV and drought frequency), August NDVI (CV and drought frequency), and cropping pattern (crop type and area weight index). Murthy et al. (2015b) used only season's integrated NDVI (range, CV and drought frequency). Sehgal and Dhakar (2016) described that agricultural sensitivity based on soil water holding capacity, frequency, and intensity of adjusted VCI that derived from NDVI. Pei et al. (2016) used population density, proportion of agricultural population, proportion of agricultural GDP, food yield per unit area, and per capita arable land as sensitivity factors. While, Antwi-Agyei et al. (2012) selected crop yield sensitivity index that is proportion of expected yield per actual yield.

2.5.3 Adaptive capacity

Sehgal and Dhakar (2016) used percent irrigated area as a measure of adaptive capacity. Pei et al. (2016) used irrigation index, per capita GDP, rural per capita net income, fertilizer scalar unit area, and agricultural machinery power per unit area as adaptive capacity factors. While, Antwi-Agyei et al. (2012) considered adaptive capacity factors consist of literacy rate and poverty rate factors.

Besides, the combination of all components is various methods such as Antwi-Agyei et al. (2012) calculated the overall mean vulnerability as

$$\text{Vulnerability} = (\text{crop yield sensitivity index} + \text{exposure index}) - \text{adaptive capacity} \quad (2.33)$$

Murthy et al. (2014; 2015a) used three composite indices including exposure index (EI), sensitivity index (SI) and adaptive capacity index (AI) in order to create agricultural drought vulnerability index (ADVI) as:

$$ADVI = EI + SI - AI \quad (2.34)$$

The ADVI and component indices reflect relative difference among the Mandals (within the district's administrative units), moreover representing specific condition of crop growing environment. It is converted to Bata probabilities was divided in to five classes (Less, Moderately, Vulnerable, Highly and Very highly) of vulnerability through linear intervals such that each interval has the same probability weight of 20 percent. Sehgal and Dhakar (2016) described that two main problem are found during compositing factors that consist of 1) removing biasness of scale among factors and 2) determination of weights for each of the factors. In order to solve those problems, they used the five-point ordered scale ranking to remove the biasness among scales and calculated weights of individual factors by multi-criteria evaluation (MCE) with linear combination weighting system (LCWS).

In conclusion, several studies on drought vulnerability which include exposure, sensitivity and adaptive capacity have been used various factors according to local study context and its availability as summary in Tables 2.5 to 2.7.

Table 2.5 List of factors of exposure drought vulnerability.

Factors	Reference
Frequency of SPI	Sehgal and Dhakar (2016)
Intensity of SPI	Sehgal and Dhakar (2016)
SPI	Xiaoqian et al. (2013)
Total seasonal rainfall (mean, CV and drought frequency)	Murthy et al. (2014; 2015a)
Sowing period rainfall (mean, CV and drought frequency)	Murthy et al. (2014; 2015a)
Total season rainy days (mean, CV and drought frequency)	Murthy et al. (2014; 2015a)
Sowing period rainy days (mean, CV and drought frequency)	Murthy et al. (2014; 2015a)
Total season rainfall (mean, CV and drought frequency)	Murthy et al. (2015b)
Total season rainy days (mean, CV and drought frequency)	Murthy et al. (2015b)
Annual precipitation	Pei et al. (2016)
Forest coverage (%)	Pei et al. (2016)
exposure index (monthly rainfall) (Meteorological drought)	Antwi-Agyei et al. (2012)

Table 2.6 List of factors of sensitivity agricultural drought vulnerability.

Factors	Reference
Frequency of VCI	Sehgal and Dhakar (2016)
Intensity of VCI	Sehgal and Dhakar (2016)
Soil water holding capacity	Sehgal and Dhakar (2016)
Percent Annual Seasonal Greenness (PASG)	Wardlow (2010)
Start of Season Anomaly (SOSA)	Wardlow (2010)
SPI	Wardlow (2010)
Ecoregion type	Wardlow (2010)
PDSI	Wardlow (2010)
Season’s integrated NDVI (CV and drought frequency)	Murthy et al. (2014; 2015a)
Season’ s maximum NDVI (CV and drought frequency)	Murthy et al. (2014; 2015a)

Table 2.6 (Continued).

Factors	Reference
August NDVI (CV and drought frequency)	Murthy et al. (2014; 2015a)
Cropping pattern (crop type and area weight index)	Murthy et al. (2014; 2015a)
Seasonal' s integrated NDVI (range, CV and drought frequency)	Murthy et al. (2015b)
Proportion of agricultural population (%)	Pei et al. (2016)
Proportion of agricultural GDP (%)	Pei et al. (2016)
Food yield per unit area (ton ha-6)	Pei et al. (2016)
Per capita arable land (ha person-1)	Pei et al. (2016)
Crop yield sensitivity index (expected yield/actual yield)	Antwi-Agyei et al. (2012)
Temperature (CV)	Xiaoqian et al. (2013)
Precipitation (CV)	Xiaoqian et al. (2013)
NDVI (CV)	Xiaoqian et al. (2013)
Elevation	Xiaoqian et al. (2013); Wardlow (2010)
Agriculture occupation	Kim et al. (2015)
Proportion of agricultural population (%)	Pei et al. (2016)
Percentage of people depending on agriculture	Shahid and Behrawan (2008)
Food production per unit area	Shahid and Behrawan (2008)
Population density	Shahid and Behrawan (2008); Kim et al. (2015); Jain et al. (2015); Gbetibouo and Ringler (2009); Pei et al. (2016)
Slope	Jain et al. (2015); Thomas et al. (2016); Prathumchai et al (2001); Sudaryatno (2016)
Distance from river reach (km)	Jain et al. (2015)
River reach	Thomas et al. (2016)
Elevation zones	Jain et al. (2015)
LULC	Jain et al. (2015); Pandey et al. (2010); Thomas et al. (2016); Sudaryatno (2016); Wardlow (2010)
Irrigation support	Jain et al. (2015)
Irrigated land	Kim et al. (2015); Wardlow (2010)

Table 2.6 (Continued).

Factors	**Reference**
Percentage of irrigated land	Shahid and Behrawan (2008); Gbetibouo and Ringler (2009)
Soil type (Soil Water Holding Capacity)	Pandey et al. (2010); Thomas et al. (2016); Jain et al. (2015)
Soil moisture holding capacity	Shahid and Behrawan (2008)
Available water capacity (AWC)	Sudaryatno (2016)
Female to male ratio (Sex ratio)	Shahid and Behrawan (2008)
Municipal water	Kim et al. (2015)
Industrial water	Kim et al. (2015)

Table 2.7 List of factors of adaptive capacity drought vulnerability.

Factors	**Reference**
Literacy rate	Gbetibiuo and Ringler (2009); Antwi-Agyei et al. (2012)
Percentage of people below the poverty line	Gbetibiuo and Ringler (2009)
Farm income	Gbetibiuo and Ringler (2009)
Farm holding size	Gbetibiuo and Ringler (2009)
Farm organization	Gbetibiuo and Ringler (2009)
Share of agricultural GDP	Gbetibiuo and Ringler (2009)
HIV prevalence	Gbetibiuo and Ringler (2009)
Access to credit	Gbetibiuo and Ringler (2009)
Infrastructure	Gbetibiuo and Ringler (2009)
Access to market	Gbetibiuo and Ringler (2009)
Farm assets	Gbetibiuo and Ringler (2009)
Access to information	Assimacopoulos et al. (2014)
Population density	Xiaoqian et al. (2013)
Per capita cultivated land area	Xiaoqian et al. (2013)
Technologists per 1000 persons	Xiaoqian et al. (2013)
Per capita business volume of post and telecom service	Xiaoqian et al. (2013)
Per capita GDP	Xiaoqian et al. (2013)
Physicians per 1000 persons	Xiaoqian et al. (2013)

Table 2.7 (Continued).

Factors	**Reference**
Ratio of agriculture and industry output	Xiaoqian et al. (2013)
Per capita savings deposit	Xiaoqian et al. (2013)
Percent irrigated area	Sehgal and Dhakar (2016)
Soil (available water content)	Murthy et al. (2014; 2015)
Irrigation support (% crop area irrigated)	Murthy et al. (2014; 2015)
Land holding (% crop area with small holding)	Murthy et al. (2014; 2015)
Soil (depth and texture) (mean value of soil water holding capacity)	Murthy et al. (2015b)
Groundwater quality (% area under fresh and marginal groundwater quality)	Murthy et al. (2015b)
Irrigated index (%)	Pei et al. (2016)
Per capita GDP (RMB yuan)	Pei et al. (2016)
Rural per capita net area (ton ha-1)	Pei et al. (2016)
Fertilizer scalar unit area (ton ha-1)	Pei et al. (2016)
Agricultural machinery power per unit area	Pei et al. (2016)
Percentage of people below poverty line	Gbetibiuo and Ringler (2009); Antwi-Agyei et al. (2012)
Farm holding size	Gbetibiuo and Ringler (2009)
Income from agricultural sector	Gbetibiuo and Ringler (2009)
Literacy rate	Gbetibiuo and Ringler (2009); Antwi-Agyei et al. (2012)
Information accessibility	Assimacopoulos et al. (2014)

2.6 Literature reviews

A literature reviews include exposure hazard assessment (meteorological agricultural and hydrological droughts hazard), drought vulnerability assessment and research on drought assessment in Thailand are here reviewed and separately summarized in the following section.

2.6.1 Exposure hazard assessment

Kogan (1995) studied the application of vegetation index and brightness temperature for drought detection by using drought indices (NDVI, VCI, TCI and VHI) from AVHRR NOAA data. The results founded that the VCI is a good tool to detect drought and to measure time of its onset, intensity, duration, dynamics, and impact on vegetation. While the TCI can identify information about vegetation stress in order to classify drought and non-drought events. Finally, the combination between VCI and TCI as VHI can provide a new tool for monitoring drought and excessive wetness.

Wardlow et al. (2010) studied Vegetation Drought Response Index (VegDRI) that is Hybrid-Based Approach for Vegetation Drought Monitoring. VegDRI is a new "hybrid" drought index that integrates satellite-based observations of vegetation conditions, climate-based drought index data, and biophysical characteristics of the environment to produce 1-km resolution maps that depict 'drought-related' vegetation stress. VegDRI methodology consists of three major components: (1) historical database development, (2) model development, and (3) map generation. The results of VegDRI has national-level monitoring capabilities and can provide local-scale information (i.e., county to sub-county level) regarding the level of drought stress on vegetation in near real-time.

Quiring and Ganesh (2010) studies the relationship between the satellite-based Vegetation Condition Index (VCI) and a number of frequently used meteorological drought indices (PDSI, Moisture Anomaly Index (Z-index), PN, Decile, SPI) was evaluated using data from all 254 Texas counties during 18 growing-seasons. They concluded that the meteorological drought indices are not strongly correlated with the VCI. The Z-index, PN, and deciles is nearly uncorrelated with the VCI. In addition, VCI strongly responds to measures of prolonged moisture stress (6–9 months) and appears to be less sensitive to short-term precipitation deficiencies.

Son et al. (2012) explored the applicability of monthly TRMM, monthly MODIS NDVI and LST data using the Temperature Vegetation Dryness Index (TVDI) and Crop Water Stress Index (CWSI) for agricultural drought monitoring in the Lower Mekong Basin (LMB) in the dry season from November 2001 to April 2010. They were found that both TVDI and TRMM precipitation dataset showed highly correlated in the study period. Likewise, TVDI was more sensitive to soil moisture content stress than CWSI, indicating that TVDI is a good indicator for assessment and monitoring of droughts in LMB. In addition, the results achieved by comparisons between TVDI and CWSI deduced from MODIS LST alone also showed strong spatio-temporal correlations between both datasets. Finally, findings demonstrate the merit of using monthly MODIS NDVI and LST data for regional drought monitoring.

Zhang and Jia (2013) assessed the capability of microwave drought indices in monitoring drought and compared with different time scale SPI over space and developed microwave integrated multi-sensor drought index for drought monitoring over semi-arid regions. Moreover, they investigated the characteristics of microwave multi - sensor remote sensing to detect and map drought. The major methodology consists of:

(1) To create drought indices from In-situ precipitation data such as percent of normal and SPI by using Kriging Interpolation;

(2) To create drought indices based on remote sensing data such as NDVI, VCI, TCI, and LST. The TRMM Precipitation Condition Index (PCI), the Soil Moisture Condition Index (SMCI) and Temperature Condition Index (TCI) based on microwave remote sensed created. There are components of MIDI, PSMCI, PTCI, and SMTCI.

(3) To compare In-situ drought indices and microwave remote sensing indices by using Pearson correlation.

The results demonstrated that PCI showed the highest correlation with SPI 1 month. While SMCI and VCI had more correlation with SPI 3, 6, 9, and 12 months. The correlation between PCI, SMCI, VCI and SPI are reversal correlation. The MIDI was found to be the most reliable microwave remote sensing drought index. Lastly, the spatial pattern and temporal changes of monitor drought by MIDI is similar with SPI 1 month and SPI 3 month.

Liang et al. (2014) studied drought change trend in China from 2001 to 2010 using MODIS data that were used to calculate the Temperature Vegetation Drought Index (TVDI). TVDI based on the relationship between vegetation and land surface temperature in order to identify a characterization index of drought. Moreover, the relationships between TVDI and climate factors (the mean temperature, mean precipitation, mean relative humidity, and mean sunshine duration) were also analyzed by using the correlation coefficient and a partial correlation coefficient. Results showed that drought change trend from meteorological data between 2001 and 2010 demonstrated the difference among geographical regions. The influence of mean precipitation is less than the other climate factors because the artificial irrigation of China has plenty in recent years. Accordingly, the relatively complete water conservancy system has reduced.

Eklund and Seaquist (2015) assessed the spatial and temporal characteristics of meteorological, agricultural, and socioeconomic drought at province and village level, in the Duhok Governorate, Iraqi Kurdistan. Meteorological drought was assessed based on rainfall data from TRMM data while agricultural drought was estimated the decreased precipitation effects on vegetation using EVI from MODIS MOD13Q1 (250 m. of spatial resolution, 16 days per cycle). In order to facilitate comparison between different areas, EVI sum for the period 2001 – 2010 were converted to Z score to represent the number of standard deviations at certain pixel's annual EVI sum falls above or below the long-term mean (normal condition) of the sum of growing season. Moreover, a digital elevation model (DEM) from ASTER GLOBAL DEM was used to determine topography of areas. The results showed that assessment of meteorological drought by using TRMM data measure a decline in rainy season rainfall between 2007 and 2009 especially the hydrological year 2007/2008 that is almost 50 % below the 2000 – 2010 total average.

Rahmat et al. (2015) assessed meteorological drought by using the SPI, the Reconnaissance Drought Index (RDI) and decile in Victoria, Australia. The results found that RDI is more response to climate variability because it consists of both rainfall and potential evapotranspiration that suitable to agricultural drought.

Park et al. (2016) studied drought assessment and monitoring through multi-sensor indices (MODIS and TRMM) using rule-based machine approaches: random forest, boosted regression trees, and Cubist to examine the relationship between drought variables and its condition. They concluded that RF model showed the best performance with R^2 > 0.9 and RMSE between 0.2 and 0.4 in all regions and it selected the most important six variables (LST, NDVI, NDWI, NMDI, ET, and TRMM) with the consideration of the inter-relation of the variables based on relative variable importance. For monitoring agricultural drought, they found that 3-month SPI showed the highest relative importance for estimating crop yield. Moreover, the most important variables for crop yield were NDVI (in the arid region) and LST (in the humid region).

Stagge et al. (2015) applied meteorological indices (SPI and SPEI) to estimate variety impacts for 5 European countries (Bulgaria, Germany, Norway, Slovenia, and the United Kingdom). The considered impact consists of agricultural and livestock farming, energy and industry, public water supply, and freshwater supply. The results showed that the SPI and SPEI are suitable to detect agricultural and livestock farming impact in pattern of seasonal and inter-annual periods. For energy and industry impact, they suitable to detect in medium to long periods while public water supply and freshwater ecosystem showed good response to short to long periods. The differences of each impact factors are more highly dependent on regional characteristics. For example, Norway, Bulgaria, and Slovenia tend to response more rapidly to meteorological drought due to the topographical difference and a stronger dependence on surface water. In contrast, the United Kingdom and Germany had the slowest drought response because they have slowly respond on groundwater storage. Additionally, they found that SPEI was a better impact predictor than SPI for drought impact assessment in all countries.

2.6.2 Drought vulnerability assessment

Yusuf and Francisco (2009) studied to identify which regions in Southeast Asia are the most vulnerable to climate change. They applied population density as human factor and protected areas as ecological factor to create sensitivity map of Southeast Asia. The overall sensitivity map was derived using weighted average of the standardized values of population density and protection area for each of provinces or districts in Southeast Asia. While, adaptive capacity is the degree to which adjustments in practices, processes, or structures can moderate or offset potential damage or take advantage of opportunities (from climate change). It appeared to play important role in changing the spatial pattern of vulnerability. They found that Thailand, Malaysia and Vietnam have areas with relatively high adaptive capacity more than others country from multiple hazard risk exposure.

Pandey et al. (2010) studied regional drought characteristics in Sonar basin, and created a technique for assessment of vulnerability to drought (Drought Vulnerability Index: DVI) using multiple factors. The DVI has been defined as the ratio of sum of the weights of factors to the sum of their maximum weight values. The indicators of DVI consist of topography characteristics, land-use types, soil types, relative availability of surface water and groundwater, water demand and utilization and the rainfall departures from corresponding mean values. The results showed that DVI in identification of drought vulnerabilities in space and time lead to effective response for coping with drought. However, it requires further verification and insertion of other relevant social factors for more comprehensive assessment of vulnerability.

Maria et al. (2015) studied socioeconomic evaluation of drought effects by using the main supply and demand characteristics of a region (water sources and associated uses), and the hydrological interlinked effects of drought situations in the Guadiana and the Ribeiras do Algarve river basin in Portugal. They discovered that the socioeconomic evaluation of drought effects could be an important methodology for drought severity assessment. For agriculture, the procedure based on assessing decrease on framers' income compared to a normal year (by both a reduction of crop yields and an increase in the production costs). For urban water supply, the evaluation method based on the estimation of additional costs of using other water sources to avoid water shortages.

Jain et al. (2015) assessed the spatial and temporal of vulnerability to drought by using Integrated Drought Vulnerability Index (IDVI) on the Ken river basin, located in the Bundelkhand region in central India. The results showed that: (1) rainfall departures for the month are sensitive and identifies realistic distribution of relative vulnerability to drought in time and space. (2) the areas nearly canal command could recover fully from drought vulnerability due to irrigation support. (3) SWAT model can produce soil moisture data at such finer scale in order to use as input data for calculate SMDI. (4) differential weighting scheme of factors for calculated TDVI provided more sensitive and realistic assessment of the drought situation than uniform weighting scheme. (5) area with low rainfall deficit could be more vulnerable to water shortages and drought because of the physical factors making the place more exposed to water shortage.

Sudaryatno (2016) analyzed the level of vulnerability of the geomorphologic drought that occurred in Central Java and Yogyakarta Special

Region. Parameters of vulnerability of the geomorphologic drought consist of slope, drainage, available water capacity (AWC), permeability, landform, and land use using scoring and weighting. The results showed that: (1) the distribution of dry class is more prevalent than other classes. Most of the dry classes are distributed in steep to sheer slopes and have structural and karst landform. This is related to the type of land on those areas, which affect high level of AWC, so that the drainage became bad. (2) Normal classes are distributed at scarps to gentle slope. This class had average drainage to good, so that the AWC level is low. (3) Wet classes are distributed at gentle slope to plains. Mostly distributed at middle and down slopes to coast, this class had good drainage so that most of the land uses are settlement and farming.

2.6.3 Research on drought assessment in Thailand

Research on drought assessment in Thailand are here summarized as shown Table 2.8.

Table 2.8 Research on drought assessment in Thailand.

Authors and Topic	Objective	Input	Process/model	Output
Prathumchai et al. (2001). Drought risk evaluation using remote sensing and GIS: A case study in Lop Buri Province.	To evaluate the criteria for identifying drought risk areas modified from Ministry of Science, Technology and Environment (MOSTE) criteria by investigating the decrease in NDVI evident in a drought year.	1) Meteorological data consist of annual rainfall average, frequency of rainfall days and Annual evaporation. 2) Physical data consist of Irrigation area, ground water resource, topology (slope) and soil drainage 3) Satellite data (JERS-1) used data in 1955 and 1997.	- Geometric and radiometric correction - Maximum likelihood classification - NDVI - Weighting linear combination	1) The results showed a decrease of NDVI in January1995, which correlate to the reduced rainfall quantity during year 1994. Thus, Vegetation condition (NDVI) can be used as the main indicator to evaluate drought. 2) The drought risk area is located outside the boundaries of irrigated land; the ground water resource can produce a flow of less than 10 M^3 per hour and slope aspect is more than 16% the area’s soils are moderately well drained.
Suwanwerakamtorn et al. (2005). Drought assessment using GIS technology in the Nam Choen watershed, Northeast part of Thailand.	To assess the feasibility of utilizing index overlay function to analyze drought risk area.	1) Meteorological data consist of mean annual rainfall. 2) Hydrological data consist of water resource, irrigation area, groundwater yield and TDS and Stream density. 3) Physical terrain data consist of land use, soil drainage condition and-slope. 4) NRD2C survey data.	- Decile rainfall - Weighting overlay function	1) The severe overall drought area covers mainly the middle and the east of the region and approximately 60% of the Nam Choen watershed. 2) The comparison between NRD2C villages on the item of availability of water for agriculture and drought risk found that only 60% of villages location of each water shortage class matches the drought class studied

Table 2.8 (Continued).

Authors and Topic	**Objective**	**Input**	**Process/model**	**Output**
Baimoung et al. (2005). Meteorological drought classification using Normalized Different Vegetation Index.	1) To compute meteorological parameters was the main data input for agrometeorological model so-called Soil-Water-Atmosphere-Plant model (SWAP) in order to calculate the water balance parameters 2) To compute, interpolate and extend the severity of Palmer meteorological drought indices by using Kriging technique. 3) To find out a relationship between the Palmer meteorological drought indices and NDVI of NOAA imageries.	1) Meteorological parameters consist of solar radiation, maximum-minimum air temperature, relative humidity, rainfall and wind 2) Soil data consist of Available Water Capacity: AWC, Field capacity: FC, Permanent Wilting Point: PWT and PH. 3) Agricultural data consist of land use. 4) SWAP output consists of potential water runoff, water runoff, potential water loss, water loss, potential water recharge, water recharge, potential ET and ET. 5) Satellite data input consist of NOAA imagery (NDVI)	- SWAP model - Kriging technique - Palmer meteorological drought indices - NDVI	1) the comparison between the average monthly of Palmer meteorological drought indices and monthly climatic parameters of summer, rainy and winter seasons, it has been very corresponding and compromising in term of areal average for each season. 2) the correlation between NDVI and Palmer meteorological drought indices have been correlated in 92 linear regression equations with correlation coefficient, r = 0.47-0.99, df = 3-6. 3) The integration of satellites remote sensing and numerical weather prediction techniques should have been used to increase an accuracy and potential of meteorological drought estimating and forecasting for a routine work.

Table 2.8 (Continued).

Authors and Topic	Objective	Input	Process/model	Output
Kaewpruksapimon (2006). Fuzzy logic technique for drought risk identification of Buriram province.	1) To identify state of drought in Buriram Province. 2) To investigate drought risk area by using fuzzy logic technique.	1) Climate consist of rainfall (dry season), number of rainy day and water deficit. 2) Soil science consist of soil texture and evaporation. 3) Topographic is slope. 4) Hydrology and Hydrogeology consists of surface water and ground water aquifer.	- Multi-Criteria Evaluation (MCE) - Fuzzy logic technique - Potential Surface Analysis technique (PSA) - Kappa index method	1) The fuzzy logic technique showed that the high potential areas for drought were approximately about 8,780.44 km2 or 85.14%. While, the PSA results for drought risk identification found that the high potential areas for drought were approximately about 1,664.93 km2 or 16.14 %. 2) The fuzzy logic technique revealed the percentages of accuracy, which is 0.75. At the same time, PSA demonstrated the percentage of accuracy, which is 0.47. The accuracy of the fuzzy logic technique was superior to PSA.

Table 2.8 (Continued).

Authors and Topic	Objective	Input	Process/model	Output
Chanchaeng (2012). Drought risk assessment in the areas of Kamphaeng Saen District in Nakhon Pathom Province through using Geographic Information System.	To studied factors which influenced drought and analyzed the risk of drought including the equation of the relationship between the factors and risk of drought.	1) The factors related to natural feature consist of Annual rainfall, the amount of ground water, soil texture and drainage. 2) The factors related to man-made physical characteristics consist of irrigation canals and land use.	- Weighting Linear method and overlay technique - Linear regression analysis - Pearson Product Moment Correlation Coefficient	1) The results revealed that factors influencing drought risk at the statistically significant level (95%) were drainage and soil texture with high correlation coefficients (r = 0.911 and r = 0.852, respectively). 2) The correlation between factors and drought risk are positively correlation.
Ano et al. (2013). The Estimation of Drought Risk Area using Potential Surface Analysis Technique.	To studied estimation of drought risk area in Huai Aek sub basin in upper Mun river basin by Potential Surface Analysis technique (PSA) to assess drought by participation of irrigation experts and supervisors in conjunction with applying GIS for mapping and represent if drought risk areas in the sub basin.	- Amount of precipitation - Number of rainy day - Water resource and irrigation - Land use - Density of streamflow - Soil texture - Aquifer - Slope	- Potential Surface Analysis technique (PSA) - Expert weighting - Weighting Linear method and overlay technique	The results show that the most drought risk areas of Huai Aek was moderate drought risk of 694 square kilometers (59%), nearby high drought risk of 300 square kilometers (26%) and the low drought risk of 173 square kilometers (15%), respectively. The high drought risk level covered 79 villages (24%), the moderate level covered 197 villages (60%) while the low drought risk level covered 54 villages (16%).

Table 2.8 (Continued).

Authors and Topic	**Objective**	**Input**	**Process/model**	**Output**
Homdee et al. (2016). A comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand.	To evaluate the performance of three standardized climatic drought indices (SPI, SPEI and Standardized Precipitation Actual Evapotranspiration Index: SPAEI) to characterize the drought trends at local scale (the Chi River basin, Thailand)	- Monthly precipitation - Maximum and minimum temperatures - Relative humidity - Wind speed - Solar radiation - DEM - Land use	- Soil Water Assessment Tool (SWAT) model - SPI, SPEI and SPAEI - The Kolmogorov-Smirnov (K-S) test. - Pearson r coefficient	1) A severe drought (SPI-3M) was experienced in 2004-2005. This was in accordance with the reported by the National Weather Service as years of El Nino. 2) The category moderately and severely dry (-1.99 <SPI<-1) was simply dry spells in the summer monsoon season in this region which may not cause damage to agricultural fields. 3) The SPEI and the SPAEI showed substantial higher severity and longer durations of droughts than the SPI. This may have been due to the temperature rise which was conducive to an increase in the water demand of PET and AET that triggered the severity of droughts especially on longer timescales. 4) The correlation between the SPI and the SPEI was relatively close at shorter timescales (1-6 months) and dramatically decreased at longer timescales (9-24 months).

CHAPTER III

RESEARCH METHODOLOGY

Research methodology, which is designed to serve the main objectives of the research, consists of major unique components: exposure hazard assessment based on meteorological drought, agricultural drought sensitivity, adaptive capability assessment and agriculture drought vulnerability analysis and mapping. Schematic diagram of research methodology framework is displayed in Figure 3.1. Details of main components and data collection and preparation are separately described in this chapter.

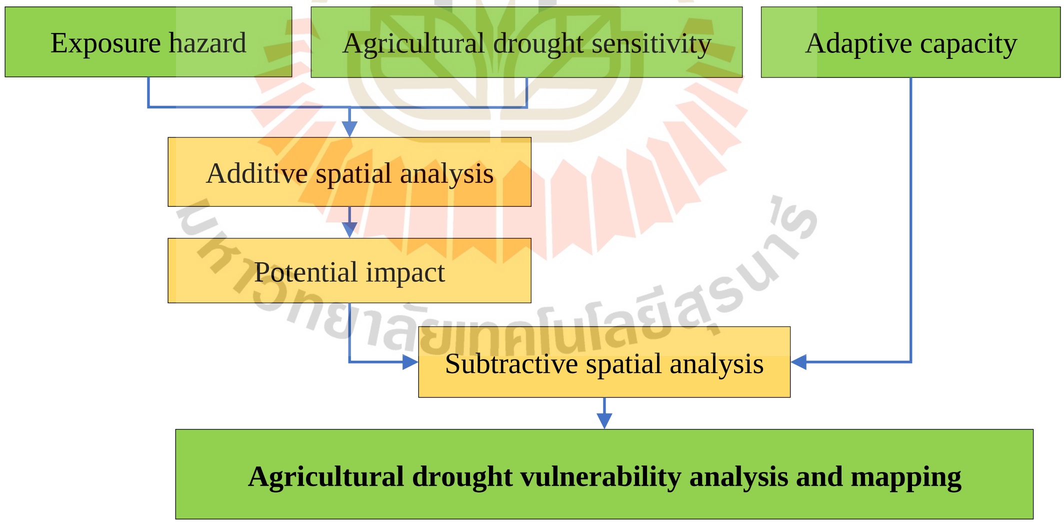


Figure 3.1 Overview of research methodology framework.

3.1 Data collection and preparation

The required input data from historical and recent records for agricultural drought vulnerability analysis and mapping are collected and prepared as summarized in Table 3.1.

3.2 Exposure drought hazard assessment

Under this component, two main exposure drought hazard assessment include meteorological drought hazard frequency and intensity are firstly separately assessed and then they are combined using additive operation to create exposure drought hazard index and map as shown in Figure 3.2. In this study, yield data of main crops (paddy field, cassava, and maize) during 2011-2015 are used to validate exposure drought hazard classification map using coefficient variation (CV) using Eq. 3.1.

$$CV = \frac{\sigma}{\mu} \qquad (3.1)$$

where, σ is standard deviation at district level.

μ is mean at district level.

In practice, crop yield data between 2011 and 2015 at district level is firstly used calculate CV value and then reclassify crop yield dispersion into 5 classes (very low, low, moderate, high, and very high variation) using natural break method. Then derived CV map of 2 high and very high variation classes as representative of drought effect is compared with drought exposure hazard classification for consistency test using coincident matrix.

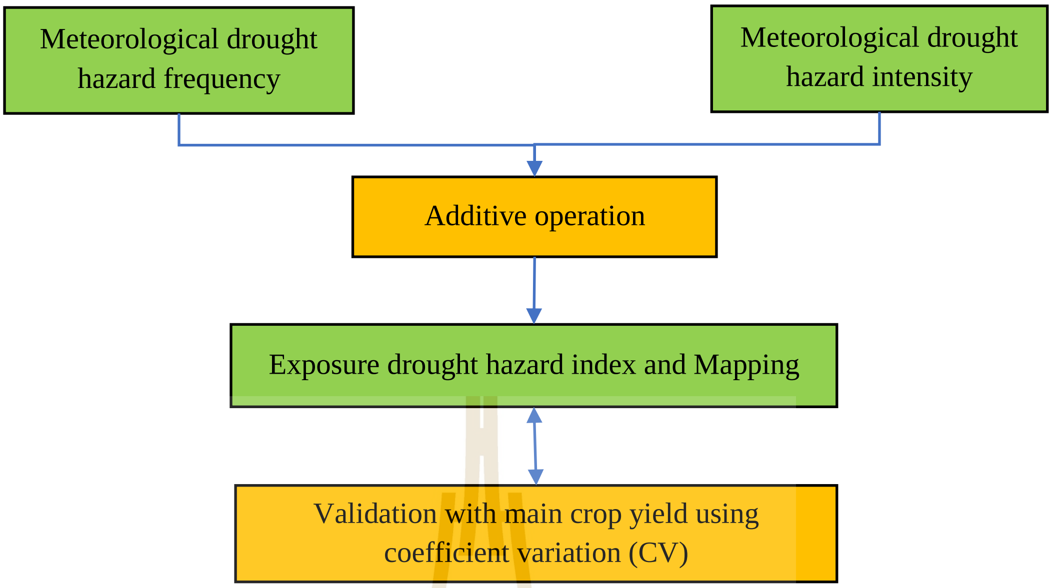


Figure 3.2 The main procedure of exposure hazard index and map.

Table 3.1 List of collection and preparation data.

Component	**Data collection**	**Data preparation**	**Output**	**Scale**	**Source**	**Date**
Exposure	Rainfall data	Input format for calculate SPI and interpolation	SPI , frequency, and intensity	No scale	TMD	1976-2016
Sensitivity	Rainfall data	Input format for calculate SPI and interpolation	SPI , frequency, and intensity	No scale	TMD	1976-2016
	Monthly mean temperature data	Calculate SPEI	SPEI	No scale	TMD	2004-2016
	NDVI-MODIS	Mosaic, clip boundary, filtering and smoothing,	NDVI, VCI	250 m.	NASA	2000-2016
	LST-MODIS	Conversion of temperature to Celsius	SPEI	5600 m.	NASA	2004-2016
	Agricultural irrigation area	Buffer and reclassified	Agricultural irrigation areas		DEQP	
	Soil series	Reclassified	Soil drainage	1: 100,000	LDD, DEQP	
	Slope	Reclassified	Slope	1: 50,000	LDD, DEQP	
	Elevation	Generate	Elevation	90 meter	DEQP	
	Land use	Reclassified	Land use		LDD	2000-2015
	Stream	Calculated length of stream/sub-watershed area	Drainage density Distance to river	1: 50,000	DEQP	
	Agricultural occupation	Calculated and reclassified	Agricultural occupation	Sub-district	NRD2C	2003-2015
	Economic crop production	Natural break method	Economic crop production	Sub-district	NRD2C	2003-2015
	Population	Calculated and reclassified	Population density	Sub-district	NRD2C	2003-2015

Table 3.1 (Continued).

Component	Data collection	Data preparation	Output	Scale	Source	Date
Adaptive capacity	Illiteracy	Natural break method	Illiteracy	Sub-district	NRD2C	2003-2015
	Proportion of people below poverty line	Natural break method	Proportion of people below poverty line	Sub-district	National Statistical Office	2003-2015
	Farm holding size	Natural break method	Farm holding size	Sub-district	NRD2C	2003-2015
	Income from agricultural sector	Natural break method	Income from agricultural sector	Sub-district	NRD2C	2003-2015
	Income from non-agricultural sector	Natural break method	Income from non-agricultural sector	Sub-district	NRD2C	2003-2015
	Information accessibility	Natural break method	Information accessibility	Sub-district	NRD2C	2003-2015

Note: Department of Disaster Prevention and Mitigation (DDPM);

Department of Environmental Quality Promotion; (DEQP);

Land Development Department (LDD);

National Aeronautics and Space Administration; (NASA);

National Economic and Social Development Board (NRD2C);

Thai Meteorological Department (TMD);

3.2.1 Meteorological drought hazard frequency

The rainfall data records about 41 years (between 1976 and 2016) is firstly used to calculate SPI for extracting spatial extent, frequency and intensity of drought. Then frequency of drought is applied to generate probability of drought occurrence. After that, weight and rating are assigned for drought severity based on the derived SPI to create meteorological drought hazard frequency map (Figure 3.3).

In practice, meteorological drought hazard frequency assessment is conducted in the following steps:

1) The rainfall data record is used to calculate SPI for extracting spatial extent, frequency and intensity of drought in each meteorological stationary. In this study, the temporal of SPI is applied using crop phenology for meteorological drought hazard assessment.

2) Weights of meteorological drought categories include near normal drought (NND), moderate drought (MD), severe drought (SD) and extreme drought (ED) are 1, 2, 3, and 4, respectively as suggested by Kim et al. (2015) (Table 3.2).

3) Because of the area vulnerable to drought at different time scales is identified on the basis on their percentage of occurrences (Shahid and Behrawan, 2008). Thus, the percentage of meteorological drought occurrence computed by taking ratio of drought occurrences in each time step to the total drought occurrences in the same time step and drought category (Sonmez et al., 2005; Shahid and Behrawan, 2008). The unit of number of SPI values is months.

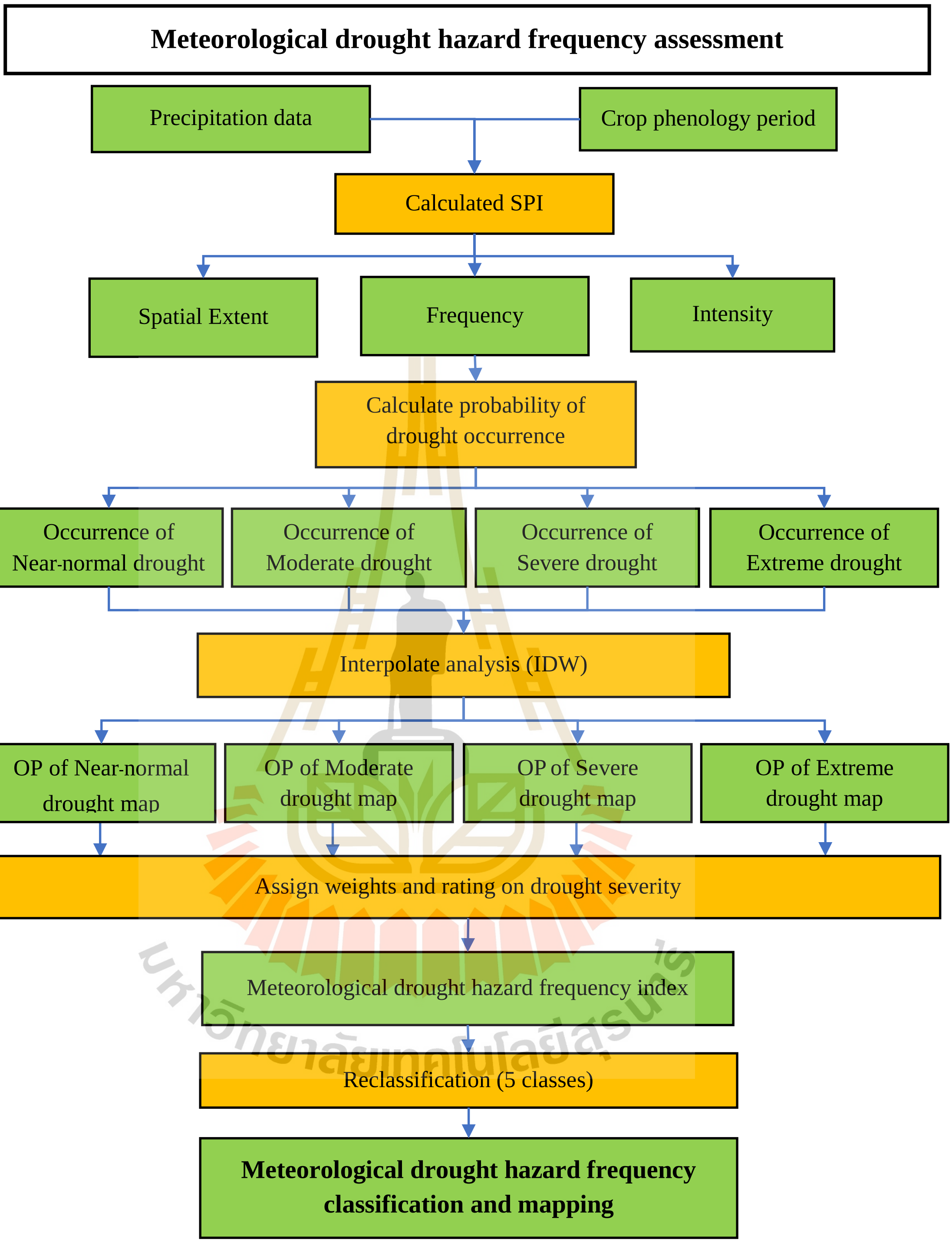


Figure 3.3 The procedure of meteorological drought hazard frequency assessment.

4) Each meteorological stationary is calculated probability of drought occurrence (%) for each period of interest (SPI-3M7, SPI-3M10 and SPI-6m10) and drought categories (near normal, moderate, severe and extreme drought). The probability of drought occurrence of all meteorological stationary is interpolated using Inverse Distance Weight (IDW) technique (Tadesse et al., 2015).

5) The occurrence probability (OP) of subclass drought category is assigned by dividing the range into 4 levels in order to assigned rating (See example in Table 3.3).

6) The meteorological drought hazard index is calculated by integrating weights and ratings as follows:

$$DHI_{Met} = (NND_w \text{ x } NND_r) + (MD_w \text{ x } MD_r) + (SD_w \text{ x } SD_r) + (ED_w \text{ x } ED_r) \quad (3.2)$$

7) The meteorological drought hazard frequency index is divided into 5 levels using natural break method in order to create meteorological drought hazard frequency map.

Table 3.2 The SPI drought classification and weighting.

Category	**SPI**	**Weights**
Near-normal (NND)	0 to -0.99	1
Moderate drought (MD)	-1.00 to -1.49	2
Severe drought (SD)	-1.50 to -1.99	3
Extreme drought (ED)	-2.00 and less	4

Source: Adapted from Shahid and Behrawan (2008) and Kim et al. (2015).

Table 3.3 Example for rating assignment based on occurrence probability (OP) by each drought severity category.

Category	Occurrence probability (%)	Rating
Near-normal (NND)	OP < 64.16	4
	64.16 ≤ OP < 67.76	3
	67.76 ≤OP < 71.36	2
	71.36 ≤OP < 74.79	1
Moderate drought (MD)	OP < 9.11	1
	9.11 ≤OP < 11.46	2
	11.46 ≤ OP < 13.82	3
	13.82 ≤ OP < 16.18	4
Severe drought (SD)	OP < 2.01	1
	2.01 ≤OP < 3.18	2
	3.18 ≤ OP < 4.35	3
	4.35 ≤OP < 5.52	4
Extreme drought (ED)	OP < 0.60	1
	0.60 ≤ OP <0.91	2
	0.91 ≤ OP < 1.22	3
	1.22 ≤ OP <1.53	4

Source: Kim et al. (2015).

3.2.2 Meteorological drought hazard intensity

Like meteorological drought hazard frequency assessment, meteorological drought hazard intensity is considered as the degree of the precipitation deficiency and the severity of drought measures by SPI when it is less than -1 and equals -1 (Figure 3.4).

In practice, since incomplete rainfall record of some meteorological stations during 42 years, so average intensity value (total of intensity/years) of each station was here interpolated to create continuous surface using Inverse Distance Weight (IDW) method. After that, the interpolated intensity values are applied to classify severity with 5 levels (very low, low, moderate, high and very high) using natural break method and to assign weight value of each level with 1, 2, 3, 4 and 5, respectively.

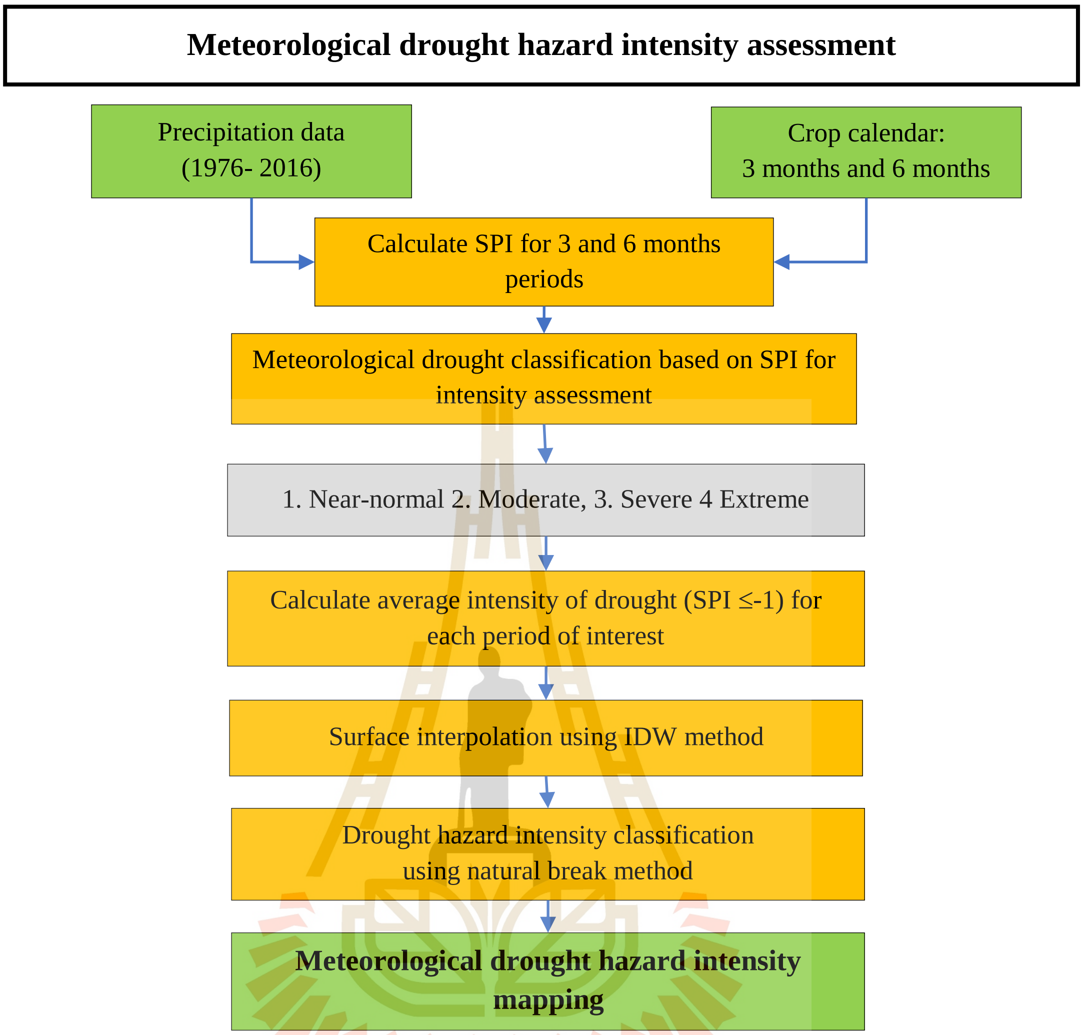


Figure 3.4 The procedure of meteorological drought hazard intensity assessment.

3.3 Agricultural drought sensitivity assessment

In this study, two approaches of agricultural drought sensitivity assessment are conducted including overall agricultural drought sensitivity analysis and annual agricultural drought sensitivity analysis. In practice, four common input data of two approaches include vegetation, climate, physical and socioeconomic conditions are firstly collected and prepared. Details of both approaches are separately described in the following sections:

3.3.1 Overall agricultural drought sensitivity analysis

Workflow of overall agricultural drought sensitivity analysis is presented in Figure 3.5. To accomplish overall agricultural drought sensitivity analysis, four distinct factors are firstly prepared in advance include:

(1) Vegetation condition: vegetation condition identified agricultural frequency drought (number of years that VCI less than 30 in crop season) and agricultural intensity drought (using average VCI value in crop season) by using satellite-based information. Firstly, pre-processing of VCI MODIS data consist of subset, re-projection, filter and smooth signal in order to analyze time series of VCI that indicates vegetation condition in crop season. Detailed workflow of vegetation condition assessment is displayed in Figure 3.6.

(2) Climate condition: climate factors are importance to assign wet, normal or dry condition in areas, consist of SPI and SPEI. In this study, SPI is the derived exposure hazard index that applies average SPI. Meanwhile SPEI as specifically characteristics climatic of the region is an average of historical SPEI value during 2001 to 2016.

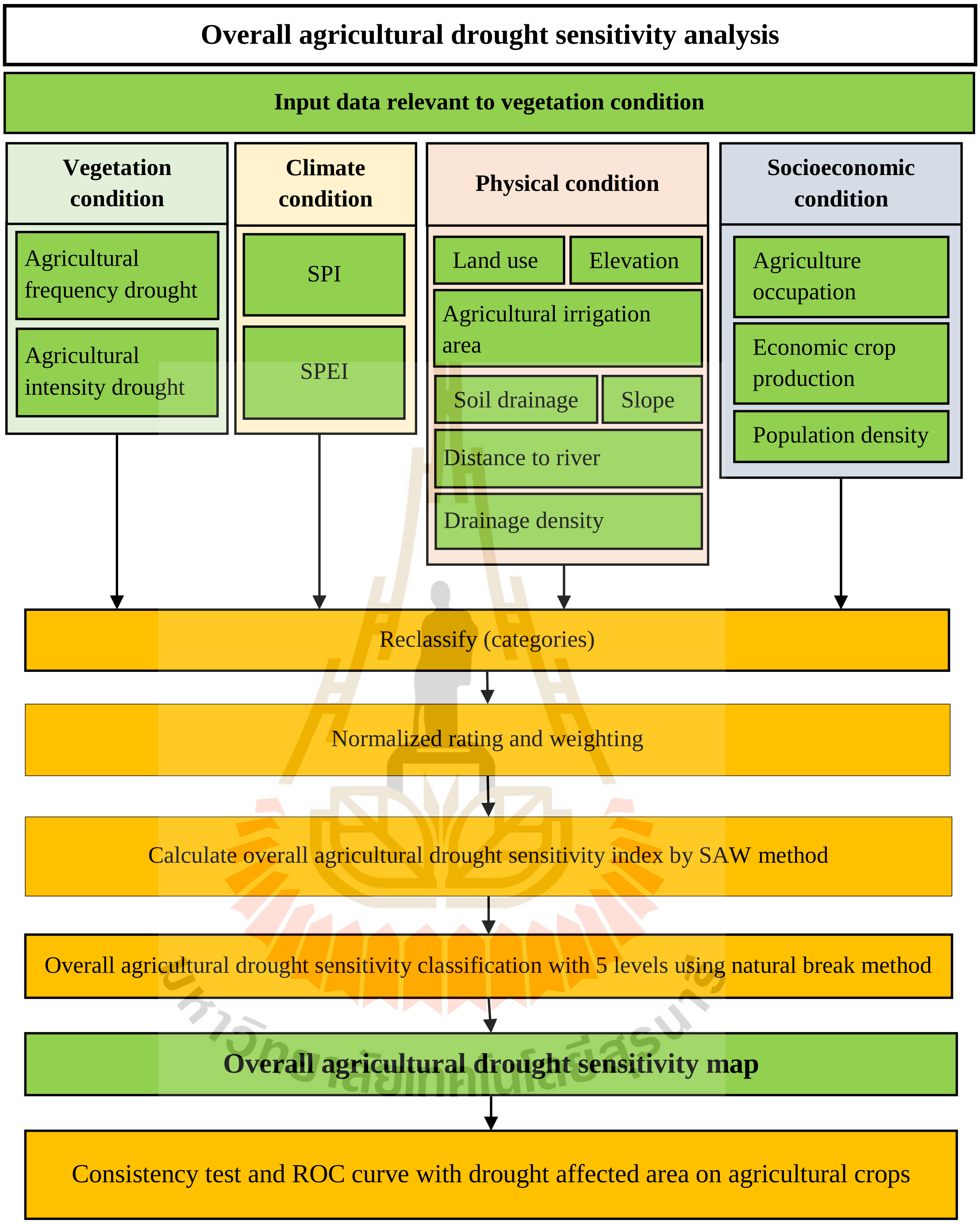


Figure 3.5 The procedure of overall agricultural drought sensitivity assessment.

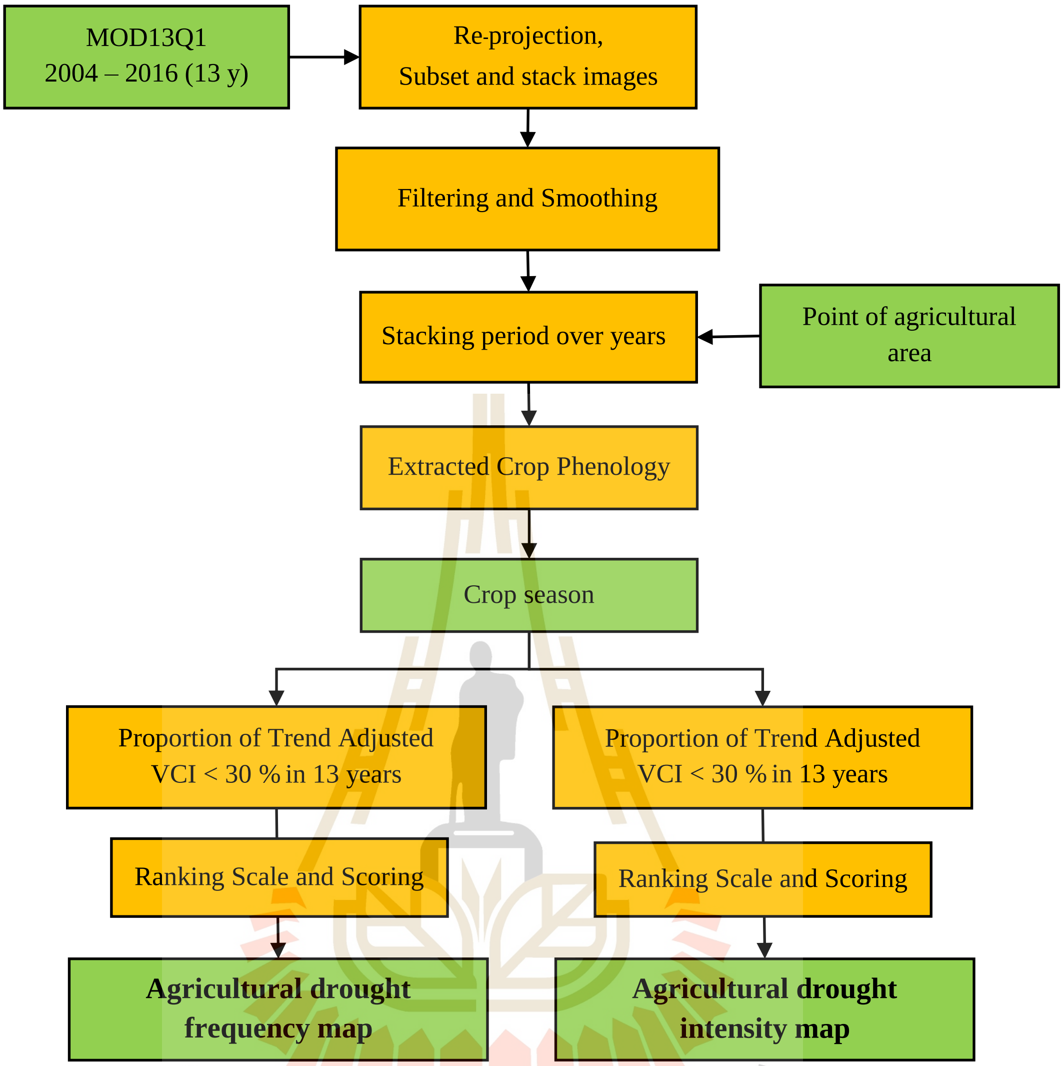


Figure 3.6 The procedure of vegetation condition assessment.

(3) Physical condition: physical factors are characteristics of areas that relevant to growing and healthy of vegetation. They consist of land use, agricultural irrigation area, soil drainage, slope, elevation, distance to river and drainage density. For example, land use is the driving force more than water demand and critical factors of agricultural drought vulnerability or the geographic pattern of soil drainage is important for studying water stress in plants and critical to water management planning for irrigation.

(4) Socioeconomic condition: socioeconomic factors indicate situation of social and economic influence from agricultural drought. It consists of agricultural occupation, population density and economic crop production.

After that, all factors of agricultural drought sensitivity were converted to raster format with normalization and then calculated an agricultural drought sensitivity index using simple additive weighting (SAW) method. This method requires standardized of rating and weighting in order to create total of agricultural drought vulnerability index because factors of agricultural drought sensitivity have different unit and range of data, therefore they require to standardize. After that the derived agricultural drought sensitivity index is used to classify 5 levels (very low, low, moderate, high, and very high) of overall agricultural drought sensitivity using natural break method.

In this research, rating of individual factors is assigned based literature reviews while weighting of all factors will analyzed according to knowledge and experience from experts (15 persons) using questionnaire. Herein, assigned weigh from experts were normalized using standardized rank value as suggested by Tsangaratos et al. (2013) as:

$$v = a + (b - a) * \left[\frac{V - A}{B - A} \right] \tag{3.3}$$

Where v is new weighting value that is between a and b values

V is original weighting value that is between A and B values

A is minimum of original weighting values

B is maximum of original weighting values

a is minimum of standardized weighting values

b is maximum of standardized weighting values

Finally, the derived result of overall agricultural sensitivity classification is validated with accumulate drought affected area on agricultural crops from year 2012, 2014, and 2015. Herein, consistency test with coincident matrix and receiver operating characteristic (ROC) curve by comparison between accumulate drought affected area and overall agricultural drought sensitivity classification are applied to validate the result.

Basically, ROC determines whether the model is fit or not by checking the prediction performance of the model. It determines the accuracy of classification model at a user defined threshold value using Area under Curve (AUC) of ROC. The result of ROC measured by area under ROC curve varies from 0.5 to 1. If ROC value is equal to 1, it indicates a perfect fit and ROC value of 0.5 indicates a random fit (Pontius and Schneider, 2001).

3.3.2 Annual agricultural drought sensitivity analysis

Under this component, CART is applied to derive annual agricultural drought sensitivity map based on the derived overall agricultural drought sensitivity as dependent variable and significant conditions on drought response including vegetation, climatic, physical and socioeconomic conditions as independent variables. Workflow of annual agricultural drought sensitivity assessment is presented in Figure 3.7.

The characteristic of significant conditions and its factor are described in the following sections.

(1) Vegetation condition: Two factors are here selected to represent vegetation condition on drought response include Percent Annual Seasonal Greenness (PASG) and Start of Season Anomaly (SOSA). Both factors are derived from MODIS NDVI product (MOD13Q1) in order to create VCI that indicates vegetation condition in crop seasonal.

(1.1) Percent Annual Seasonal Greenness (PASG)

PASG demonstrated that a measure of how the general vegetation conditions for a specific period during the growing season compare to historical average conditions for that same period over time series historical record. In order to calculate the PASG is necessary to know SOST and EOST of 16-day composite VCI of growing season so that calculation of seasonal greenness (SG) represented the accumulated VCI specified a 16-day composite to compare historical average VCI the same a 16-day composite in start and end periods. Finally, PASG is calculated by dividing the SG for a 16-day composite period by the historical mean SG for the same period using Eq. 3.4.

$$PASG_{PnYn} = \left(\frac{SG_{PnYn}}{xSG_{Pn}} \right) * 100 \qquad (3.4)$$

where SG_{PnYn} is the SG for a 16-day composite period (Pn) of the specific year (Yn), xSG_{Pn} is the historical average SG (x) for the same 16-day composite period (Pn).

If the accumulated SG for a period is less than the historical average, the PASG values is less than 100 percent and indicate vegetation stress or poor vegetation condition (Brown et al., 2008).

(1.2) Start of Season Anomaly (SOSA)

The SOSA demonstrated that the departure in the SOSA for a specific year ($SOST_n$) from the average historical SOST ($SOST_{avg}$) for a given pixel. The SOSA was calculated at the pixel level for each year in the time series using Eq. 3.5.

$$SOSA_n = SOST_n - SOST_{avg} \quad (3.5)$$

where $SOSA_n$ is the SOSA (in number of day) for year n, $SOST_n$ is the start of season DOY for year n, and $SOST_{avg}$ is the average start of season DOY from historical data.

(2) Climate condition: Climate condition is important to assign wet, normal or dry condition in areas, consist of SPI and SPEI. They identified wet or dry condition that caused from rainfall abnormally. Moreover, Wilhelmi and Wilhite (2002) described that the best characterization of the climatology of the state from the drought variability perspective is the probability of seasonal crop moisture deficiency.

(3) Physical condition: Physical condition is characteristics of areas that relevant to growing and healthy of vegetation. It consists of LULC, agricultural irrigation area, soil drainages, slope, elevation, distance to river and drainage density. For example, land use is the driving force more than water demand and critical factors of agricultural drought vulnerability or the geographic pattern of SAWC are important for studying water stress in plants and critical to water management planning for irrigation and dryland crops (Wilhelmi and Wilhite (2002)).

(4) Socioeconomic factors: socioeconomic factors indicated situation of social and economic influenced from agricultural drought. It's consist of agricultural occupation, population density and economic crop production.

All factors are converted to raster format and extracted training data in order to use for input data of CART model with CuBist Software (Available: https://cran.r-project.org/web/packages/Cubist/). The result of CART model will provide multiple linear equations with the significant factors and its decision rule for annual agricultural drought sensitivity mapping. Finally, the derived result is also validated using consistency test with coincident matrix and receiver operating characteristic (ROC) curve by comparing with drought affected area on agricultural crops from each from each corresponding year. In addition, the derived multiple linear equation for annual agricultural drought sensitivity classification from 3 SPI periods that provides the highest ROC value is identified as an optimum equation to classify annual agricultural drought sensitivity.

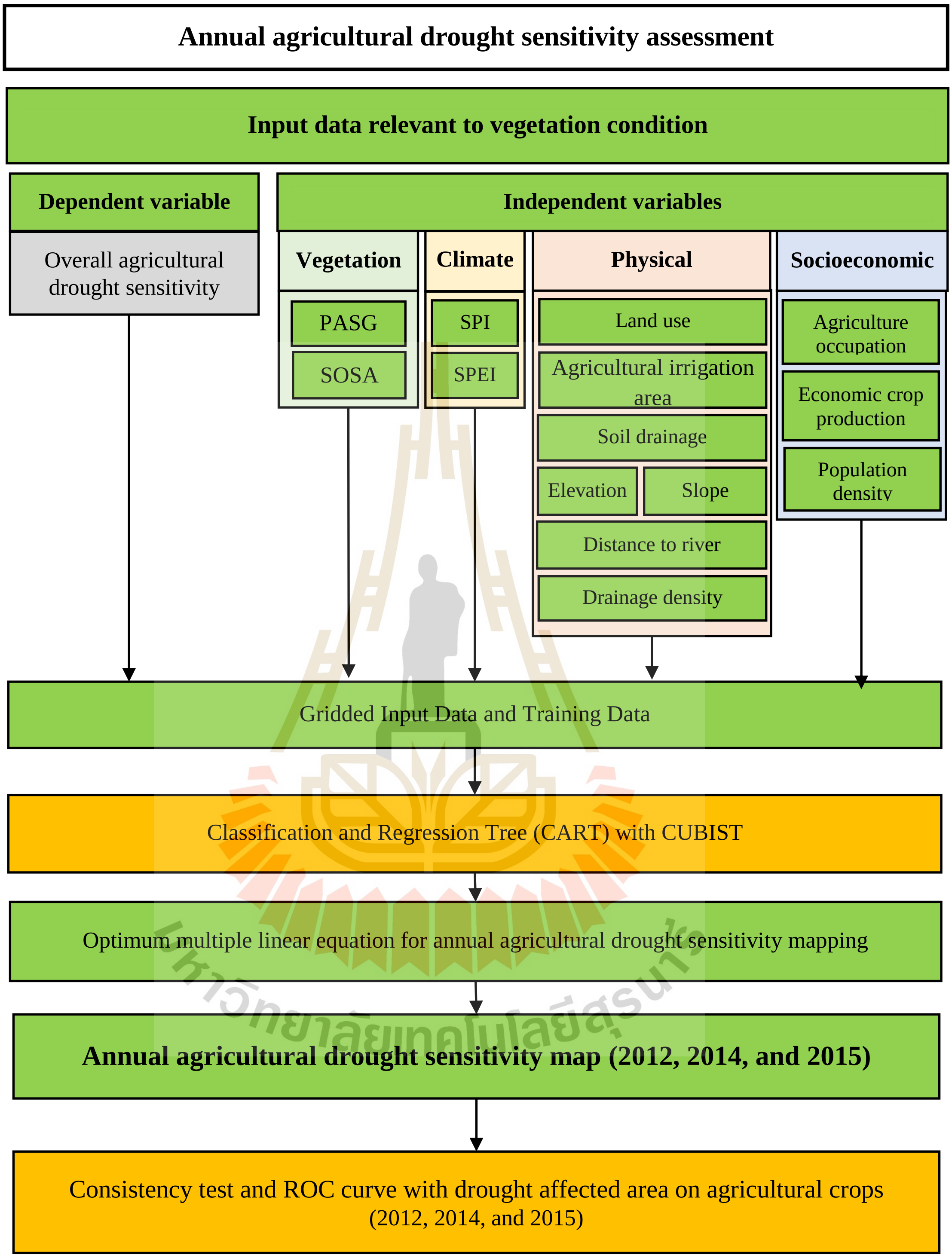


Figure 3.7 The procedure of annual agricultural drought sensitivity assessment.

3.4 Adaptive capacity assessment

Adaptive capacity factors are the degree ability of people to adjust to drought impacted. It is composed of proportion of people below poverty line, illiteracy, income from agricultural sector, farm holding size, income from non-agricultural sector and information accessibility using adaptive capacity index (ACI). They are derived from individual rating of each factors is here exercised. In practice, all factors are firstly classified into 5 classes using natural break method and then calculated ACI index using Eq. 3.6.

$$ACI = \sum_{i=1}^{N} \frac{X_i}{N} \qquad (3.6)$$

where X_i is rating value of factor i, N is number of indicators

The adaptive capacity factors are briefly described as:

(1) Proportion of people below poverty line: Shahid and Behrawan (2008) described that poverty level represents proportion of people living below the lower poverty line in an area. Vulnerability is a combination of characteristics of a person or group, which derives from the social and economic condition of the individual, family, or community concerned (Blaikie et al., 1994). Therefore, there is a direct and absolute correlation between poverty and vulnerability. As a rule, the poor suffer more from hazards than the rich (Yodmani, 2001). Gbetibouo and Ringler (2009) described that the higher the proportion of people below the poverty line, the higher the vulnerability level. In conclusion, if the proportions of people below poverty line are high, the vulnerability will be high or low adaptive capacity.

(2) Illiteracy: illiteracy represented human capital. Leichenko et al. (2002) described that increased overall literacy levels reduce vulnerability by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities. Gbetibouo and Ringler (2009) described that the higher the literacy rate, the lower the vulnerability level. In conclusion, if illiteracy is high, the vulnerability will be high or low adaptive capacity.

(3) Income from agricultural sector: Regions with higher farm income are able to prepare and respond to effect of drought (Gbetibouo and Ringler, 2009). Therefore, if income from agricultural sector is high, the vulnerability will be low or high adaptive capacity.

(4) Farm holding size: Regions with higher farm holding size are able to prepare and respond to impacted of drought (Gbetibouo and Ringler, 2009). Therefore, if farm holding size is large, the vulnerability will be low.

(5) Income from non-agricultural sector: Region with a higher dependence on agricultural are assumed to be a less economically diversified and thus more susceptible to climatic events and change (Gbetibouo and Ringler, 2009). Hired household's income (except agriculture incomes) solved drought impacted that declining agricultural production. Thus, if region is higher hired household's income, it will be lower vulnerable or high adaptive capacity.

(6) Information accessibility: The quality of infrastructure is an important measure of the relative adaptive capacity of a region. Region with better infrastructure may reduce transaction cost, and strengthen the links between labor and product markets (Gbetibouo and Ringler, 2009). Moreover, a household that accessed the internet, telephone and television, high capability to adapt to drought impacted.

3.5 Agriculture drought vulnerability analysis

For agriculture drought vulnerability analysis (Figure 3.8 and Table 3.4), three selected main factors include drought exposure hazard, agricultural drought sensitivity, and adaptive capacity classifications are applied to create agricultural drought vulnerability index. In this study, exposure hazard and agricultural drought sensitivity classification is firstly combined using additive operation and the derived index is the combined with adaptive capacity classification using subtractive operation for final drought vulnerability map.

Table 3.4 The influential factors for agricultural drought vulnerability analysis.

Categories	Factors
Exposure	Meteorological drought frequency
	Meteorological drought intensity
Sensitivity	Agricultural frequency drought
	Agricultural intensity drought
	Percent Annual Seasonal Greenness (PASG)
	Start of Season Anomaly (SOSA)
	Standardized Precipitation Evapotranspiration Index (SPEI)
	LULC
	Soil drainage
	Agricultural irrigation area
	Slope
	Elevation
	Distance to river
	Drainage density
	Agriculture occupation
	Economic crop production
	Population density
Adaptive capacity	Percentage of people below poverty line
	Farm holding size
	Income from agricultural sector
	Income from non-agricultural sector
	Illiteracy
	Information accessibility

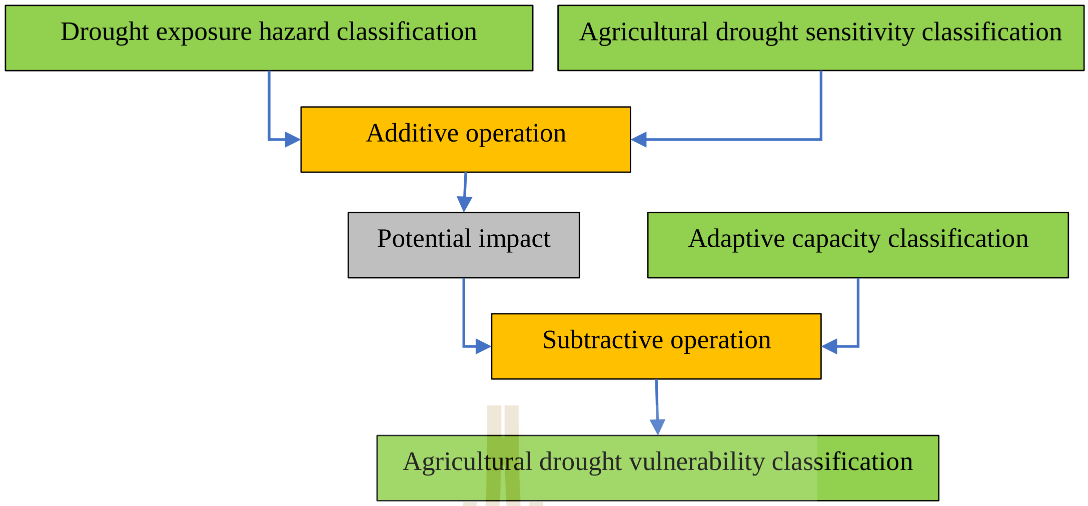


Figure 3.8 The procedure of agricultural drought vulnerability analysis.

CHAPTER IV

PREPROCESSING DATA FOR AGRICULTURAL DROUGHT SENSITIVITY ANALYSIS

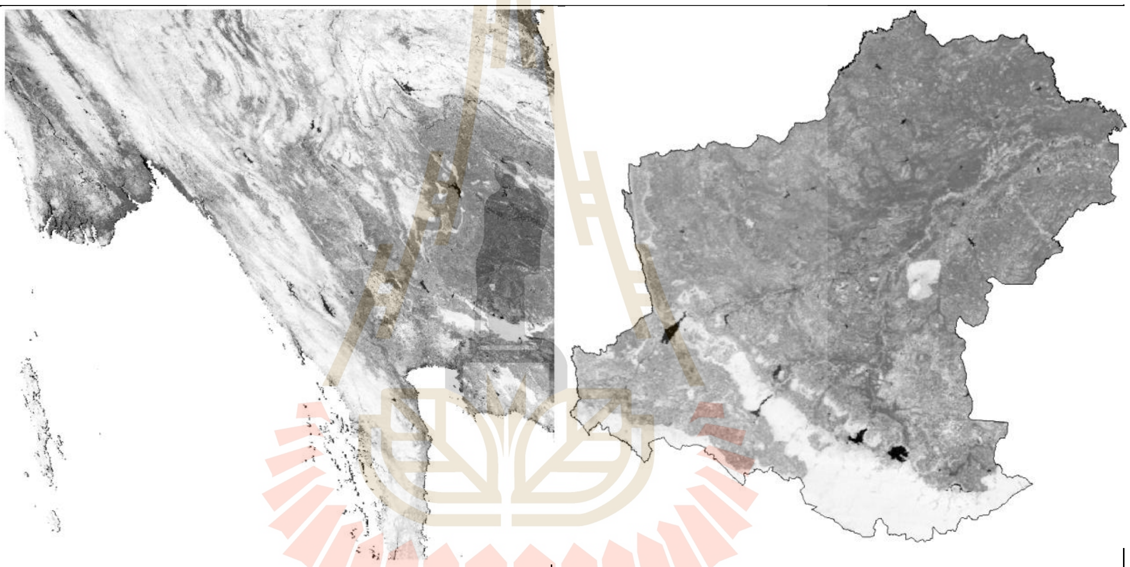
This chapter presents results of preprocessing data for overall and annual agricultural drought sensitivity analysis. Main results consist of preprocessing data of 4 conditions of agricultural drought include (1) vegetation (2) climate (3) physical and (4) socioeconomic conditions. Details of each condition and its derived output is separately described and discussed in this chapter.

4.1. Vegetation condition

This study applied NDVI and VCI from MODIS product (MOD13Q1) to characterize vegetation condition for extracting agricultural drought frequency and intensity. In brief, MOD13Q1 product consists of 12 layers including NDVI and NDVI layer is 250 meter spatial resolution, 16 days composite, bit type is 16 bit signed integer, fill value is -3000), valid domain range varies between -2000 and 10,000, scale factor is 0.0001 and grid projection is Sinusoidal. Major steps are here required to preprocess NDVI for extracting agricultural drought frequency and intensity factors of overall agricultural drought sensitivity as following.

4.1.1 Preparation of NDVI band

The NDVI data requires to re-project from Sinusoid projection into WGS 1984 Zone 47N, to edit header file of all data, to rescale and fill data and to extract study area. In this study NDVI dataset covers between 2004 and 2016 and number of NDVI images is 299 scenes (23 scenes/year). Figure 4.1 displays an example NDVI data extraction.



Original data (Sinusoidal projection)	Processed data (WGS1984 Zone47N)

Figure 4.1 An example of NDVI data extraction.

4.1.2 Preparation of quality of vegetation index (Reliability)

The processing of quality of vegetation index (Reliability) consists of extract reliability of vegetation index band, reprojection into WGS1984 Zone 47N, edit header file of all data, rescale, and subset by study area. Table 4.1 shows the details of overall pixel quality data that consist of rank key, summary quality data and description. For instance, rank key is 1 that illustrates a good data (QA) and it can uses with high confidence. After that, quality of vegetation data is assigned the weights for adjust NDVI data. Herein, the file values will assign the weights in the right column to the data range under file value such as good data (file values = 1) assigned weight is 1.0 that means high quality data. While, assign weights of marginal data (rank key = 2) equals to 0.5 that means mixed class. At the same time, assign weights of cloud data (rank key = 3) equals to 0.1 that means low quality data (Table 4.2). Figure 4.2 displays a comparison of quality vegetation between winter and rainy season in 2004, it is found that rainy season almost covers by cloud.

Table 4.1 Details of the pixel reliability data.

Rank key	Summary QA	Description
0	Fill/No Data	Not Processed
1	Good Data	Use with high confidence
2	Marginal data	Useful, but look at other QA information
3	Cloudy	Target not visible, covered with cloud

Sources: https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13q1

Table 4.2 Weighting of vegetation data quality (NDVI).

File Value				Weight
From	0	to	1	1.0
From	2	to	2	0.5
From	3	to	3	0.1

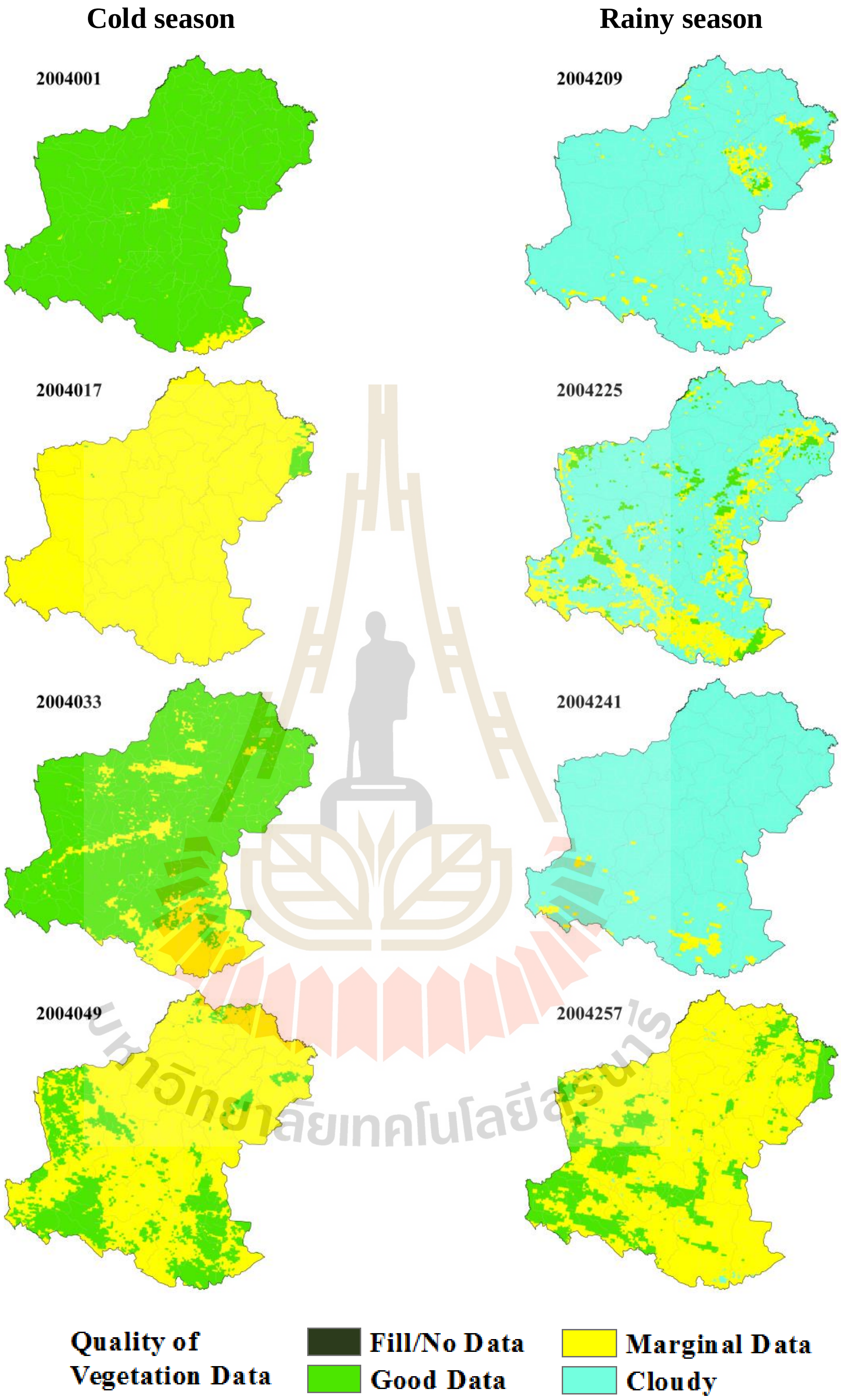


Figure 4.2 Comparison of quality vegetation between cold and rainy season in 2004.

4.1.3 NDVI data filtering

The Savitsky-Golay filtering algorithm was here applied to enhance quality of NDVI dataset between 2004 and 2016. Characteristic of NDVI before and after filtering of selected locations: Row 6 Column 1, Row 7 Column 1 and Row 8 Column 1 is displayed in Figure 4.3. Meanwhile comparison of original NDVI and NDVI with Savitsky-Golay filtering is played in Figure 4.4.

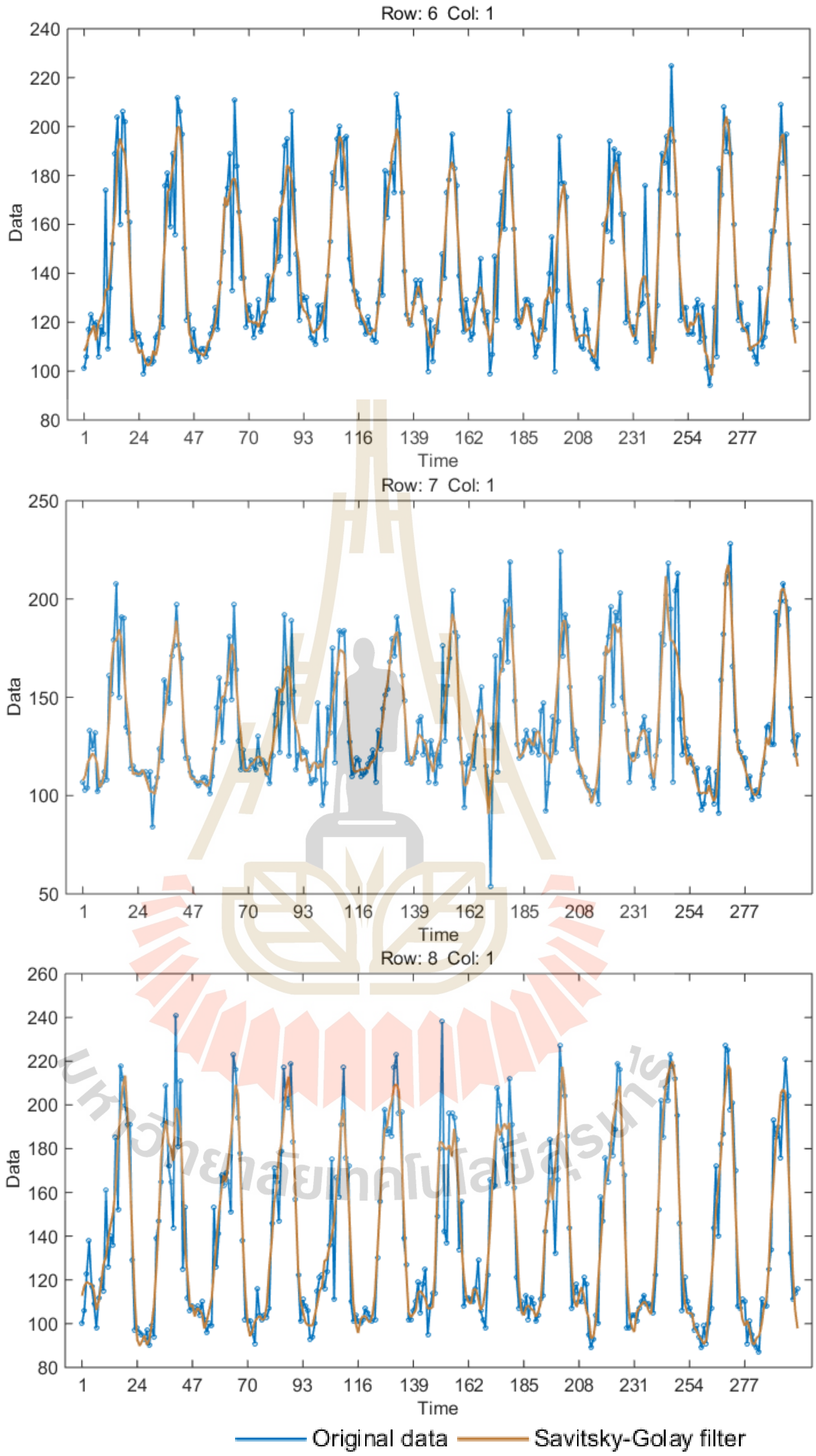


Figure 4.3 Comparison of time series NDVI data at Row 6, Column 1; Row 7, Column 1; and Row 8, Column 1 before and after filtering.

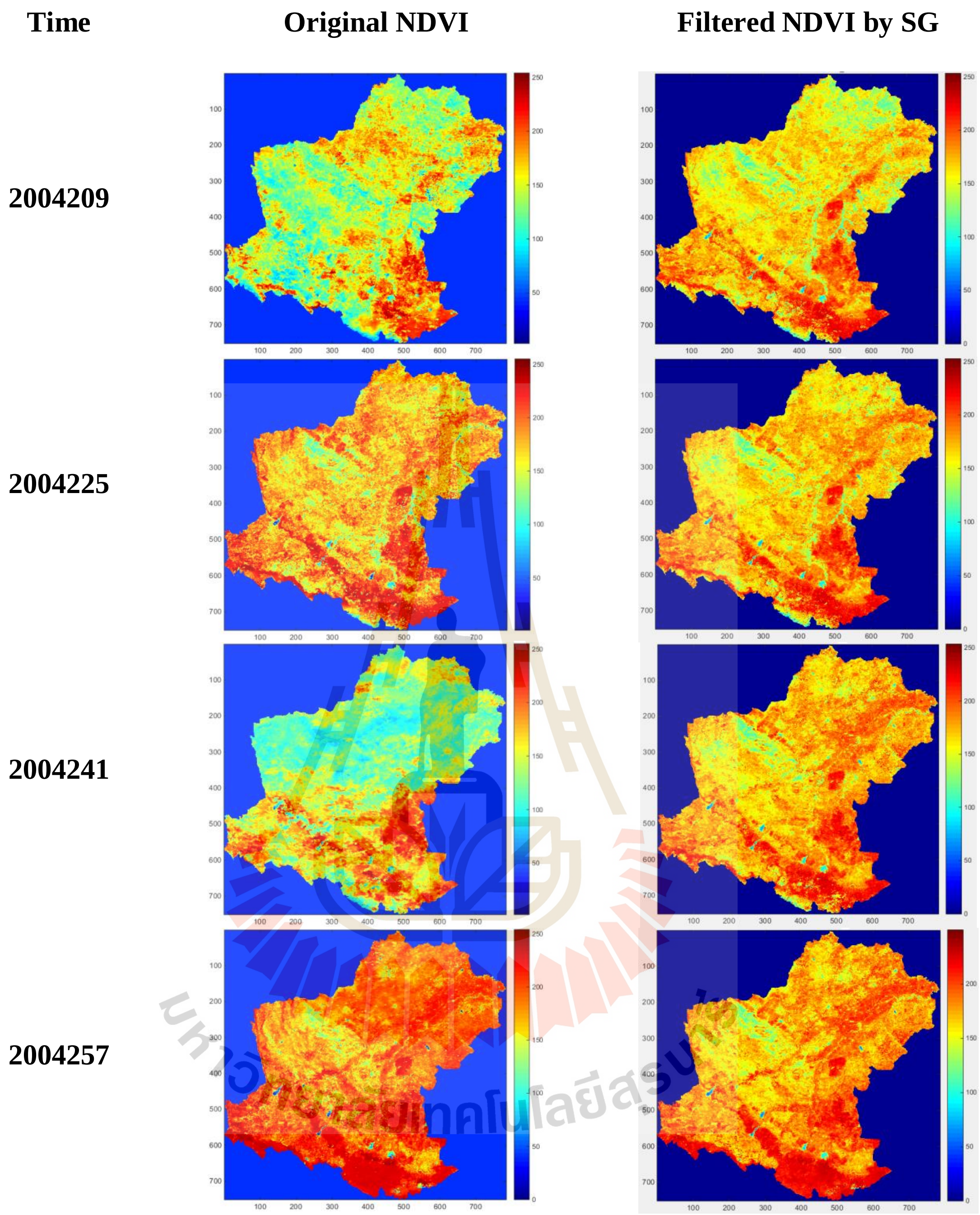
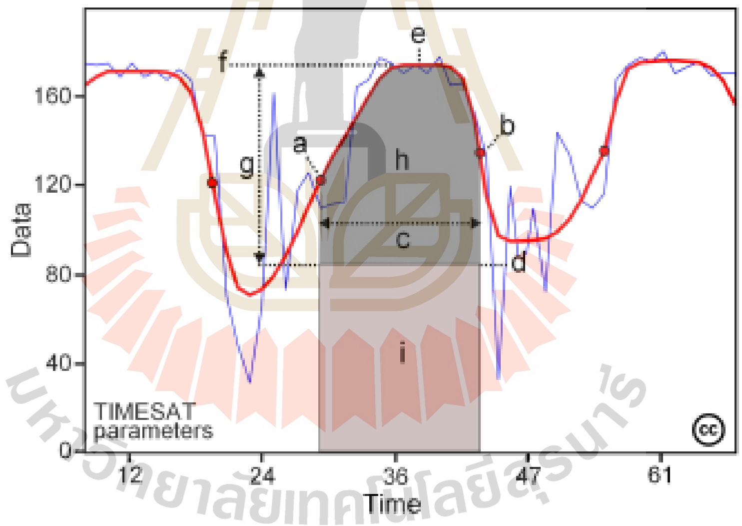


Figure 4.4 Example of original NDVI and NDVI filtered by SG in 209, 225, 241 and 257 of 2004.

4.1.4 Extraction parameters of phenology

The TimeSat software is here selected to identify starting and ending of growing season. The algorithm for identifying start and end growing season of crop is presented in Figure 4.5. Herein, 30 sample points of paddy field from reference land use map in 2000, 2007, 2008, 2011, and 2015 of LDD are applied to extract parameter of phenology. Result of phenology characteristic based on NDVI is presented in Figure 4.6. Details of sample points of start of growing season and end of growing season is reported in Table 4.3 and 4.4, respectively. In this study, an optimum starting growing season is day 177 of year while end of growing season 337 of year.



Source: Eklundh and Jonsson (2015)

Figure 4.5 Some of the seasonality parameters generated in TIMESAT: (a) beginning of season, (b) end of season, (c) length of season, (d) base value, (e) time of middle of season, (f) maximum value, (g) amplitude, (h) small integrated value, (h+i) large integrated value.

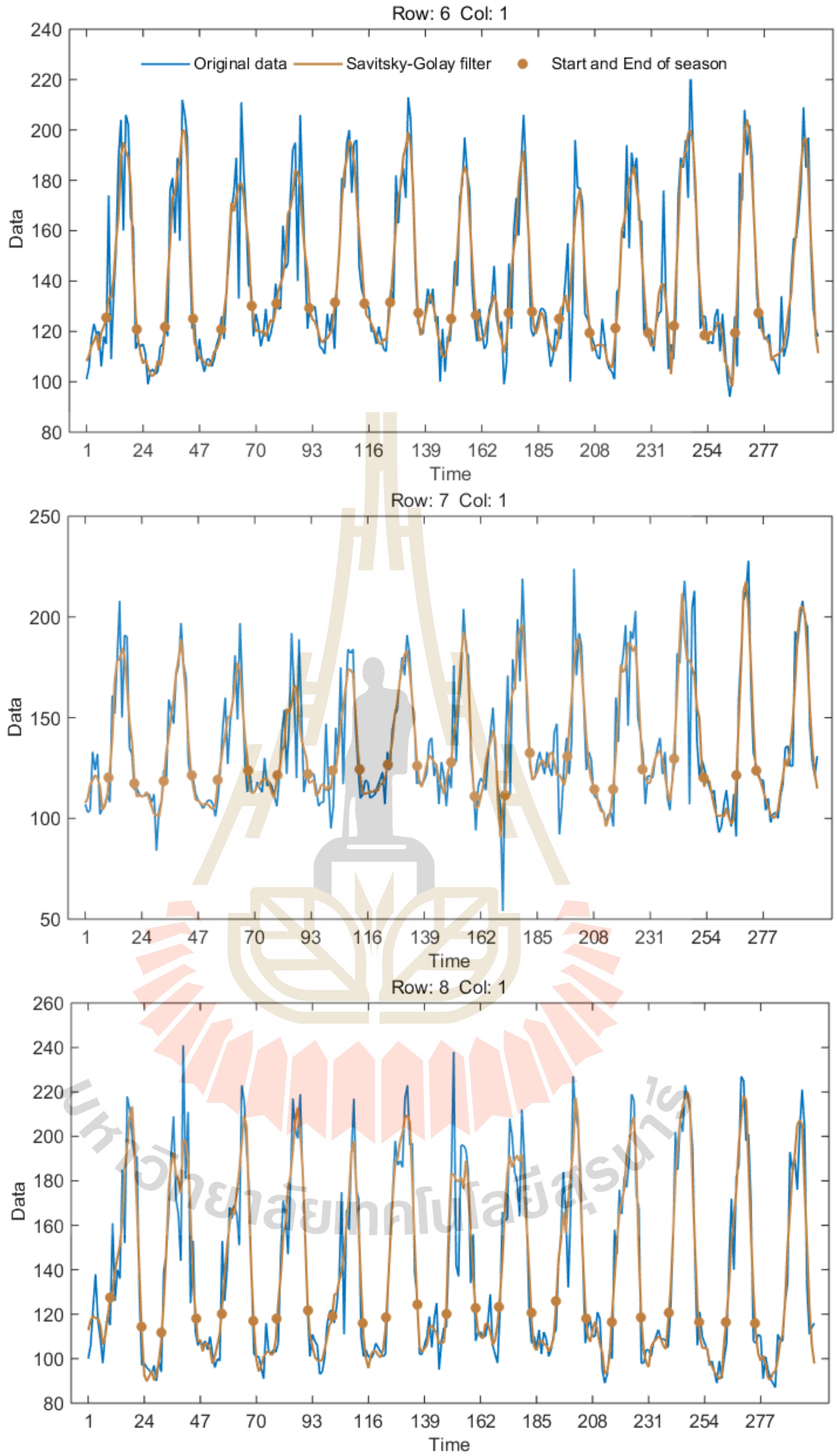


Figure 4.6 To extract start and end of seasons from 13 years of original NDVI and NDVI filtered by Savitsky-Golay filter the time series.

Table 4.3 Examples of Start of growing season.

Number of Point	Start of season (Day of years)											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
P1	224	263	220	253	239	226	231	216	256	221	224	233
P2	196	124	201	214	115	197	196	101	250	174	136	187
P3	241	249	215	223	249	196	228	135	259	209	227	236
P4	198	212	207	154	238	215	141	141	242	222	121	211
P6	106	102	212	111	131	122	117	39	200	182	262	239
P8	133	160	168	160	174	170	215	199	179	184	195	230
P9	166	161	155	178	193	162	205	171	232	169	200	243
P10	177	137	162	165	153	156	175	141	170	168	177	193

Table 4.4 Examples of End of growing season.

Number of Point	End of season (Day of years)											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
P1	347	363	374	369	362	362	351	379	394	374	370	370
P2	351	366	367	362	367	356	344	381	345	377	392	383
P3	348	369	359	372	367	380	352	371	386	379	382	380
P4	345	363	371	377	359	354	351	371	382	376	395	387
P6	378	387	377	371	366	349	344	370	379	379	367	398
P8	343	344	351	372	367	351	341	371	376	395	393	374
P9	344	346	352	370	340	354	344	359	367	369	380	371
P10	365	354	370	364	354	351	346	370	366	365	372	382

4.1.5 Agricultural drought frequency

Agricultural drought frequency was here identified based on VCI that computed using NDVI over phenology period during 2004 to 2016. Since the concept of frequency is the probability occurrence of agricultural drought. Herein, if VCI is less than 30 in cropping season, the vegetation condition will identify as agricultural drought as suggested by Segal and Dhakar (2016). Result of agricultural drought frequency classification with 5 levels and their rating scores using natural break method is presented in Table 4.5. Distribution of agricultural drought frequency classification is displayed in Figure 4.7 while percentage of agricultural drought frequency is summarized in Table 4.6. Detail of percentage of agricultural drought frequency at district level is reported in Table A-1 of Appendix A.

Table 4.5 Classification of agricultural drought frequency and its rating score.

Agricultural drought frequency domain	Drought level	Rating	Normalized
≤ 0.05	Very low (VL)	1	1
0.05-0.14	Low (L)	2	1.5
0.14-0.23	Moderate (M)	3	2
0.23-0.34	High (H)	4	2.5
> 0.34	Very high (VH)	5	3

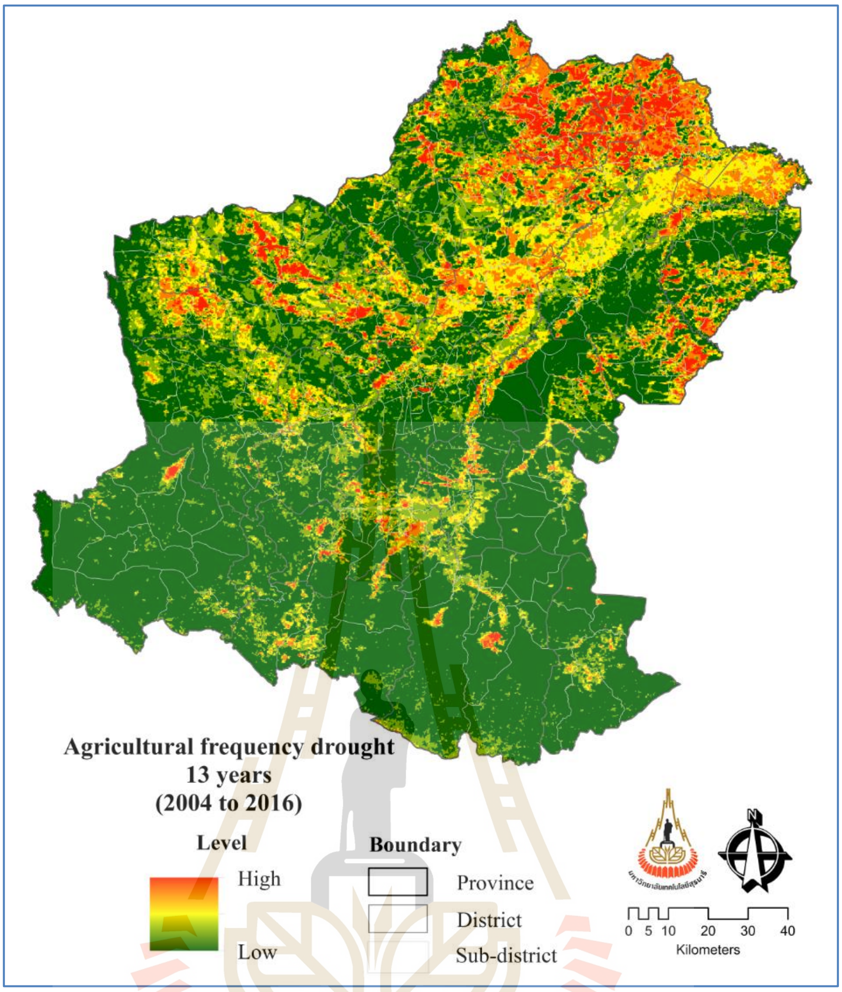


Figure 4.7 Distribution of agricultural drought frequency classification.

Table 4.6 Percentage of agricultural drought frequency at provincial level.

Factor	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
Agricultural frequency drought	57.20	18.86	11.90	8.05	3.98

4.1.6 Agricultural drought intensity

Agricultural drought intensity is considered based on an average historical VCI values (0-100) in crop season (phenology period). Basically, if VCI values are 100, it indicates healthy vegetation conditions. In contrast, if VCI values is nearly 0, it identifies as poor vegetation condition as suggested by Segal and Dhakar (2016). Result of agricultural drought intensity classification with rating score is displayed Table 4.7. Distribution of agricultural drought intensity classification is displayed in Figure 4.8 and percentage of agricultural drought intensity classification is summarized in Table 4.8. Detail of percentage of agricultural drought frequency at district level is reported in Table A-2 of Appendix A.

Table 4.7 Classification of agricultural intensity drought and its rating score.

Agricultural drought intensity domain	Drought level	Rating	Normalized
> 78.78%	VL	1	1
69.62-78.78%	L	2	1.5
61.11-69.62 %	M	3	2
51.94-61.11 %	H	4	2.5
≤51.94 %	VH	5	3

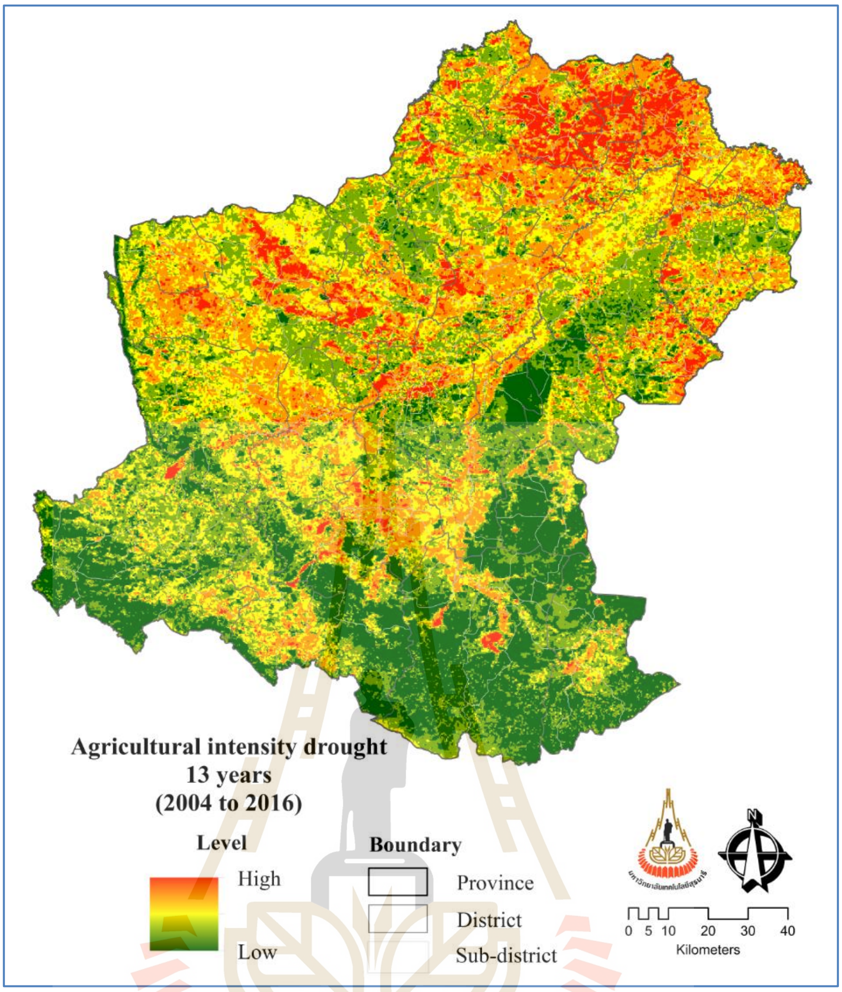


Figure 4.8 Distribution of agricultural drought intensity classification.

Table 4.8 Percentage of areas agricultural drought intensity at provincial level.

Factor	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
Agricultural intensity drought	7.78	21.18	24.03	27.16	19.85

4.2 Climate condition

Factors of climate condition include average SPI and SPEI are here selected for agricultural drought sensitivity analysis.

4.2.1 SPI

The derived SPI of 3 SPI periods (SPI-3m7: May, June, and July, SPI-3m10: August, September and October, and SPI-6m10: May, June, July, August, September and October) are averaged and classified into 5 classes same as exposure hazard (VL, L, M, H, and VH) by modification of based on Mckee et al. (1993) suggestion (Table 4.9). Figures 4.9 to 4.11 display exposure hazard of agricultural drought of 3 SPI periods while the percentage of agricultural drought by SPI of 3 periods is summarized in Table 4.10. Detail of percentage of agricultural drought by SPI of 3 periods at district level is reported in Table A-3, A-4, and A-5 of Appendix A.

Table 4.9 Classification of exposure hazard of agricultural drought by average SPI.

SPI (Average of X month)	Drought Level	Rating	Normalized
≤ -2.00	VH	5	3
-1.99 to -1.50	H	4	2.5
-1.49 to 1.49	M	3	2
1.50 to 1.99	L	2	1.5
≥2.00	VL	1	1

Source: Adapted from Mckee et al. (1993)

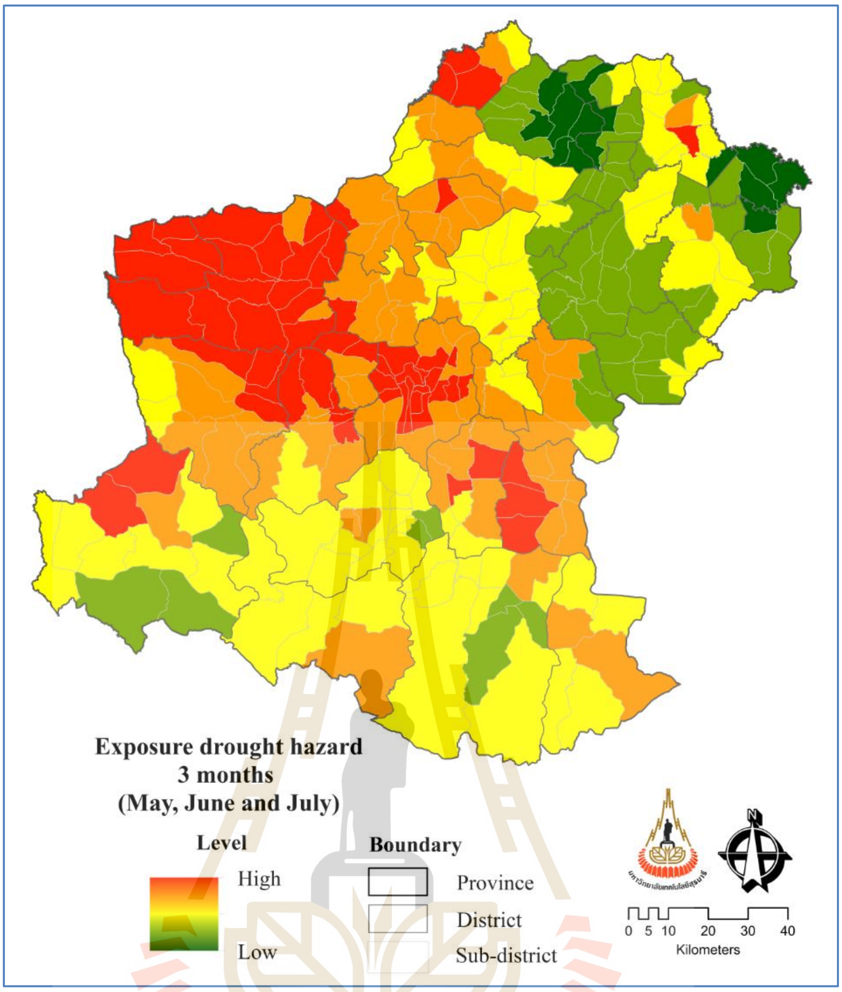


Figure 4.9 Distribution of exposure hazard of agricultural drought of SPI-3m7.

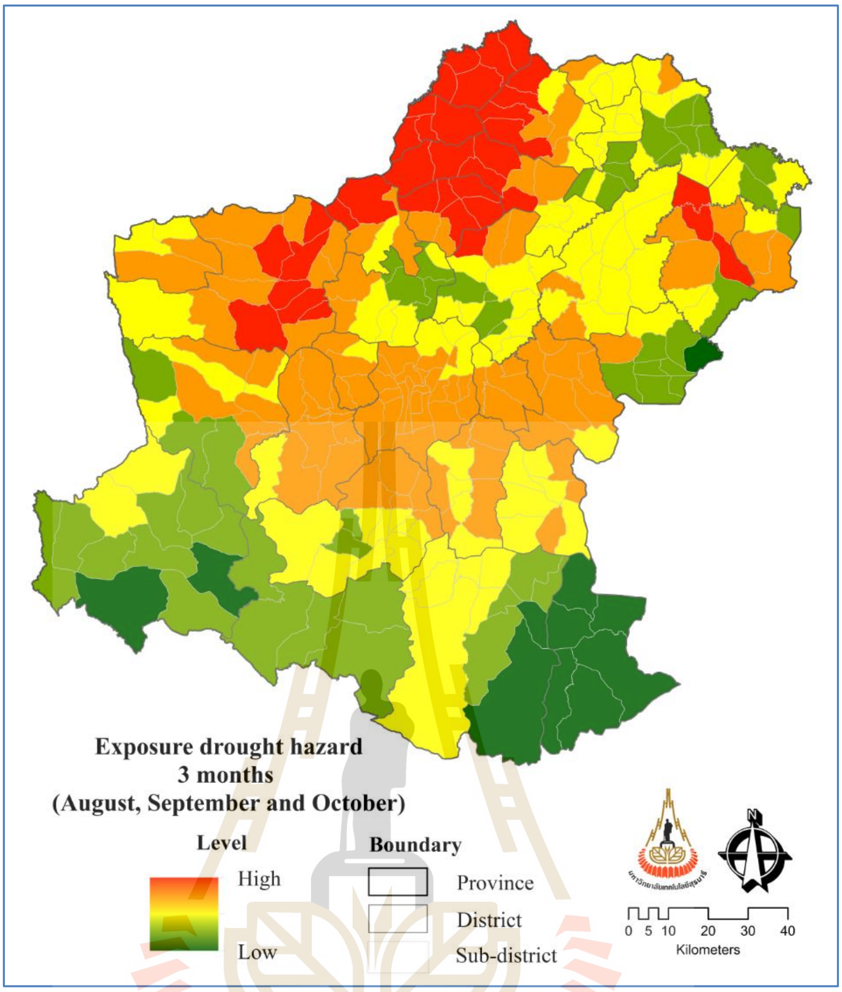


Figure 4.10 Distribution of exposure hazard of agricultural drought of SPI-3m10.

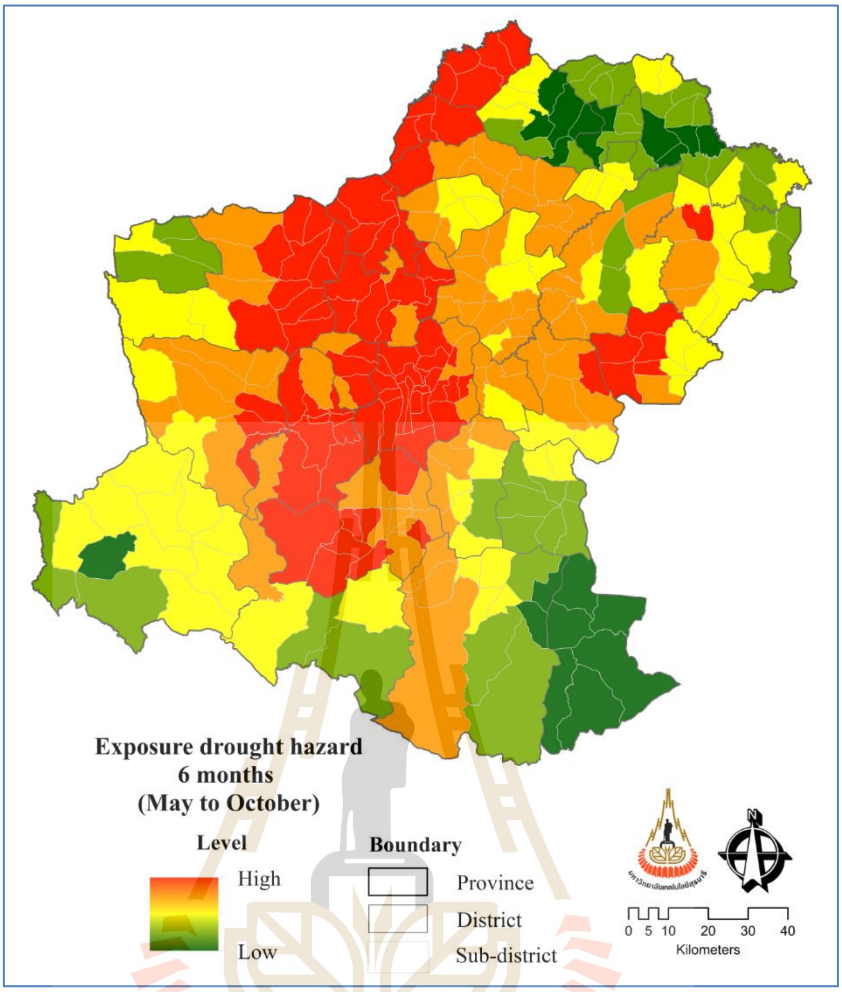


Figure 4.11 Distribution of exposure hazard of agricultural drought of SPI-6m10.

Table 4.10 Percentage of areas exposure hazard of agricultural drought of 3 SPI periods.

SPI Period (months)	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
SPI-3m7	3.2	17.2	36	26.1	17.5
SPI-3m10	9.4	21.6	29.8	28.3	10.9
SPI-6m10	7.8	18.6	24	27	22.5

4.2.2 SPEI

In general, SPEI is calculated based on monthly rainfall and potential evapotranspiration (Tan et al., 2015). Due to limit of potential evapotranspiration in the study area and it surrounding, the SPEI software is applied to calculate SPEI, because it requires on monthly rainfall, monthly average temperature and latitude observatory. Herein, monthly rainfall data is retrieved from 56 climate stations, while monthly average temperature is retrieved from 7 climate stations and extracted from MODIS LST data (MOD11C3 product) over corresponding location 49 climate stations which had no record of temperature data. In practice LST between 2001 and 2016 were firstly downloaded and preprocess as same vegetation condition under Timesat software, particularly cloud removal. Figure 4.12 shows an example of LST data in 2001 before and after filtering. Results of average SPEI of 3 periods is displayed in Figures 4.13 to 4.15 and percentage of SPEI classification is reported in Table 4.11. Detail of percentage of agricultural drought by SPEI of 3 periods at district level is reported in Table A-6, A-7, and A-8 of Appendix A.

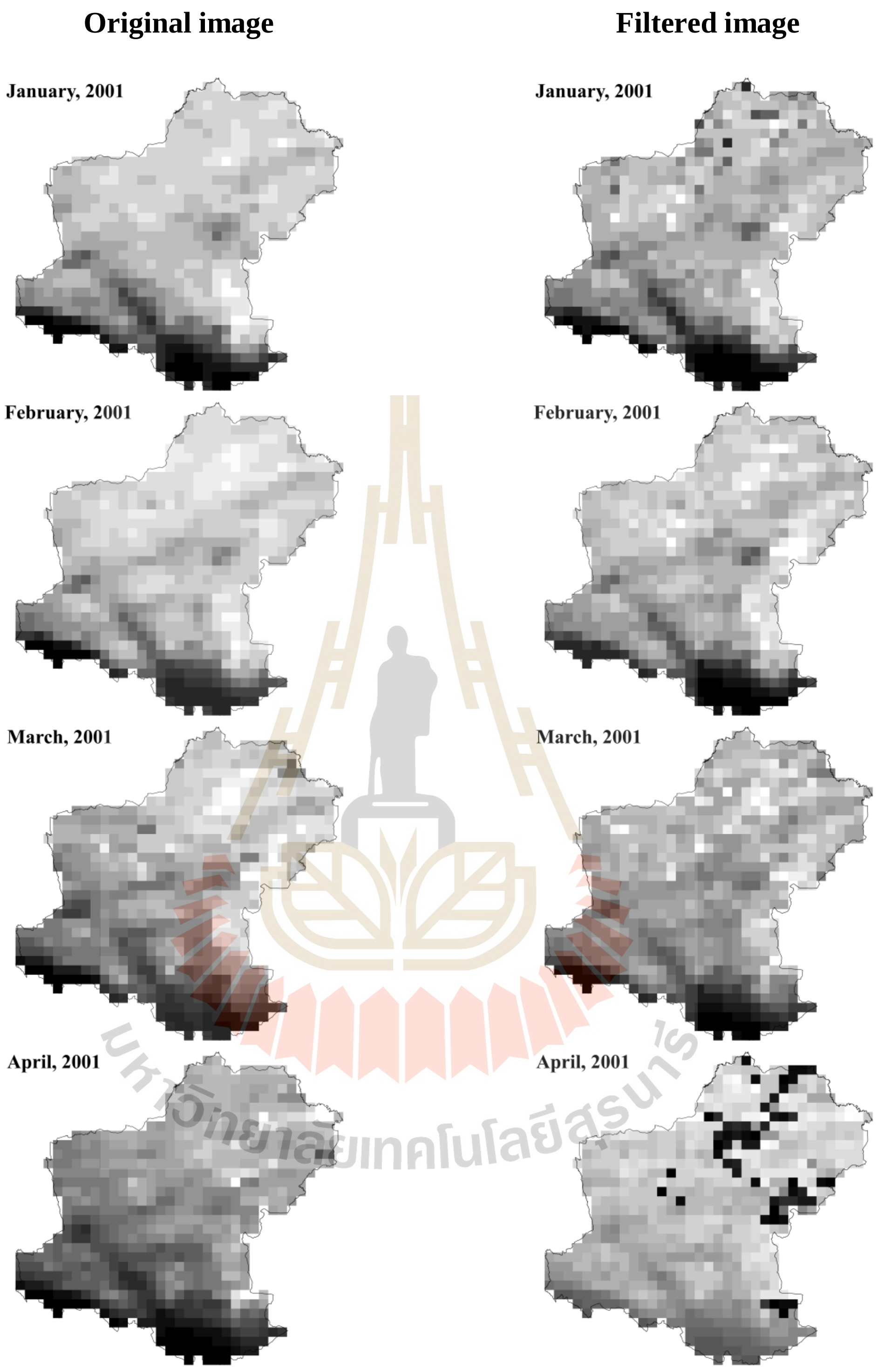


Figure 4.12 Comparison of LST data before and after filtering.

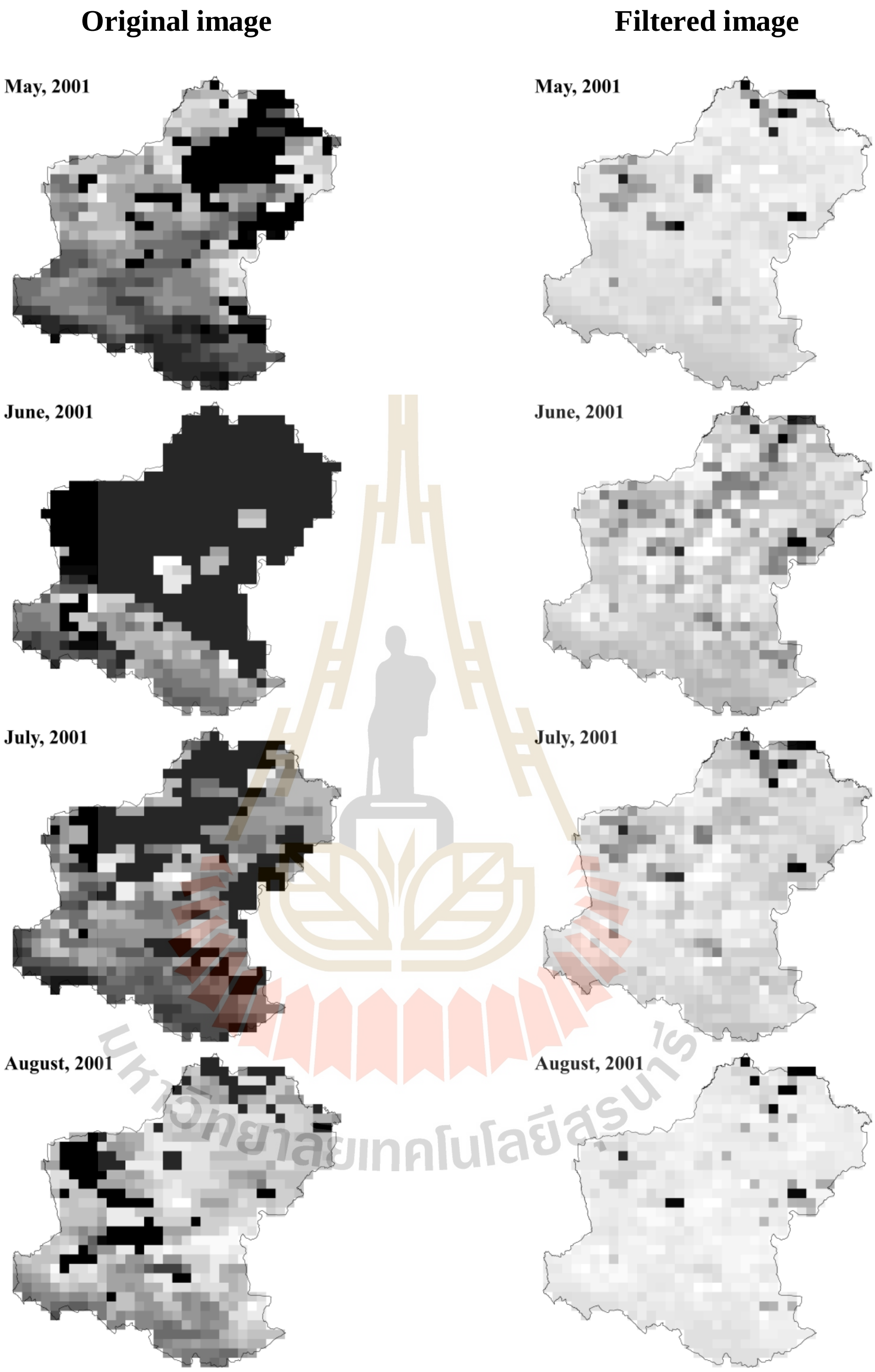


Figure 4.12 (Continued).

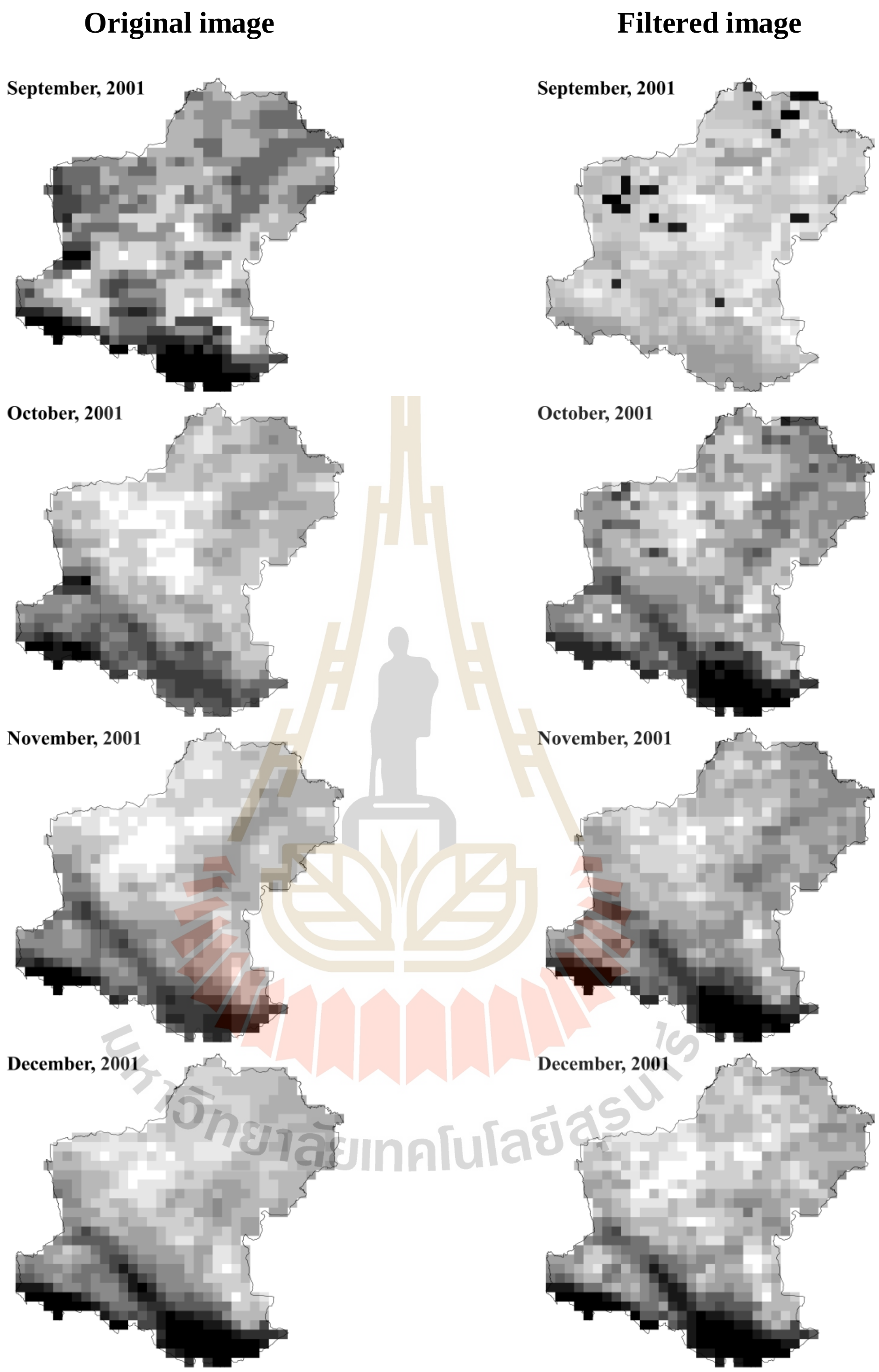


Figure 4.12 (Continued).

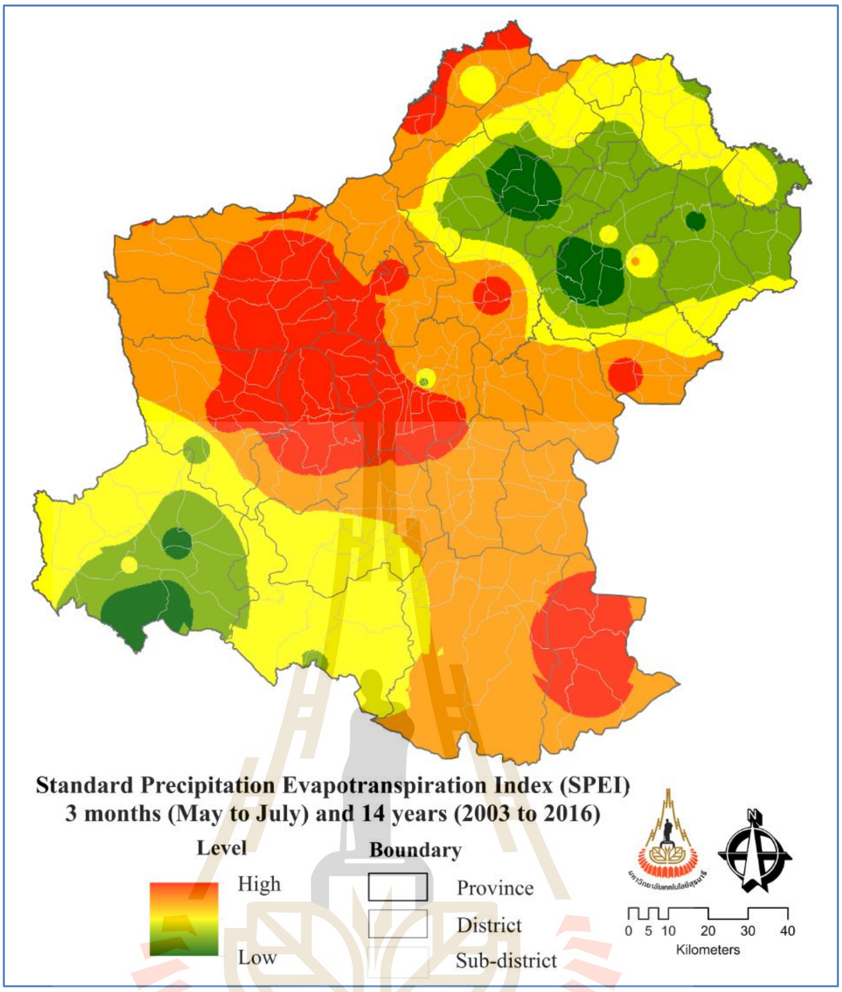


Figure 4.13 Distribution of average SPEI-3m7 (May to July).

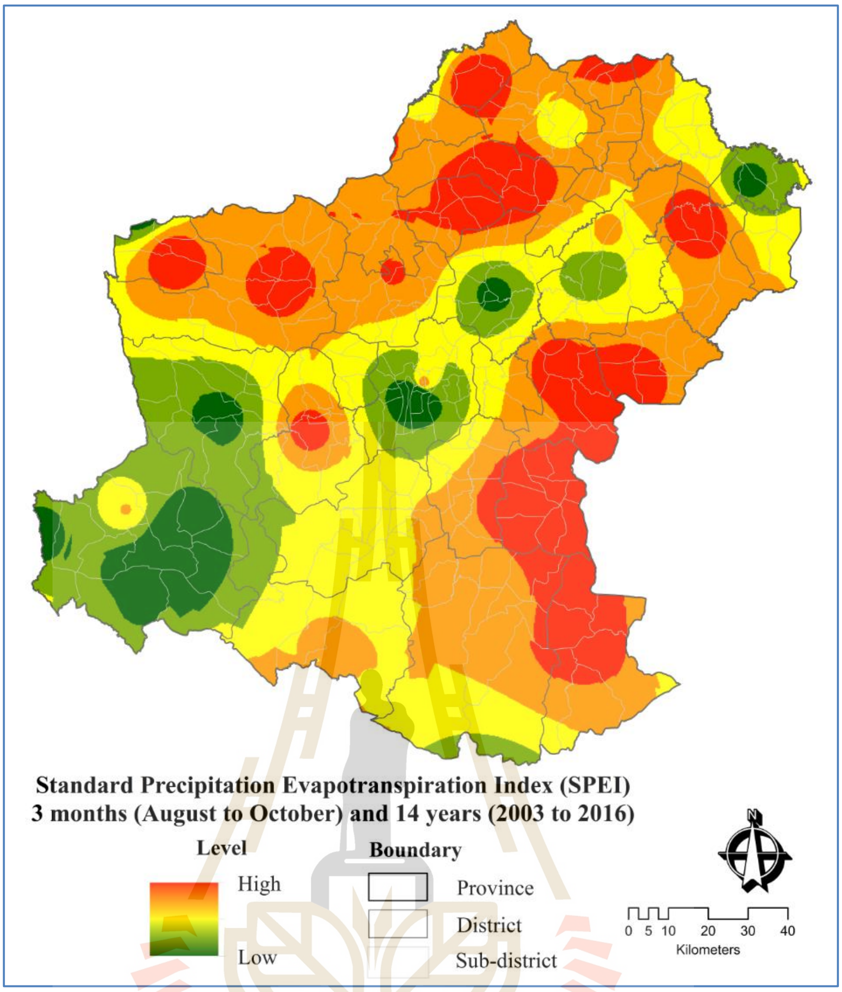


Figure 4.14 Distribution of average SPEI-3m10 (August to October).

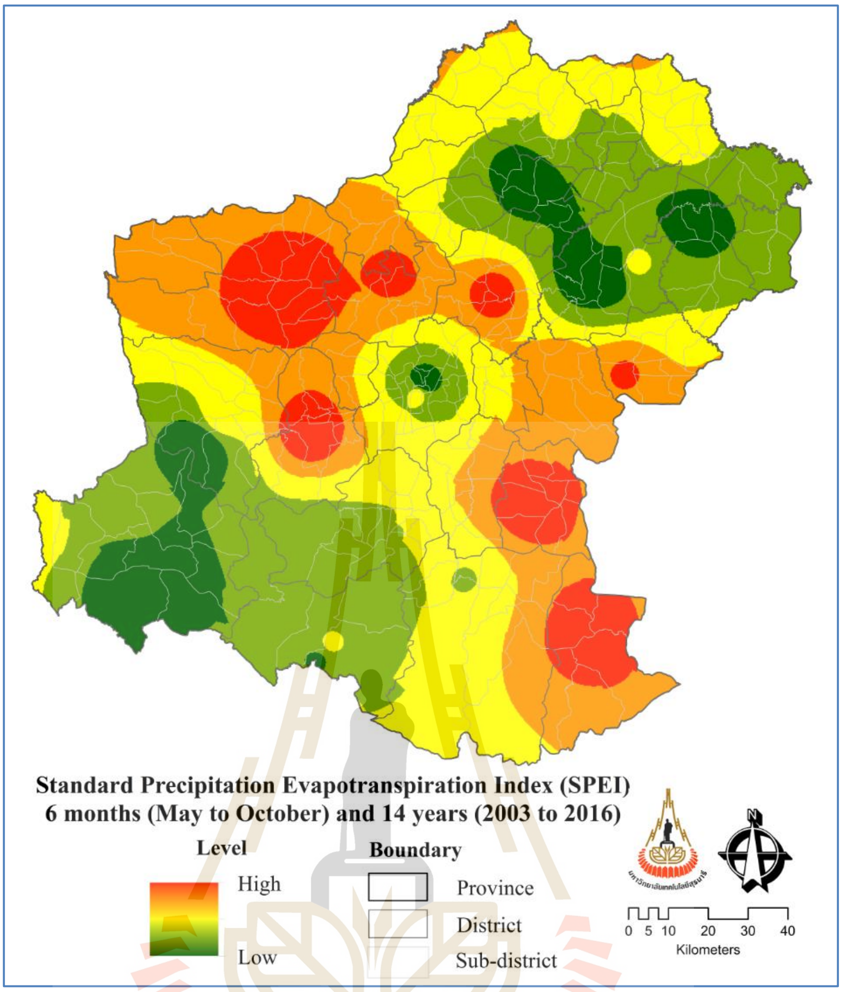


Figure 4.15 Distribution of average SPEI-6m10 (May to October).

Table 4.11 Percentage of SPEI classification at provincial level of 3 periods at provincial level.

SPEI period	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
3m7	3.91	15.98	23.82	38.24	18.05
3m10	5.78	14.84	27.87	34.33	17.17
6m10	9.98	27.61	28.42	23.88	10.1

4.3 Physical condition

Factors of physical condition include (1) land use, (2) soil drainage, (3) agricultural irrigation area, (4) elevation, (5) slope, (6) distance to river, and (7) drainage density are here selected for agricultural drought sensitivity analysis.

4.3.1 Land use

Land use data from 2000, 2007, 2008, 2011 and 2015 with drought level according to land use type (Table 4.12) are here averaged to calculate new agricultural drought classes (VL, L, M, H, VH) from land use data. The very high level of land use sensitivity drought is paddy field, because it requires water more than field crop, perennial orchard or others. In contrast, water body and miscellaneous land have less effect from drought. Distribution of agricultural drought sensitivity according land use type is displayed in Figure 4.16 and percentage of agricultural drought sensitivity classification by land use type is summarized in Table 4.13. Detail of percentage of agricultural drought by land use at district level is reported in Table A-9 of Appendix A.

Table 4.12 Classification of agricultural drought sensitivity according to land use type and its rating.

Level 1	**Level 1+2**	**Level**	**Rating**	**Normalized**
Urban and build-up land (U)	Urban and build-up land (U)	L	2	1.5
Agricultural land (A)	A1 Paddy field	VH	5	3
	A2 Field crop	H	4	2.5
	A3 Perennial	M	3	2
	A4 Orchard	M	3	2
	A5-A9	H	4	2.5
Forest land (F)	Forest land (F)	L	2	1.5
Water Body (W)	Water Body (W)	VL	1	1
Miscellaneous land (M)	Miscellaneous land (M)	VL	1	1

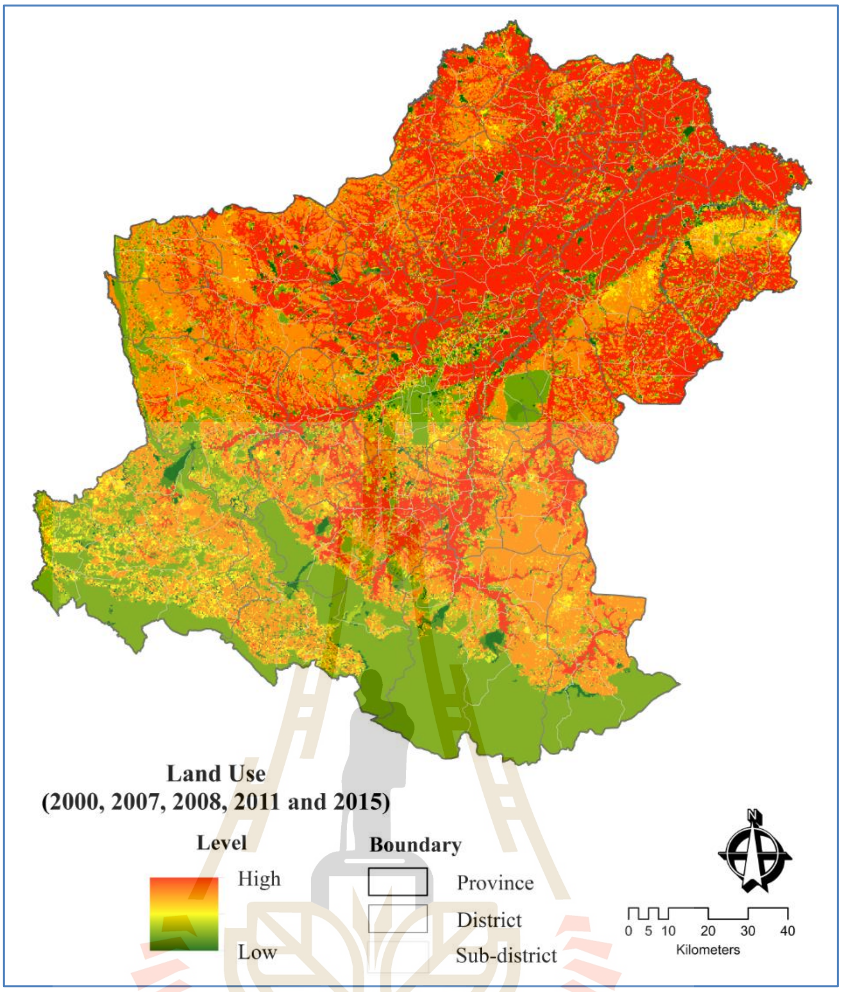


Figure 4.16 Distribution of agricultural drought sensitivity according land use type.

Table 4.13 Percentage of agricultural drought sensitivity classification by land use at provincial level.

Factor	**Percentage of areas (%)**				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Land Use	0.87	22.09	7.38	30.98	38.69

4.3.2 Soil drainage

Agricultural drought sensitivity classes (VL, L, M, H, and VH) according to soil drainage are prepared based on drainage properties of soil. Table 4.14 displays soil drainage classification and its drought sensitivity level and rating. Distribution of agricultural drought sensitivity according soil drainage is displayed in Figure 4.17 and percentage of agricultural drought sensitivity classification by soil drainage is summarized in Table 4.15. Detail of percentage of agricultural drought by soil drainage at district level is reported in Table A-10 of Appendix A.

Table 4.14 Soil drainage classification and its drought sensitivity level and rating.

Soil drainage class	Drought level	Rating	Normalized
Well drained	VH	5	3
Moderately well drained	H	4	2.5
Somewhat well drained	M	3	2
Poorly drained	L	2	1.5
Very poor drained	VL	1	1

Source: Prathumchai et al. (2001).

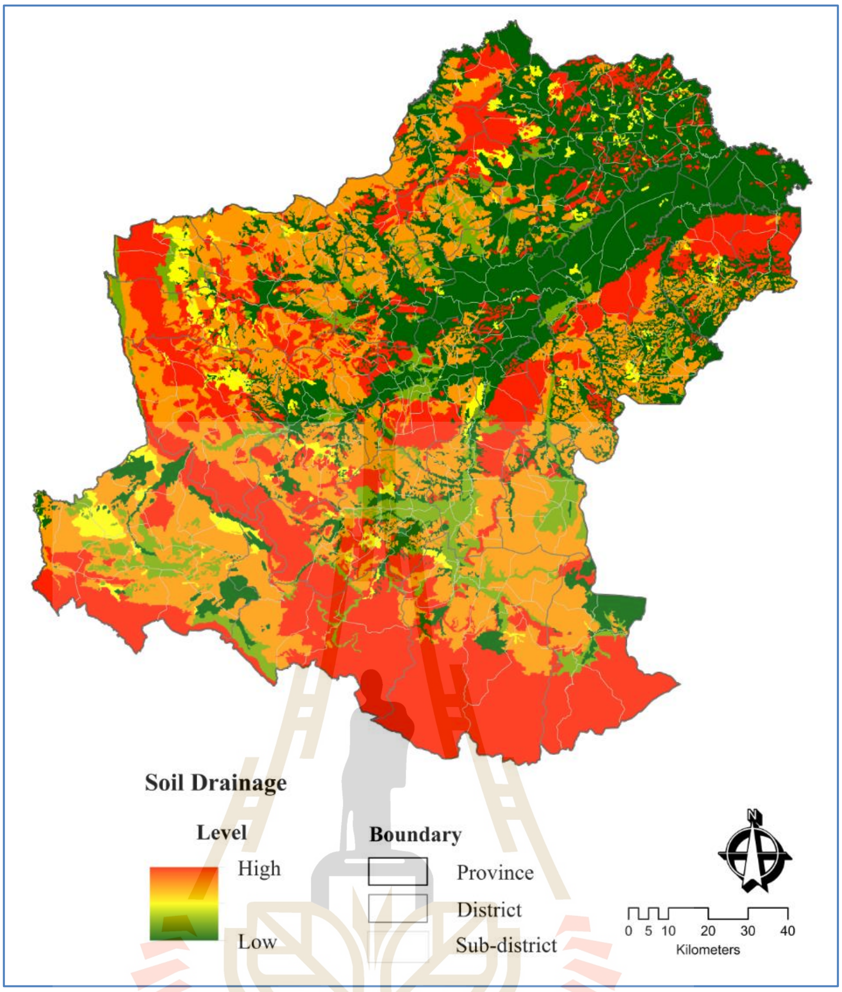


Figure 4.17 Distribution of agricultural drought sensitivity according soil drainage.

Table 4.15 Percentage of agricultural drought sensitivity classification by soil drainage at provincial level.

Factor	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Soil drainage	28.52	6.94	3.06	30.17	31.31

4.3.3 Agricultural irrigation area

Agricultural drought sensitivity classes according to agricultural irrigation area is assigned into 2 classes: irrigated and rain-fed agricultural area (Table 4.16). Meanwhile, distribution of agricultural drought sensitivity according to agricultural irrigation area is displayed in Figure 4.18 and percentage of agricultural drought sensitivity classification by agricultural irrigation area is summarized in Table 4.17. Detail of percentage of agricultural drought by agricultural irrigation area at district level is reported in Table A-11 of Appendix A.

Table 4.16 Classification of agricultural drought sensitivity according to agricultural irrigation area.

Irrigation support Class	**Drought level**	**Rating**	**Normalized**
Irrigated	VL	1	1
Rain-fed	VH	5	3

Source: Jain et al (2015)

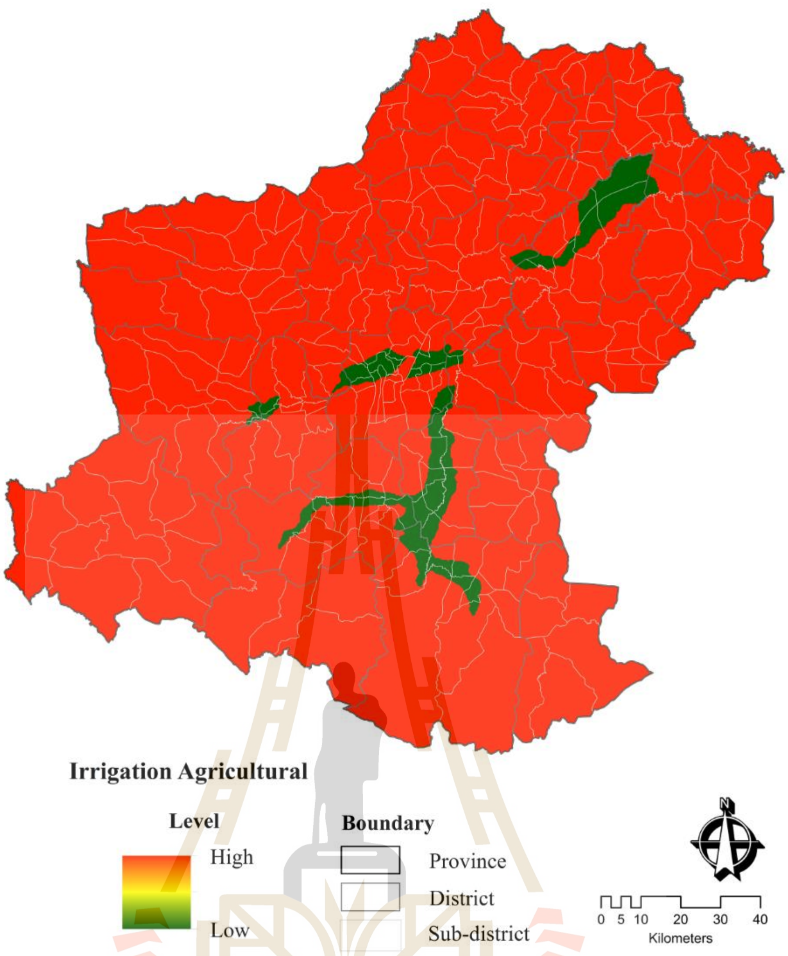


Figure 4.18 Distribution of agricultural drought sensitivity according to irrigation.

Table 4.17 Percentage of agricultural drought sensitivity classification by agricultural irrigation area at provincial level.

Factor	**Percentage of areas (%)**				
	Very low	**Low**	**Moderate**	**High**	**Very high**
agricultural irrigation area	4.55	0.00	0.00	0.00	95.45

4.3.4 Slope

Slope classification of LDD in 2009 was here applied to assign agricultural drought sensitivity classes (VL, L, M, H, and VH) as summary in Table 4.18. Distribution of agricultural drought sensitivity according slope is displayed in Figure 4.19 and percentage of agricultural drought sensitivity classification by slope is summarized in Table 4.19. Detail of percentage of agricultural drought by slope at district level is reported in Table A-12 of Appendix A.

Table 4.18 Classification of agricultural drought sensitivity according to slope.

Slope class (%)	Topography	Drought level	Rating	Normalized
0-2	Flat or almost flat	VL	1	1
2-5	Slightly undulating	L	2	1.5
5-12	Undulating	M	3	2
12-20	Rolling	H	4	2.5
20-35	Hilly	VH	5	3
>35	Steep		5	3

Sources: LDD, 2009

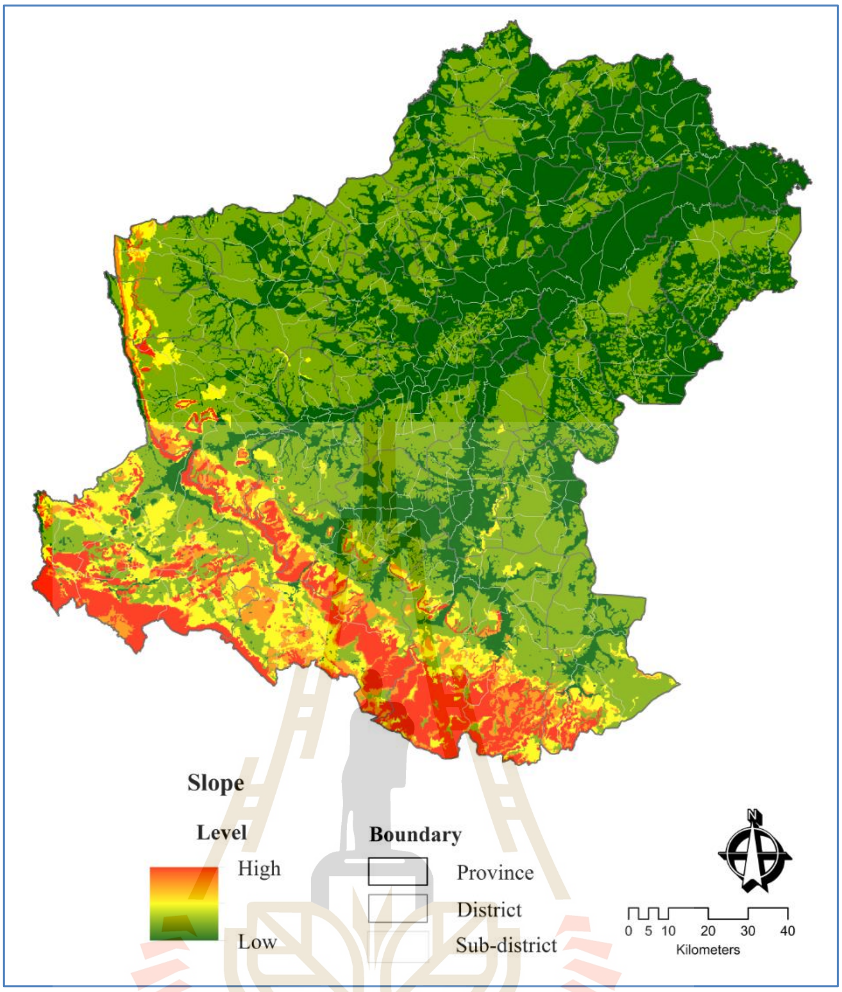


Figure 4.19 Distribution of agricultural drought sensitivity according slope.

Table 4.19 Percentage of agricultural drought sensitivity classification by slope at provincial level.

Factor	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
Slope	37.38	42.94	7.55	4.06	8.08

4.3.5 Elevation

Elevation classification of LDD in 2009 was here applied to assign agricultural drought sensitivity classes (very low, low, moderate, high and very high level) as summary in Table 4.20. Distribution of agricultural drought sensitivity according to elevation is displayed in Figure 4.20 and percentage of agricultural drought sensitivity classification by elevation is summarized in Table 4.21. Detail of percentage of agricultural drought by elevation at district level is reported in Table A-13 of Appendix A.

Table 4.20 Agricultural drought sensitivity classification according to elevation.

Elevation (m)	Drought level	Rating	Normalized
< 200	VL	1	1
200-250	L	2	1.5
250-350	M	3	2
350-750	H	4	2.5
750-800	VH	5	3
> 800	VH	5	3

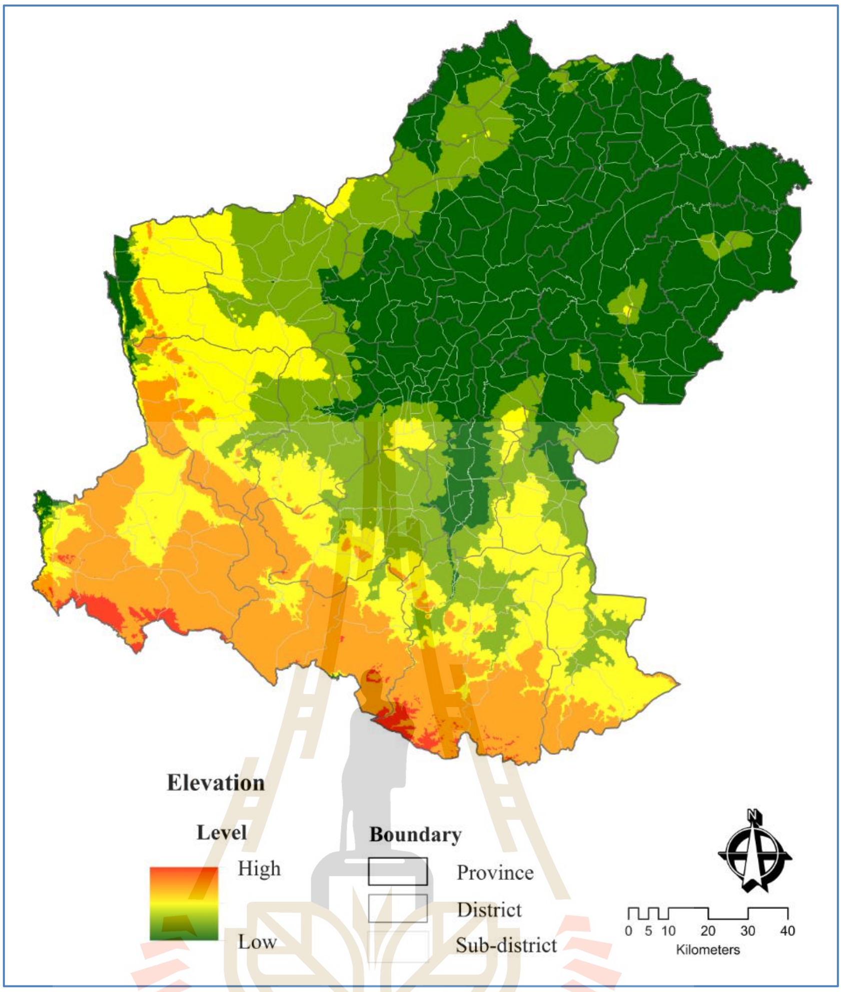


Figure 4.20 Distribution of agricultural drought sensitivity according to elevation.

Table 4.21 Percentage of agricultural drought sensitivity classification by elevation at provincial level.

Factor	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Elevation	37.99	21.38	21.1	18.43	1.09

4.3.6 Distance to river

Based on assumption, areas closer to river courses are less vulnerable to water shortages because of more recharge potential and groundwater relatively availability for longer period in comparison with areas far from the river course (Jain et al., 2015). Euclidean distance from river network is here applied to calculate distance to river and to assign agricultural drought sensitivity classes (VL, L, M, H, and VH) as summary in Table 4.22. Distribution of agricultural drought sensitivity according to distance to river is displayed in Figure 4.21 and percentage of agricultural drought sensitivity classification by distance to river is summarized in Table 4.23. Detail of percentage of agricultural drought by distance to river at district level is reported in Table A-14 of Appendix A.

Table 4.22 Agricultural drought sensitivity classification according to distance to river.

Distance to river (km.)	Drought level	Rating	Normalized
Up to 1	VL	1	1
1-3	L	2	1.5
3-5	M	3	2
5-7	H	4	2.5
> 7	VH	5	3

Source: Jain et al. (2015)

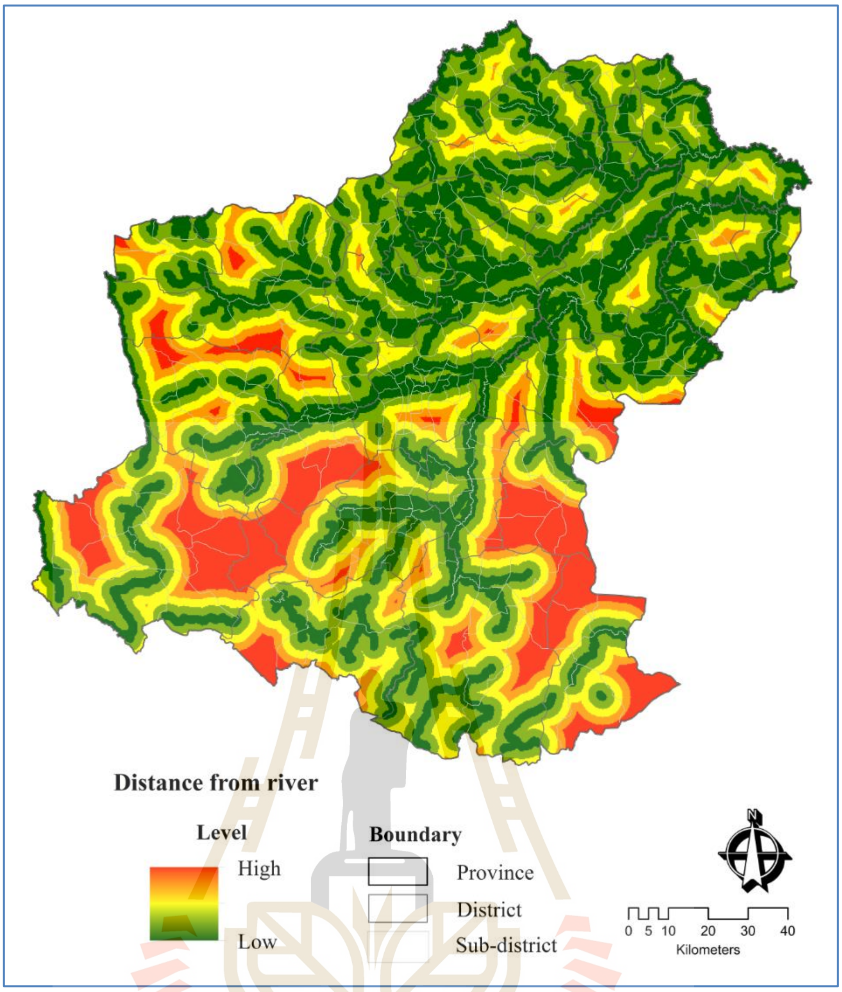


Figure 4.21 Distribution of agricultural drought sensitivity according to distance to river.

Table 4.23 Percentage of agricultural drought sensitivity classification by distance to river at provincial level.

Factor	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
Distance from river	28.31	33.02	18.79	10.06	9.82

4.3.7 Drainage density

Based on suggestion of Pandey et al. (2012), drainage density (total length of n stream channels in a drainage basin divided by the surface area of the basin) is here applied to classify agricultural drought sensitivity according its value as summary in Table 4.24. Distribution of agricultural drought sensitivity according to drainage density is displayed in Figure 4.22 and percentage of agricultural drought sensitivity classification by drainage density is summarized in Table 4.25. Detail of percentage of agricultural drought by drainage density at district level is reported in Table A-15 of Appendix A.

Table 4.24 Agricultural drought sensitivity classification according to drainage density.

Drainage density	Level	Rating	Normalized
Low density	Very high	5	3
Moderate density	Moderate	3	2
High density	Very low	1	1

Source: Adapted from Pandey et al. (2012)

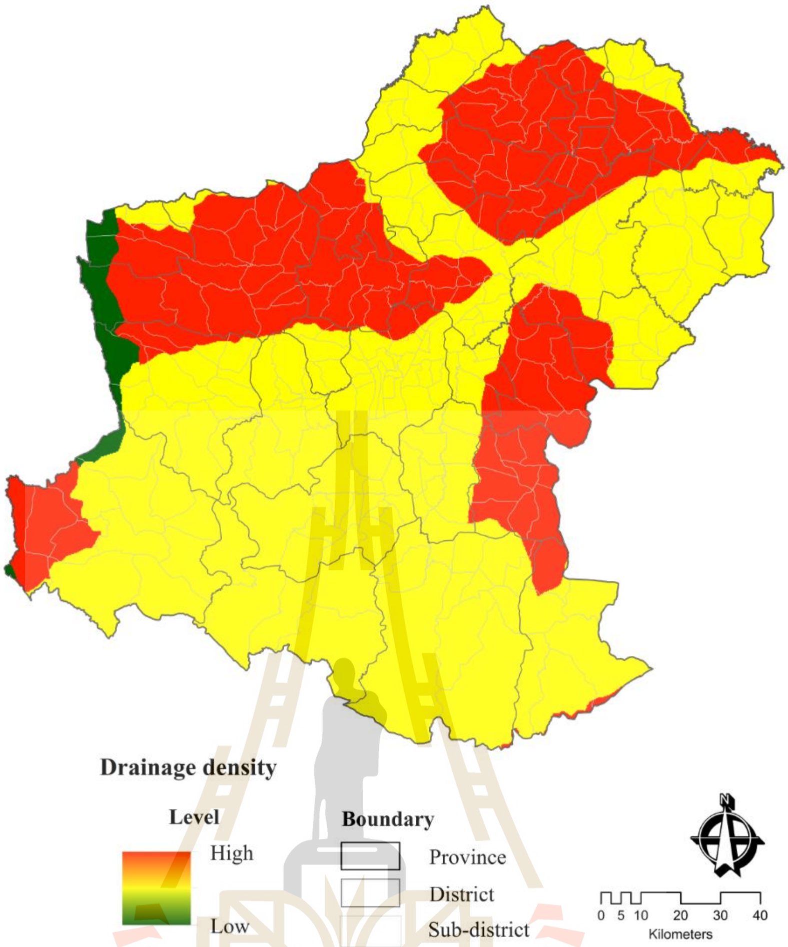


Figure 4.22 Distribution of agricultural drought sensitivity according to drainage density.

Table 4.25 Percentage of agricultural drought sensitivity classification by drainage density at provincial level.

Factor	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
Drainage density	1.72	0.00	64.53	0.00	33.75

4.4 Socio-economic condition

Factors of socio-economic physical condition include (1) agricultural occupation, (2) population density, and (3) economic crop production are here selected for agricultural drought sensitivity analysis.

4.4.1 Agricultural occupation

Percentage of agricultural occupation is calculated by using agricultural occupation divided by total population. Pei et al. (2016) stated that agricultural population is more sensitivity to drought more than the urban population, and it is more susceptible to drought. When the proportion of agricultural population is higher, the region will be more vulnerable. Whereas, Shahid and Behrawan (2008) stated that agricultural occupation represents percentage of people depending on agriculture, including farmers and agricultural workers. Herein, agricultural drought classification by agricultural occupation is divided into 5 classes (VL, L, M, H, and VH) using Natural break method (Table 4.26). Distribution of agricultural drought sensitivity according to agricultural occupation is displayed in Figure 4.23 and percentage of agricultural drought sensitivity classification by agricultural occupation is summarized in Table 4.27. Detail of percentage of agricultural drought by agricultural occupation at district level is reported in Table A-16 of Appendix A.

Table 4.26 Agricultural drought sensitivity classification according to proportion of agricultural occupation.

Proportion of agricultural occupation (100 Percent)	Drought Level	Rating	Normalized
≤ 41	VL	1	1
41 – 66.1	L	2	1.5
66.1 – 83.8	M	3	2
83.8 – 104.7	H	4	2.5
≥ 104.7	VH	5	3

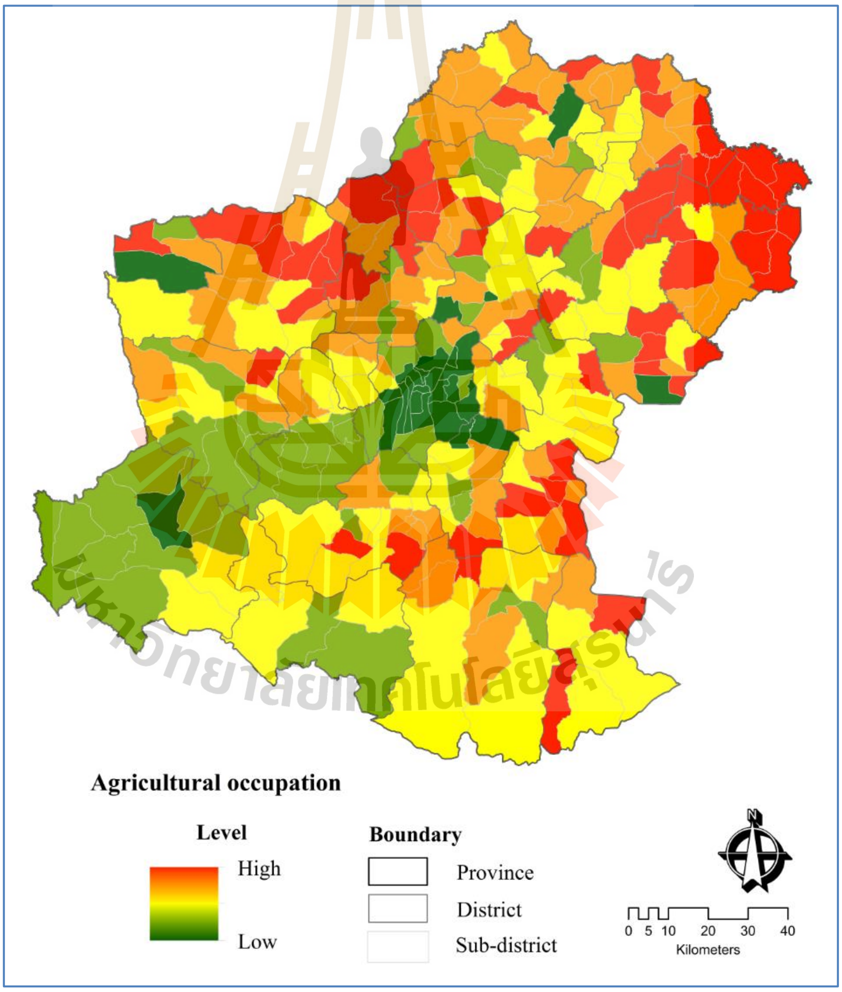


Figure 4.23 Distribution of agricultural drought sensitivity according to agricultural occupation.

Table 4.27 Percentage of agricultural drought sensitivity classification by agricultural occupation at provincial level.

Factor	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Agricultural occupation	4.91	20.36	32.88	23.16	18.7

4.4.2 Economic crop production

Drought in higher food productive area will have higher negative impact on economy compare to lower food productive area (Shahid and Behrawan, 2008). In this study, economic crop production of household (Kg per Rai) was applied to classify level of agricultural drought sensitivity (VL, L, M, H, VH) by natural break method (Table 4.28). Distribution of agricultural drought sensitivity according to economic crop production is displayed in Figure 4.24 and percentage of agricultural drought sensitivity classification by economic crop production is summarized in Table 4.29. Detail of percentage of agricultural drought by economic crop production at district level is reported in Table A-17 of Appendix A.

Table 4.28 Agricultural drought sensitivity classification according to economic crop production.

Household economic crop production (Kg. per Rai)	Level	Rating	Normalized
≤ 254.2	VL	1	1
254.2 – 536.7	L	2	1.5
536.7 – 929.7	M	3	2
929.7 – 1,685	H	4	2.5
≥ 1,685	VH	5	3

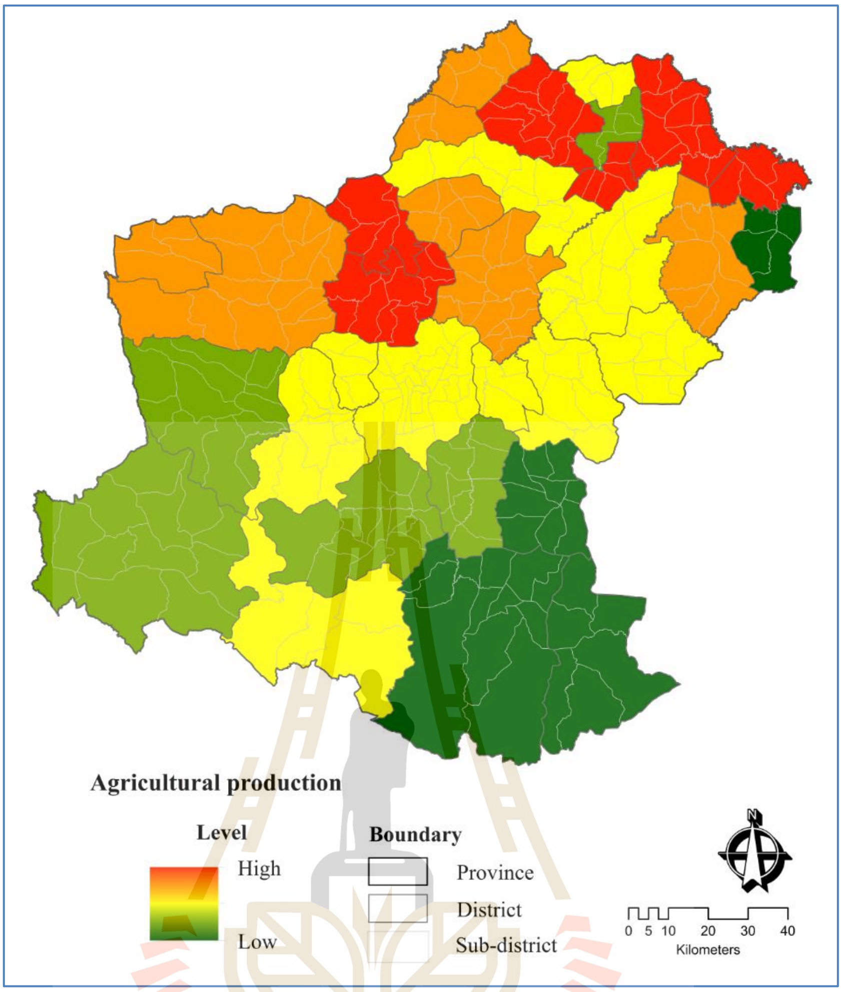


Figure 4.24 Distribution of agricultural drought sensitivity according to economic crop production.

Table 4.29 Percentage of agricultural drought sensitivity classification by economic crop production at provincial level.

Factor	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Economic crop production	17.47	22.81	28.91	19.29	11.51

4.4.3 Population density

Population density is the proportion of the population divided by area. Shahid and Behrawan (2008) applied population density person per km^2 to assign agricultural drought sensitivity. In this study, population density (person per km^2) was applied to classify level of agricultural drought sensitivity (VL, L, M, H, and VH) by natural break method as summary in Table 4.30. Distribution of agricultural drought sensitivity according to population density is displayed in Figure 4.25 and percentage of agricultural drought sensitivity classification by population density is summarized in Table 4.31. Detail of percentage of agricultural drought by population density at district level is reported in Table A-18 of Appendix A.

Table 4.30 Agricultural drought sensitivity classification according to population density.

Factor	**Class**	**Score**	**Normalized**
Population density (person / km^{-2})	≤ 68	1	1
	69 – 123	2	1.5
	124 – 233	3	2
	234 - 509	4	2.5
	≥ 510	5	3

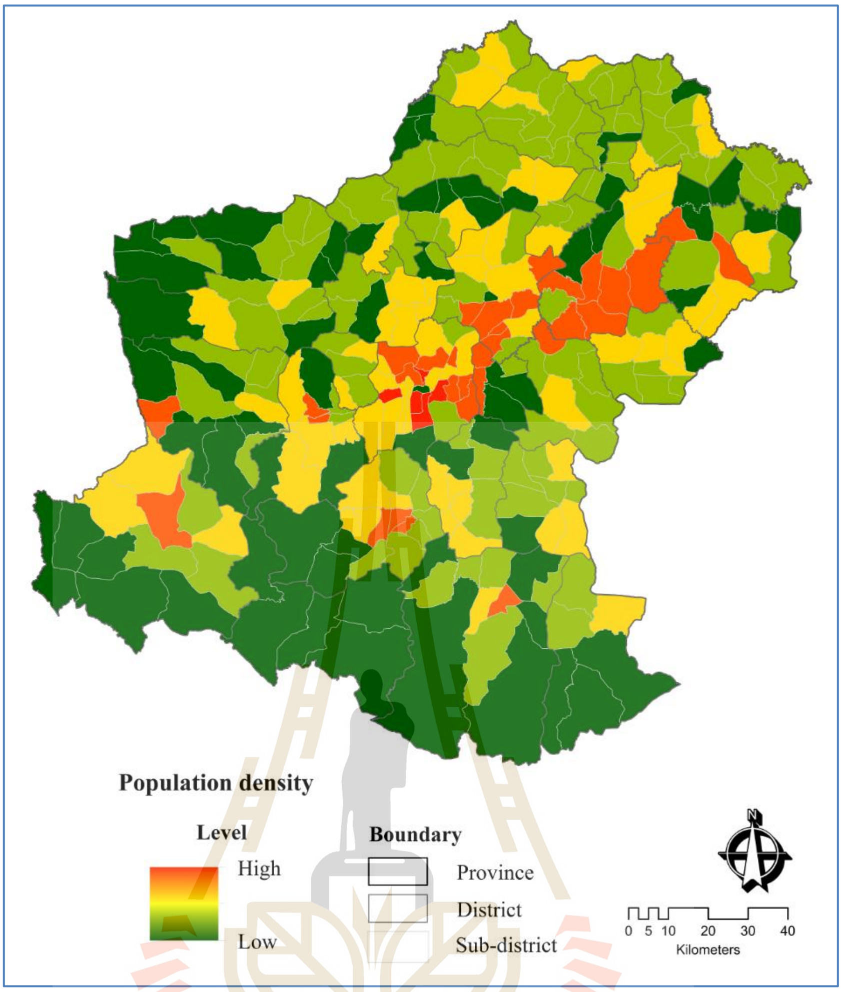


Figure 4.25 Distribution of agricultural drought sensitivity according to population density.

Table 4.31 Percentage of agricultural drought sensitivity classification by population density at provincial level.

Factor	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
Population density	38.57	34.68	19.66	6.68	0.41

CHAPTER V

DROUGHT EXPOSURE HAZARD ASSESSMENT

This chapter presents results of the first objectives focusing on meteorological drought assessment as drought exposure hazard component of agricultural drought vulnerability analysis. Main results consists of (1) SPI calculation for meteorological drought assessment, (2) drought occurrence probability by SPI, (3) meteorological drought hazard frequency assessment, (4) meteorological drought hazard intensity assessment, (5) drought exposure hazard assessment and (6) validation of drought exposure hazard assessment. Details of each component is separately described and discussed in this chapter.

5.1 SPI calculation for meteorological drought assessment

The rainfall data records 41 years (between 1976 and 2016) was here used to calculate SPI for meteorological drought assessment. In this study, time periods of SPI for drought hazard frequency and intensity assessment consisted of SPI-3m7 (May, June and July), SPI-3m10 (August, September and October) and SPI-6m10 (May, June, July, August, September and October). The characteristics and pattern of SPI generally relate with meteorological drought due to deficit rainfall or dry-spell.

Classification of meteorological drought and its weight for meteorological drought hazard frequency and intensity assessment was categorized by SPI data with modification of Shahid and Behrawan (2008) and Kim et al. (2015) suggestion as shown in Table 5.1.

Table 5.1 The SPI meteorological drought classification and weighting for meteorological drought hazard frequency and intensity assessment.

Level of drought	SPI value	Weights
Near-normal (NND)	0 to -0.99	1
Moderate drought (MD)	-1.00 to -1.49	2
Severe drought (SD)	-1.50 to -1.99	3
Extreme drought (ED)	-2.00 and less	4

Note: Modified from Shahid and Behrawan (2008) and Kim et al. (2015).

5.2 Drought occurrence probability by SPI

Results of drought occurrence probability of 3 periods: SPI-3m7 (May, June and July), SPI-3m10 (August, September and October) and SPI-6m10 (May, June, July, August, September and October) are here separately described and discussed in the following sections. Herein, spatial extent of drought occurrence probability of 4 drought categories: near normal drought (NND), moderate drought (MD), severe drought (SD) and extreme drought (ED) and their rating scores for meteorological drought hazard frequency assessment are reported.

5.2.1 Drought occurrence probability of SPI-3m7 period

The drought occurrence probability of SPI-3m7 period that calculated using SPI during rainy season and cropping season (May, June and July) is summarized in Table 5.2 and distribution of drought categories (NND, MD, SD and ED) are displayed in Figures 5.1 to 5.4, respectively.

Table 5.2 Drought occurrence probability and its rating score of SPI-3m7 period (May, June and July) by each drought category.

Drought category	Occurrence probability (%)	Rating
Near-normal (NND)	OP < 25.36	4
	25.36 ≤ OP < 33.57	3
	33.57 ≤ OP < 41.78	2
	41.78 ≤ OP < 50.0	1
Moderate drought (MD)	OP < 6.79	1
	6.79 ≤ OP < 11.19	2
	11.19 ≤ OP < 15.59	3
	15.59 ≤ OP < 20.0	4
Severe drought (SD)	OP < 4.31	1
	4.31 ≤ OP < 8.62	2
	8.62 ≤ OP < 12.93	3
	12.93 ≤ OP < 17.24	4
Extreme drought (ED)	OP < 1.72	1
	1.72 ≤ OP < 3.45	2
	3.45 ≤ OP < 5.17	3
	5.17 ≤ OP < 6.90	4

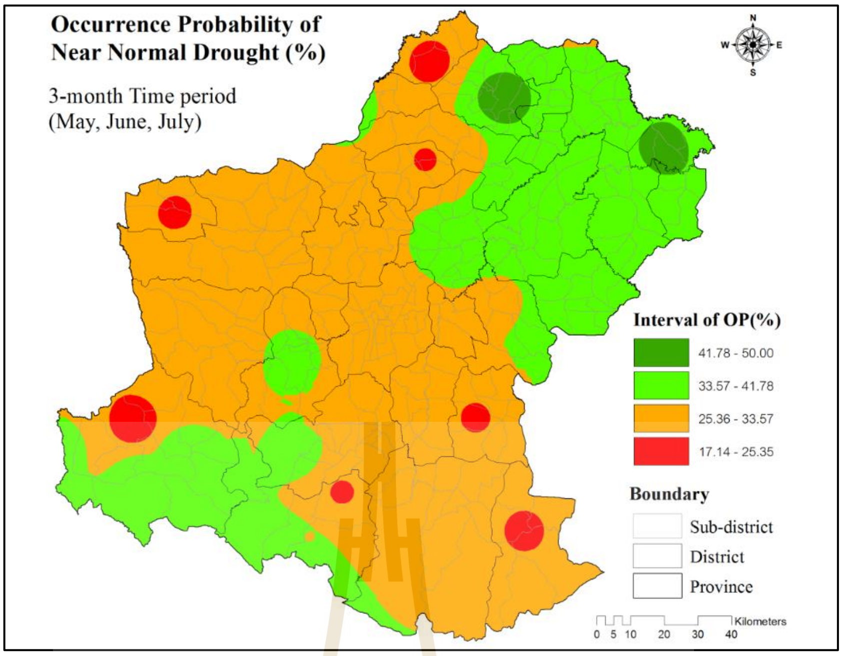


Figure 5.1 Distribution of drought occurrence probability of near normal category of SPI-3m7 period (May, June and July).

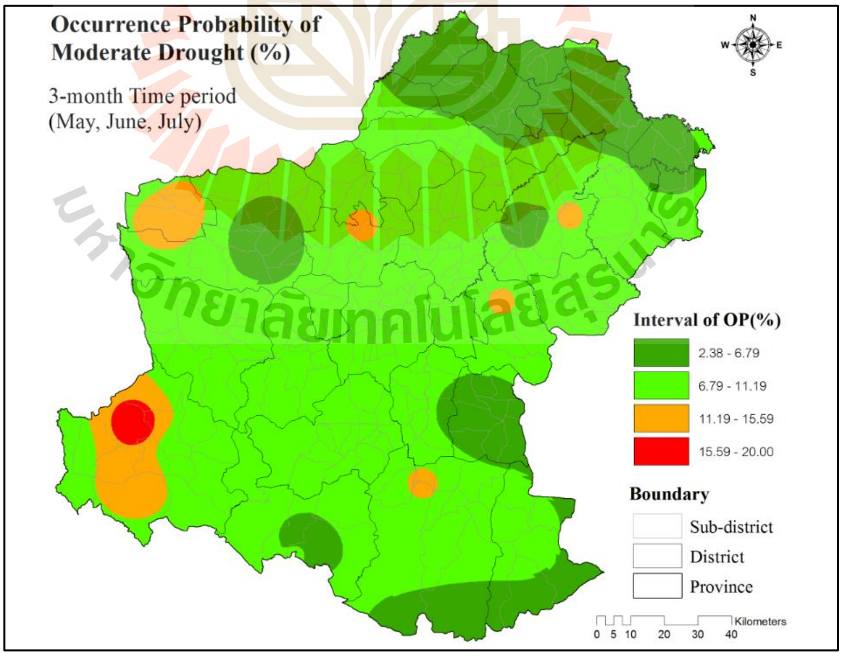


Figure 5.2 Distribution of drought occurrence probability of moderate category of SPI-3m7 period (May, June and July).

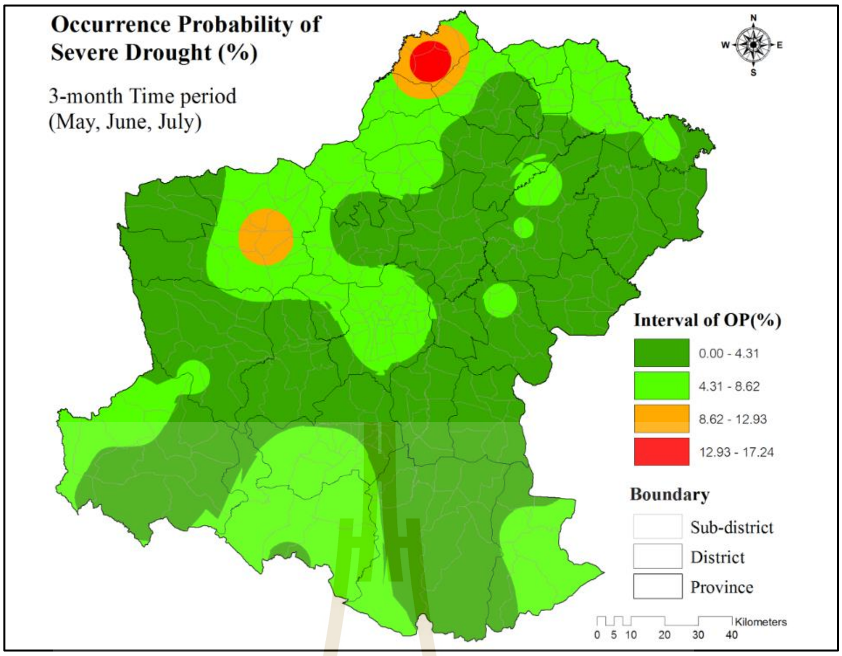


Figure 5.3 Distribution of drought occurrence probability of severe category of SPI-3m7 period (May, June and July).

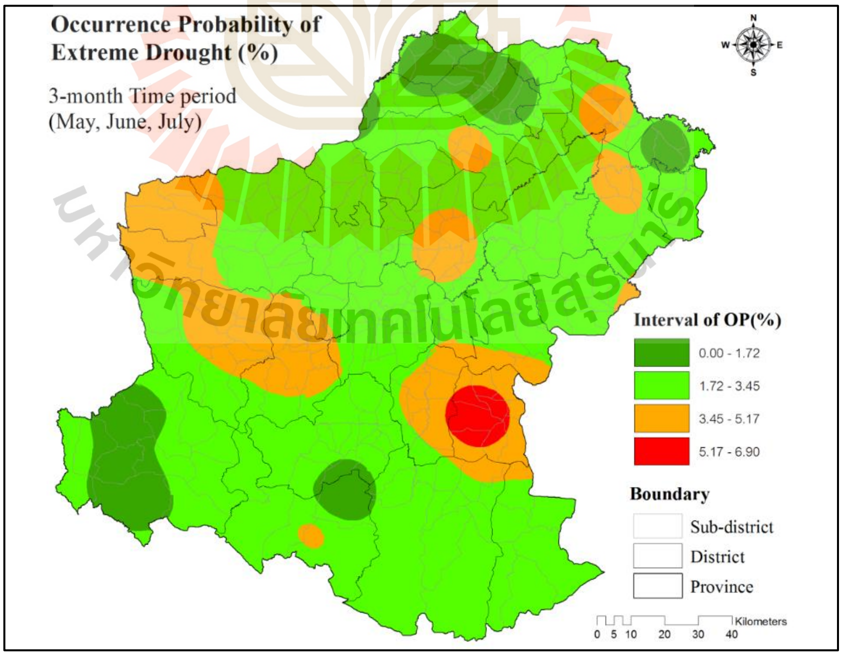


Figure 5.4 Distribution of drought occurrence probability of extreme category of SPI-3m7 period (May, June and July).

As results, it illustrates that the spatial distribution of near normal drought map tends to occur less frequency (33.47<OP<50) in northeastern and southwestern parts of the province. Because most of southwestern part is influenced by its terrain and weather of Khao Yai as shown in Figure 5.1. Meanwhile, the spatial distribution of moderate drought map (Figure 5.2) shows that most of drought occurrence probability varies between 2.38 and 11.19. In fact, the less frequency of drought occurrence spreads in the province.

In the meantime, the spatial distribution of severe drought map (Figure 5.3) shows that the less frequency of occurrence drought (0 to 8.62) occurs in most parts of the province. Meanwhile, the spatial distribution of extreme drought map (Figure 5.4) indicates that southwestern and northeastern parts of the province are high frequency of drought occurrence.

5.2.2 Drought occurrence probability of SPI-3m10 period

The drought occurrence probability of SPI-3m10 period that calculated using SPI during rainy and cropping season (August, September and October) is summarized in Table 5.3 and the distribution of drought categories (NND, MD, SD and ED) are displayed in Figures 5.5 to 5.8, respectively.

Table 5.3 Drought occurrence probability and its rating score of SPI-3m10 period (August, September and October) by each drought category.

Drought Category	Occurrence probability (%)	Rating
Near-normal (NND)	OP < 26.73	4
	26.73 ≤ OP < 32.76	3
	32.76 ≤ OP < 38.79	2
	38.79 ≤ OP < 44.83	1
Moderate drought (MD)	OP < 8.21	1
	8.21 ≤ OP < 14.04	2
	14.04 ≤ OP < 19.88	3
	19.88 ≤ OP < 25.71	4
Severe drought (SD)	OP < 3.57	1
	3.57 ≤ OP < 7.14	2
	7.14 ≤ OP < 10.72	3
	10.72 ≤ OP < 14.29	4
Extreme drought (ED)	OP < 1.78	1
	1.78 ≤ OP < 3.57	2
	3.57 ≤ OP < 5.35	3
	5.35 ≤ OP < 7.14	4

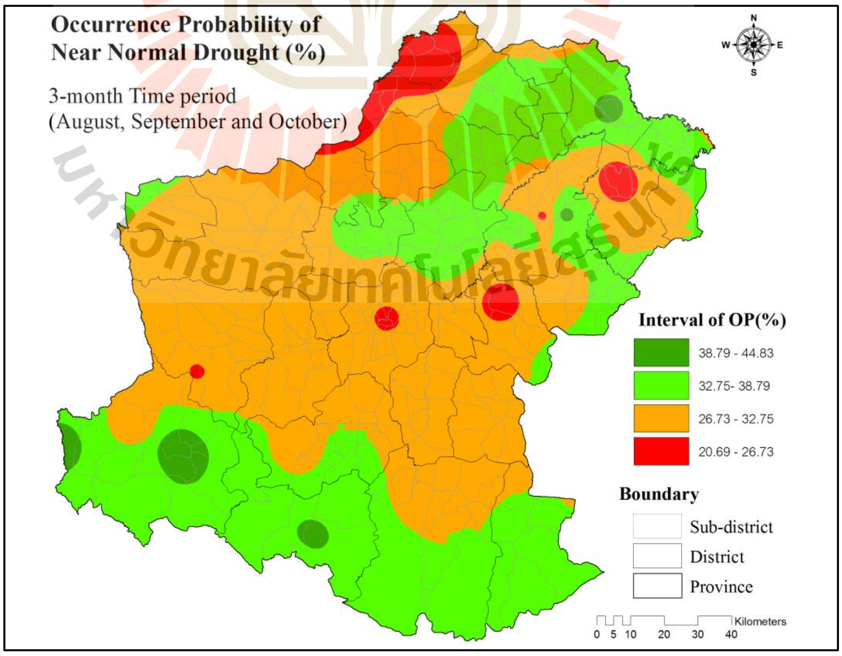


Figure 5.5 Distribution of drought occurrence probability of near normal category of SPI-3m10 period (August, September and October).

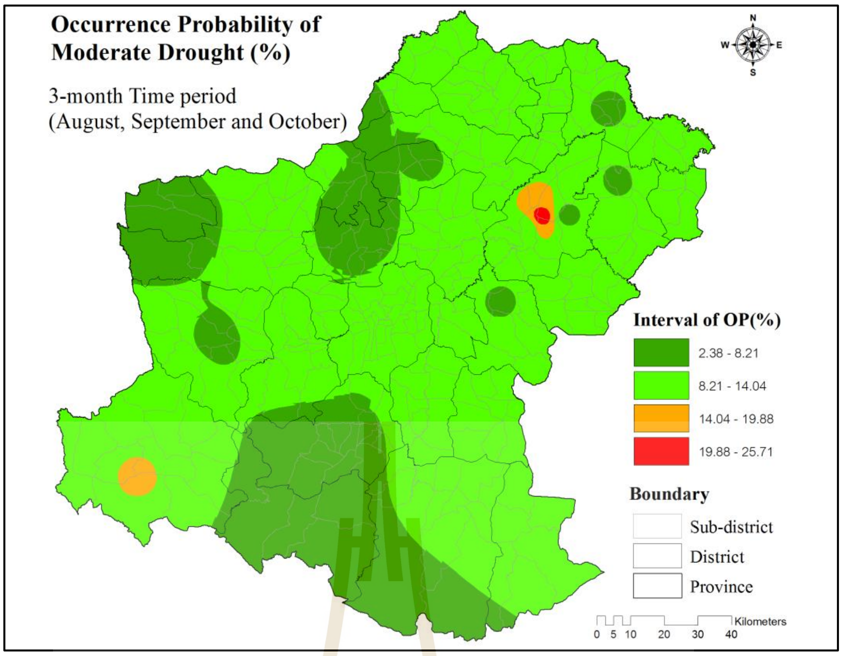


Figure 5.6 Distribution of drought occurrence probability of moderate category of SPI-3m10 period (August, September and October).

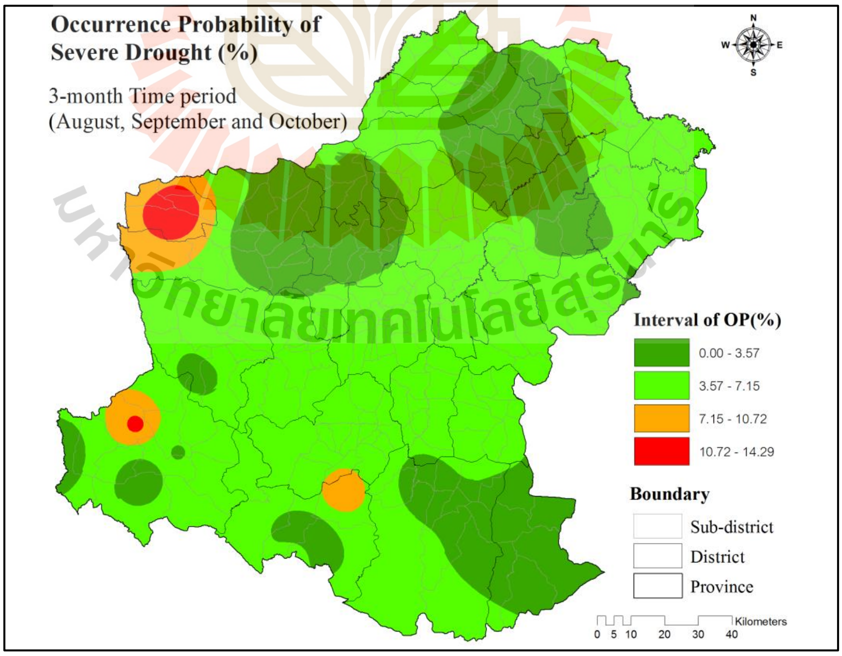


Figure 5.7 Distribution of drought occurrence probability of severe category of SPI-3m10 period (August, September and October).

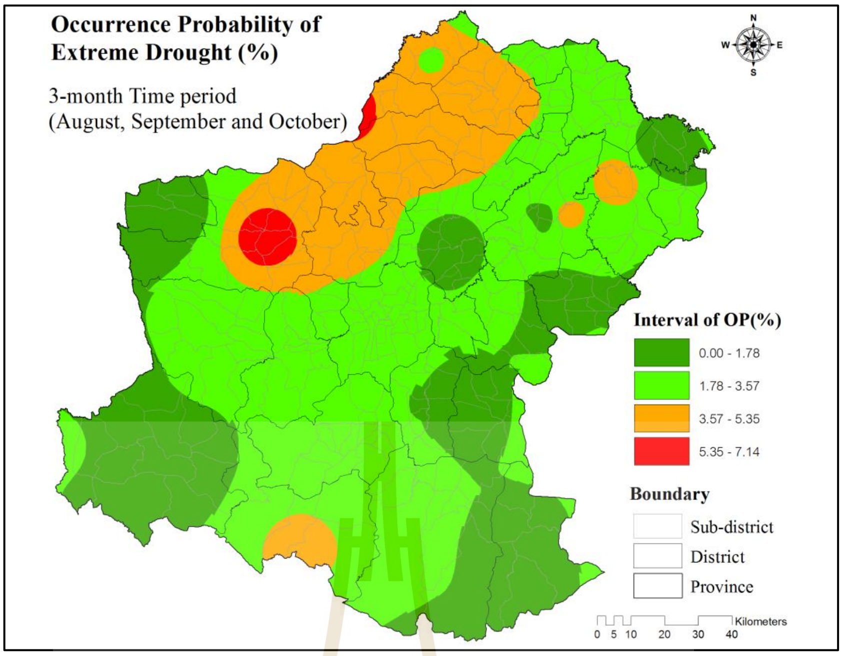


Figure 5.8 Distribution of drought occurrence probability of extreme category of SPI-3m10 period (August, September and October).

As results, it demonstrates that the spatial distribution of near normal drought map (Figure 5.5) tends to occur higher frequency in central part of the province whereas, the occurrence probability of drought at less frequency occurs in the southern and northern parts of the province. The higher level of drought probability occurrence (20.69 < OP < 26.3) is found in the northern part of the province. Meanwhile, the spatial distribution of moderate drought map is similarly as moderate drought map of SPI-3m7 period (May, June and July). It was found that less frequency of drought occurrence occurs over almost parts of the province as shown in Figure 5.6.

In the meantime, the spatial distribution of severe drought map (Figure 5.7) shows that the less frequency of drought occurrence is found in almost parts of the province but the higher frequency of drought occurrence is found in western parts.

Meanwhile, the spatial distributions of extreme drought map (Figure 5.8) illustrates that the high frequency of drought occurrence appears in northwestern part of the province.

5.2.3 Drought occurrence probability of SPI-6m10 period

The drought occurrence probability of SPI-6m10 period that calculated using SPI of whole 6 months (May, June, July, August, September and October) is summarized in Table 5.4 and the distribution of drought categories (NND, MD, SD and ED) are displayed in Figures 5.9 to 5.12, respectively.

Table 5.4 Drought occurrence probability and its rating score of SPI-6m10 period (May, June, July, August, September and October) by each drought category.

Drought category	Occurrence probability (%)	Rating
Near-normal (NND)	OP < 26.78	4
	26.78 ≤ OP < 34.53	3
	34.53 ≤ OP < 42.26	2
	42.26 ≤ OP < 500	1
Moderate drought (MD)	OP < 6.55	1
	6.55 ≤ OP < 10.72	2
	10.72 ≤ OP < 14.88	3
	14.88 ≤ OP < 19.05	4
Severe drought (SD)	OP < 2.58	1
	2.58 ≤ OP < 5.17	2
	5.17 ≤ OP < 7.75	3
	7.75 ≤ OP < 10.34	4
Extreme drought (ED)	OP < 1.78	1
	1.78 ≤ OP < 3.57	2
	3.57 ≤ OP < 5.35	3
	5.35 ≤ OP < 7.14	4

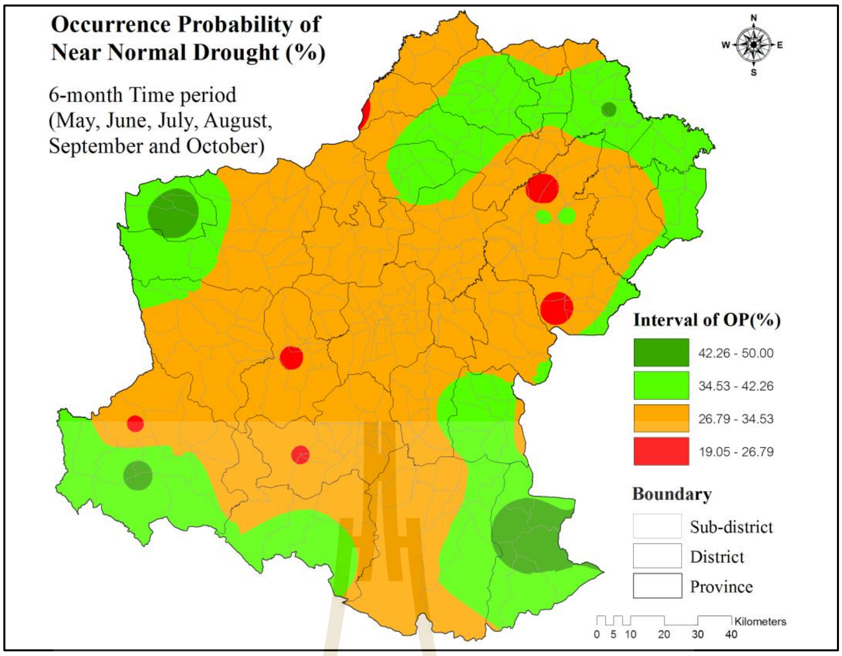


Figure 5.9 Distribution of drought occurrence probability of near normal category of SPI-6m10 period (May, June, July, August, September and October).

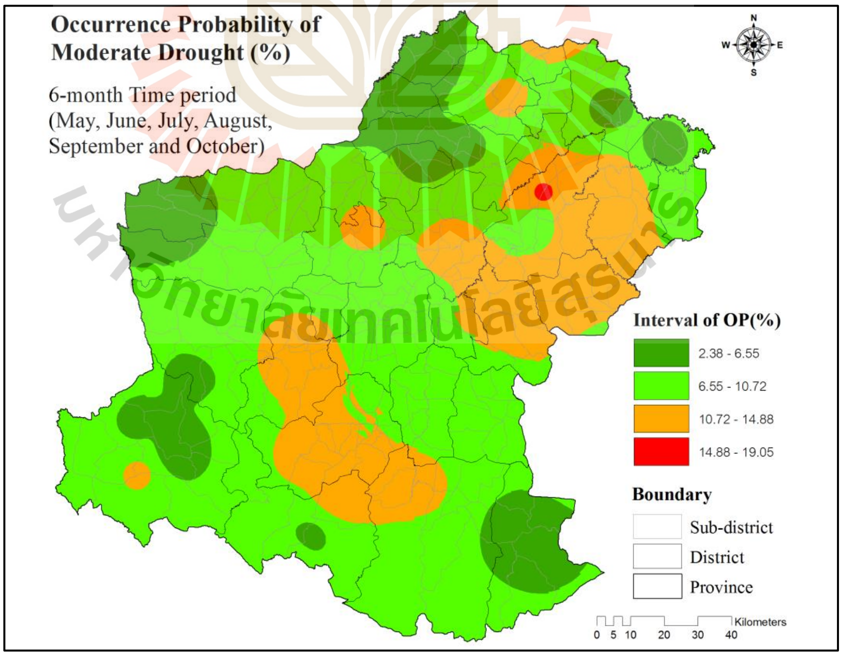


Figure 5.10 Distribution of drought occurrence probability of moderate category of SPI-6m10 period (May, June, July, August, September and October).

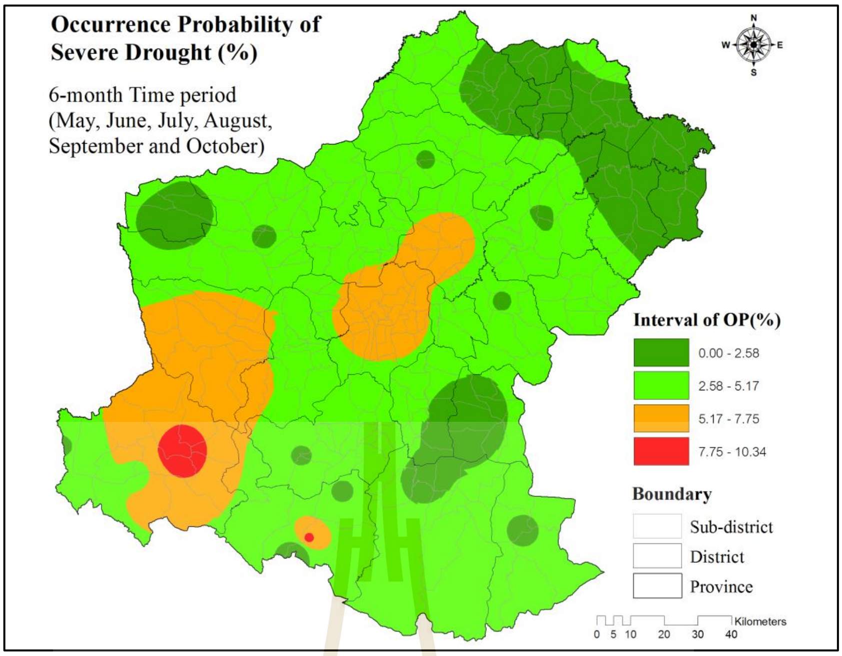


Figure 5.11 Distribution of drought occurrence probability of severe category of SPI-6m10 period (May, June, July, August, September and October).

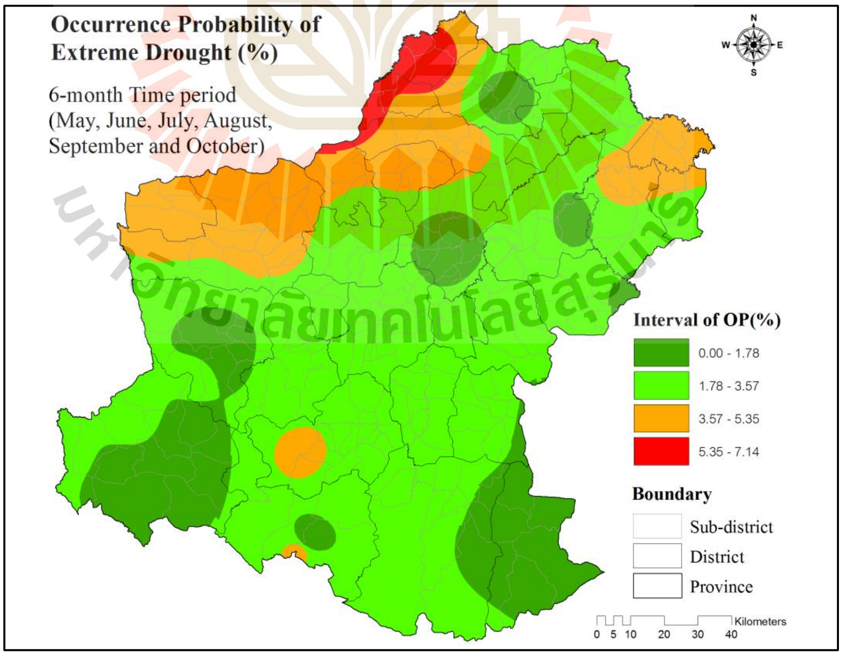


Figure 5.12 Distribution of drought occurrence probability of extreme category of SPI-6m10 period (May, June, July, August, September and October).

As results, it demonstrates that the spatial distribution of near normal drought map (Figure 5.9), high frequency of drought occurrence occur all parts of the province. Meanwhile, the spatial distributions of moderate and severe drought show that the low frequency of drought occurrence is found in all parts of the province as shown in Figure 5.10 and Figure 5.11, respectively. In the meantime, Figure 5.12 shows that the spatial distributions of extreme drought map illustrates that the high and severe frequency is found in the northwestern part of the province while the less frequency of drought occurrence covers the all parts of the province.

In summary, drought occurrence probability from different drought categories of 3 SPI periods indicates that western, central and eastern parts of the province are high and very high frequency of drought occurrence in all time periods.

5.3 Meteorological drought hazard frequency assessment

Result of drought occurrence probability classification of 3 SPI periods of 4 levels (near normal, moderate, severe, and extreme drought occurrence probability) and its rating and weight (see Tables 5.1 to 5.4) were here firstly integrated to generate meteorological drought hazard frequency index (DHI) using Equation 3.1 and the derived DHI values were then used to assess meteorological drought hazard frequency at sub-district level.

Basic statistical data of DHI of 3 SPI periods (SPI-3m7, SPI-3m10 and SPI-6m10) is summarized in Table 5.5 and distribution of DHI of 3 SPI periods is displayed in Figures 5.13 to 5.15, respectively.

To assess meteorological drought hazard frequency, the derived DHI of 3 SPI periods firstly overlaid with sub-district boundary to compute the sub-district average DHI. Then, average DHI value of 3 SPI periods were applied to classify and map meteorological drought hazard frequency into five classes (very low, low, moderate, high, and very high) using natural break at districts level. Results of meteorological drought hazard frequency classification of 3 SPI periods are here separately described and discussed in the following sections.

Table 5.5 Basic statistical data of drought hazard frequency index of 3 SPI periods.

SPI period	Statistical data of drought hazard frequency index			
	Minimum	Maximum	Mean	Standard deviation
SPI-3m7	10	25	17.87	4.53
SPI-3m10	11	28	19.06	5.00
SPI-6m10	10	29	20.39	5.39

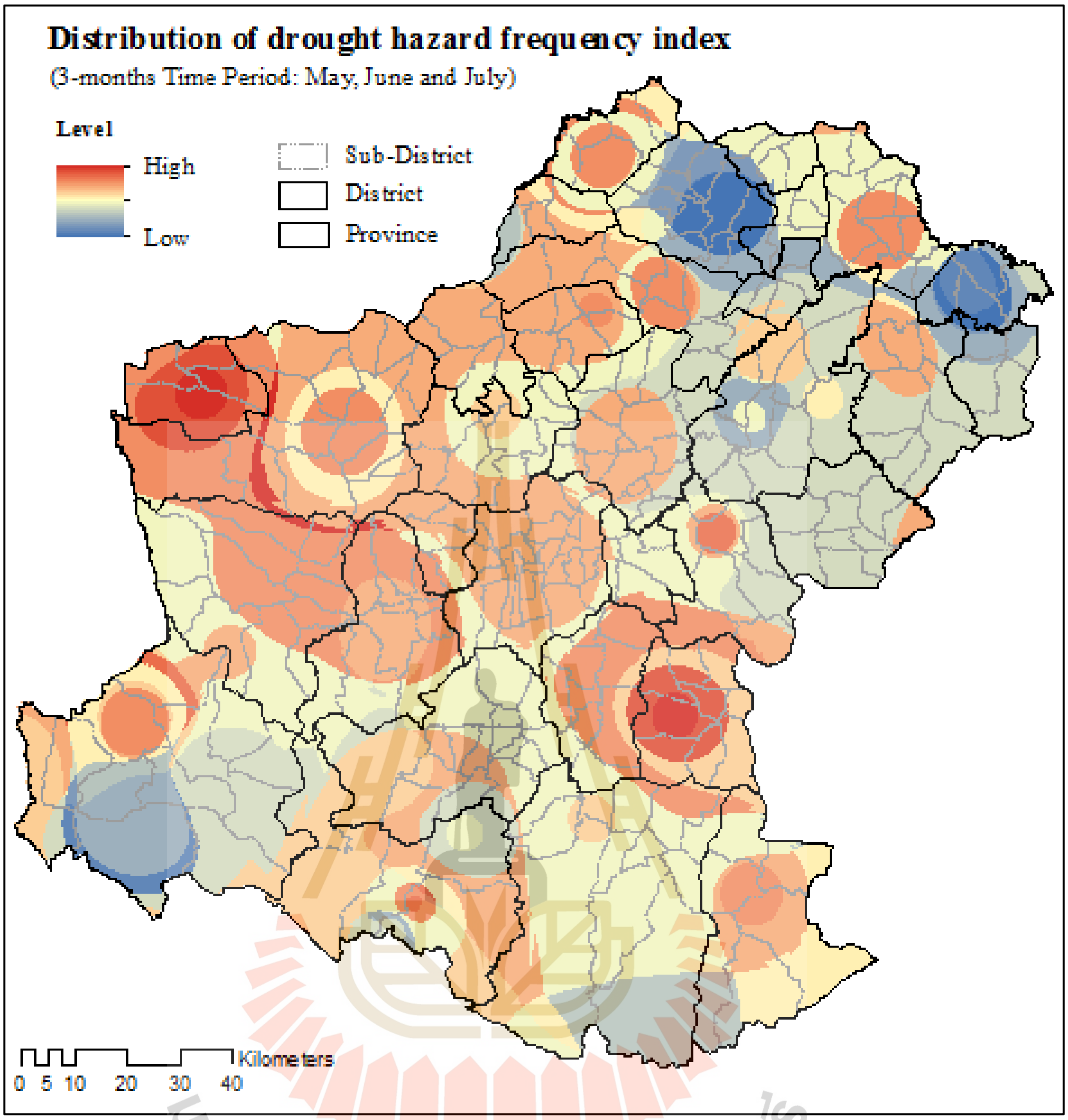


Figure 5.13 Distribution of drought hazard frequency index of SPI-3m7 period.

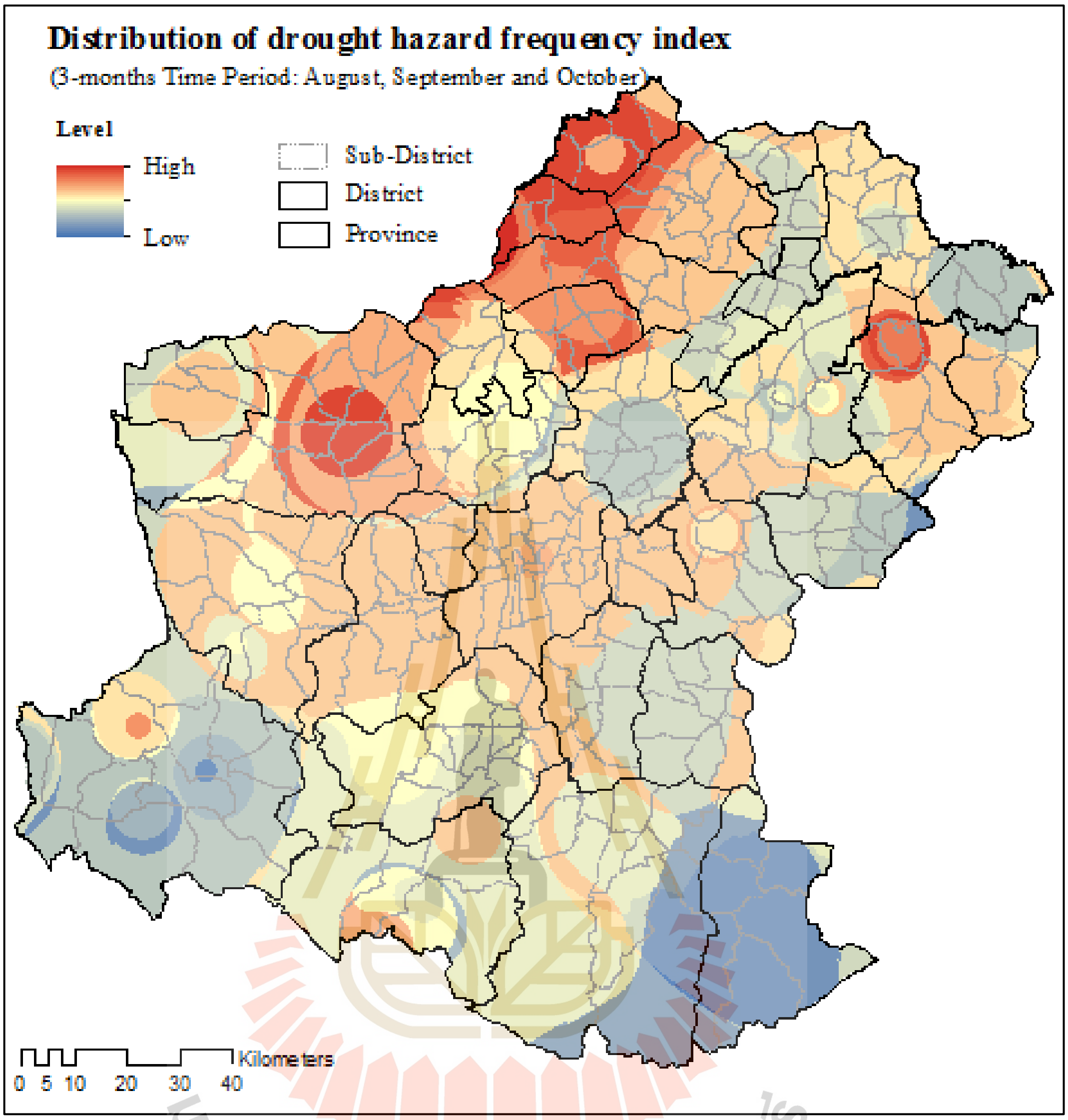


Figure 5.14 Distribution of drought hazard frequency index of SPI-3m10 period.

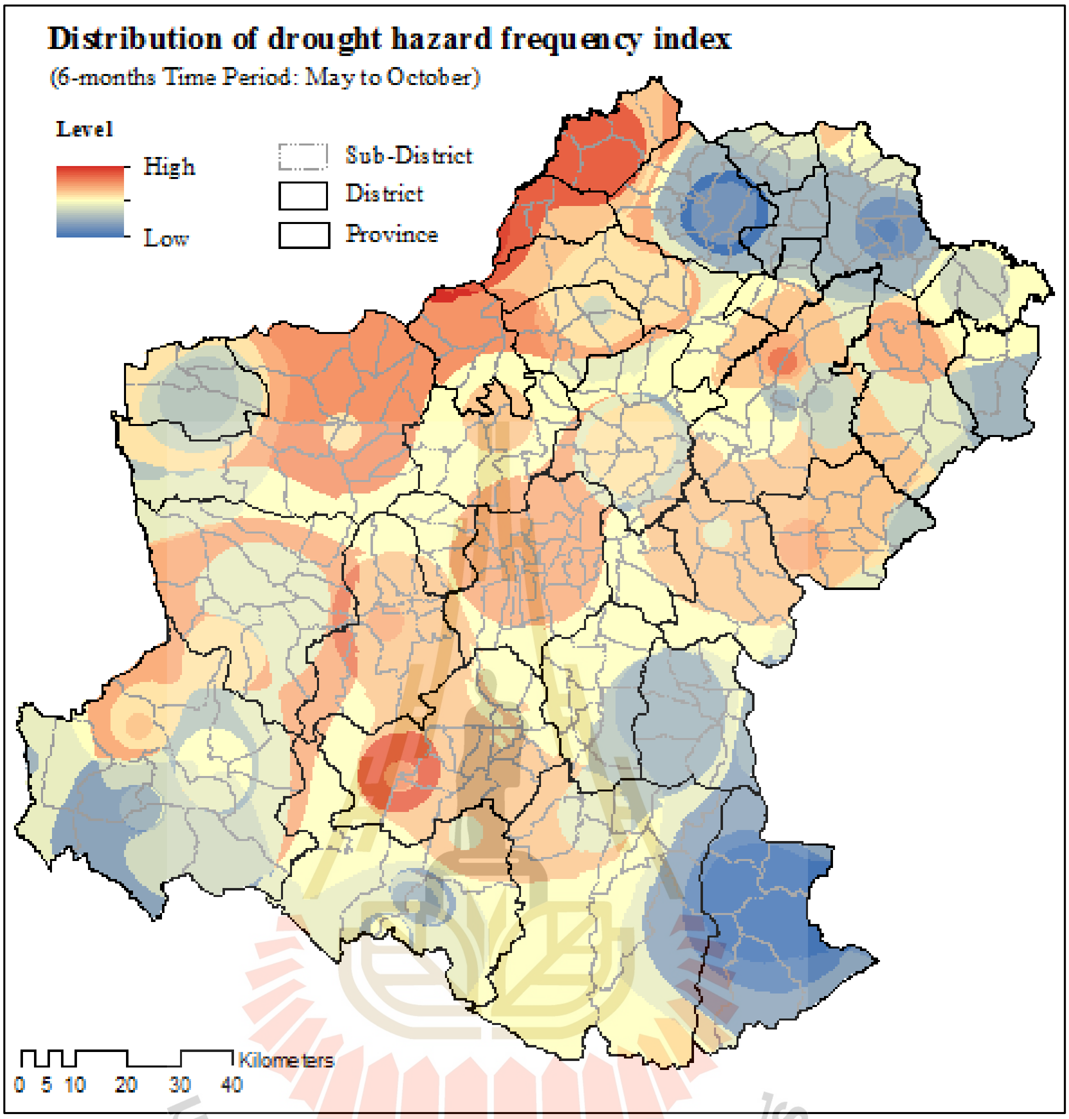


Figure 5.15 Distribution of drought hazard frequency index of SPI-6m10 period.

5.3.1 Meteorological drought hazard frequency classification of 3m7 period

Distribution of meteorological drought hazard frequency classification of SPI-3m7 period (May, June and July) at sub-district/district level is displayed in Figure 5.16.

The result at district level indicates that very low and low frequency of drought hazard are noticeably found in 10 districts include Chaloem Phrakiat, Pak Chong, Bua Lai, Phimai, Huai Thalaeng, Bua Yai, Lam Thamen Chai, Mueang Yang, Non Daeng, and Sida. On contrary, high and very high frequency of drought hazard are apparently found in 14 districts include Chok Chai, Dan Khun Thot, Nong Bunnak, Tepharak, Sikhio, Kaeng Sanam Nang, Sung Noen, Kham Sakae Saeng, Khom Thale So, Ban Lueam, Mueang Nakhon Ratchasima, Chakkarat, Soeng Sang, and Prathai. Meanwhile, moderate frequency of drought hazard obviously occurs in 8 districts include Wang Nam Khiao, Khong, Khon Buri, Phra Thong Kham, Chum Phuang, Non Thai, Non Sung, and Pak Thong Chai. Details of meteorological drought hazard frequency classification of SPI-3m7 period at district level is summarized in Table 5.6.

In addition, high and very high meteorological drought hazard frequency zones at district level can be observed in the western, eastern and central parts of the study area. Meanwhile, moderate meteorological drought hazard frequency zone is mostly found in the northern and southern parts while very low and low meteorological drought hazard frequency zones situate in the northern part.

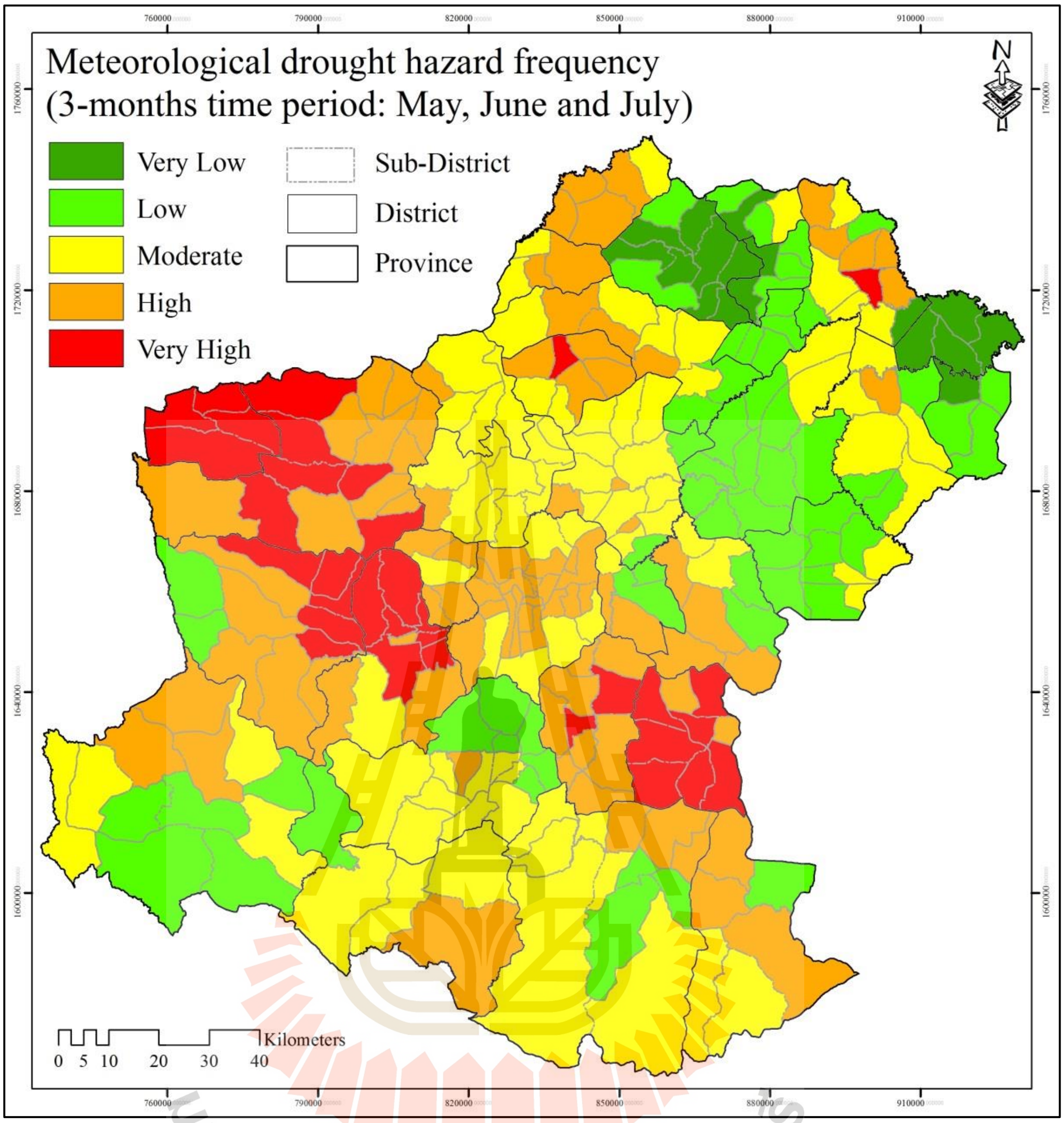


Figure 5.16 Distribution of meteorological drought hazard frequency classification of SPI-3m7 period (May, June and July).

Table 5.6 Percentage of meteorological drought hazard frequency classification of SPI-3m7 period (May, June and July) at district level.

District	Meteorological drought hazard frequency (%of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	0	0	36.5	63.6	0
Bua Lai	25	44.7	30.3	0	0
Bua Yai	70.5	29.5	0	0	0
Chakkarat	0	24.6	20	55.5	0
Chaloem Phrakiat	0	45.2	10.8	44	0
Chok Chai	0	0	0	82.4	17.6
Chum Phuang	0	24.5	67.1	8.4	0
Dan Khun Thot	0	0	0	59.1	40.9
Huai Thalaeng	0	81.4	18.6	0	0
Kaeng Sanam Nang	0	0	19.7	80.3	0
Kham Sakae Saeng	0	0	25.1	66.2	8.8
Khom Thale So	0	0	25.0	75	0
Khon Buri	0	15.4	72.4	12.2	0
Khong	0	19.1	55	26	0
Lam Thamen Chai	18.4	81.6	0	0	0
Mueang Nakhon Ratchasima	0	0	39.9	60.1	0
Mueang Yang	100	0	0	0	0
Non Daeng	0	100	0	0	0
Non Sung	0	10.5	82.0	7.4	0
Non Thai	0	0	91.7	8.3	0
Nong Bunnak	0	0	0	12.8	87.2
Pak Chong	0	44.1	31.1	24.8	0
Pak Thong Chai	0	32.4	64.2	3.4	0
Phimai	0	79.2	20.8	0	0
Phra Thong Kham	0	0	90.5	9.5	0
Prathai	6.6	12.9	34.9	39.2	6.4
Sida	39.6	60.4	0	0	0
Sikhio	0	18	0	55.3	26.7
Soeng Sang	0	11.5	36.2	52.3	0
Sung Noen	0	0	20.7	32.2	47.1
Tepharak	0	0	0	0	100
Wang Nam Khiao	0	14.5	54.5	31	0

5.3.2 Meteorological drought hazard frequency classification of 3m10 period

Distribution of meteorological drought hazard frequency classification of SPI-3m10 (August, September and October) at sub-district/district level is displayed in Figure 5.17.

The result at district level indicates that very low and low frequency of drought hazard apparently occurs in 10 districts include Non Sung, Prathai, Bua Lai, Khon Buri, Nong Bunnak, Huai Thalaeng, Non Daeng, Pak Chong, Soeng Sang, and Wang Nam Khiao. On contrary, high and very high frequency of drought hazard are obviously found in 12 districts include Ban Lueam, Kaeng Sanam Nang, Kham Sakae Saeng, Phra Thong Kham, Dan Khun Thot, Bua Yai, Mueang Nakhon Ratchasima, Chum Phuang, Lam Thamen Chai, Khom Thale So, Khong, and Chaloem Phrakiat. Meanwhile, moderate frequency of drought hazard noticeably occurs in 10 districts include Sung Noen, Chok Chai, Sikhio, Chakkarat, Non Thai, Phimai, Pak Thong Chai, Tepharak, Sida, and Mueang Yang. Details of meteorological drought hazard frequency classification of SPI-3m10 period at district level is summarized in Table 5.7.

In addition, high and very high meteorological drought hazard frequency zones at district level can be obviously observed in the northwestern and central parts of the study area. Meanwhile, moderate meteorological drought hazard frequency zone is mostly found in the central part while very low and low meteorological drought hazard frequency zones situates in the southern and northeastern part.

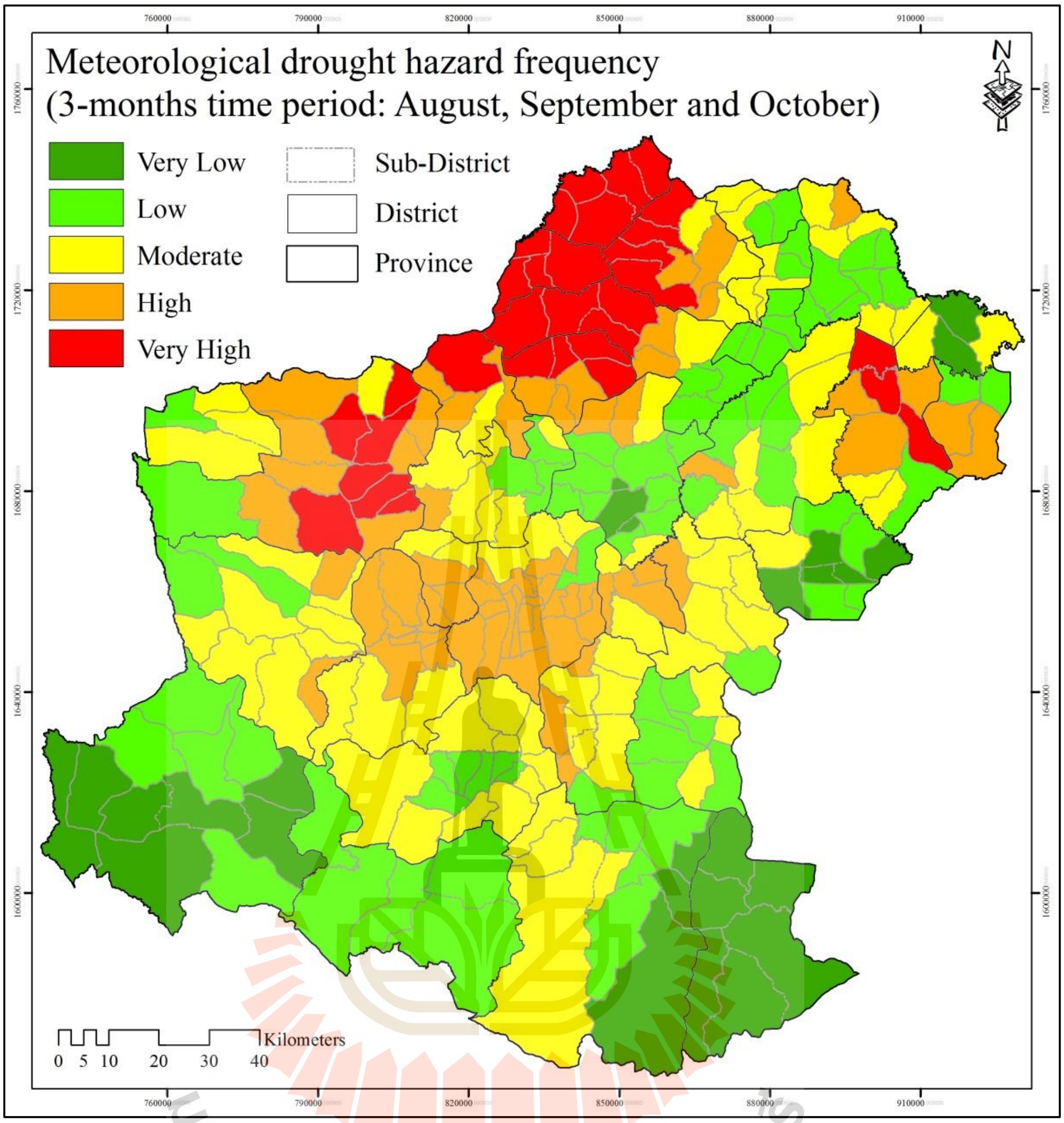


Figure 5.17 Distribution of meteorological drought hazard frequency classification of SPI-3m10 period (August, September and October).

Table 5.7 Percentage of meteorological drought hazard frequency classification of SPI-3m10 period (August, September and October) at district level.

District	Meteorological drought hazard frequency (% of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	0	0	0	0	100
Bua Lai	0	51.5	48.5	0	0
Bua Yai	0	0	24.2	27.5	48.3
Chakkarat	0	13.0	77.1	10	0
Chaloem Phrakiat	0	0	44.2	55.8	0
Chok Chai	0	11.2	69.8	19.0	0
Chum Phuang	0	15.0	14.4	43.1	27.6
Dan Khun Thot	0	18.6	4.2	43.9	33.3
Huai Thalaeng	41.3	43.6	15.1	0	0
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	0	41.9	58.1
Khom Thale So	0	0	38.4	61.7	0
Khon Buri	30.6	23.9	45.5	0	0
Khong	0	25.5	12.8	13.9	47.8
Lam Thamen Chai	0	34.7	0	65.3	0
Mueang Nakhon Ratchasima	0	7.3	18.8	74.0	0
Mueang Yang	49.7	0	50.3	0	0
Non Daeng	0	100	0	0	0
Non Sung	10.7	59.2	15.6	14.5	0
Non Thai	0	29.4	62.2	8.3	0
Nong Bunnak	0	73.2	26.8	0	0
Pak Chong	58.7	41.3	0	0	0
Pak Thong Chai	0	17.5	82.5	0	0
Phimai	0	37.5	57.5	5.0	0
Phra Thong Kham	0	0	18.4	45.1	36.5
Prathai	0	53.7	39.0	7.3	0
Sida	0	38.9	61.1	0	0
Sikhio	0	22.7	66.8	10.5	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	51.7	48.3	0
Tepharak	0	18.1	81.9	0	0
Wang Nam Khiao	0	100	0	0	0

5.3.3 Meteorological drought hazard frequency classification of 6m10 period

Distribution of meteorological drought hazard frequency classification of SPI-6m10 (May, June, July, August, September and October) at sub-district/district level is displayed in Figure 5.18.

The result at district level indicates that very low and low frequency of drought hazard are obviously found in 9 districts include Wang Nam Khiao, Bua Yai, Khon Buri, Lam Thamen Chai, Nong Bunnak, Prathai, Bua Lai, Sida, and Soeng Sang. On contrary, high and very high frequency of drought hazard are noticeably found in 17 districts include Ban Lueam, Kaeng Sanam Nang, Khong, Mueang Nakhon Ratchasima, Pak Thong Chai, Phra Thong Kham, Sung Noen, Non Thai, Dan Khun Thot, Khom Thale So, Sikhio, Huai Thalaeng, Kham Sakae Saeng, Chum Phuang, Chakkarat, Chaloem Phrakiat, and Phimai. Meanwhile, moderate frequency of drought hazard apparently occurs in 6 districts include Non Sung, Pak Chong, Chok Chai, Non Daeng, Tepharak, and Mueang Yang. Details of meteorological drought hazard frequency classification of SPI-6m10 period at district level is summarized in Table 5.8.

In addition, high and very high meteorological drought hazard frequency zones at district level can be obviously observed in the northwestern and central parts of the study area. Meanwhile, moderate meteorological drought hazard frequency zone is mostly found in the central part while very low and low meteorological drought hazard frequency zones situates in the southern and northern part.

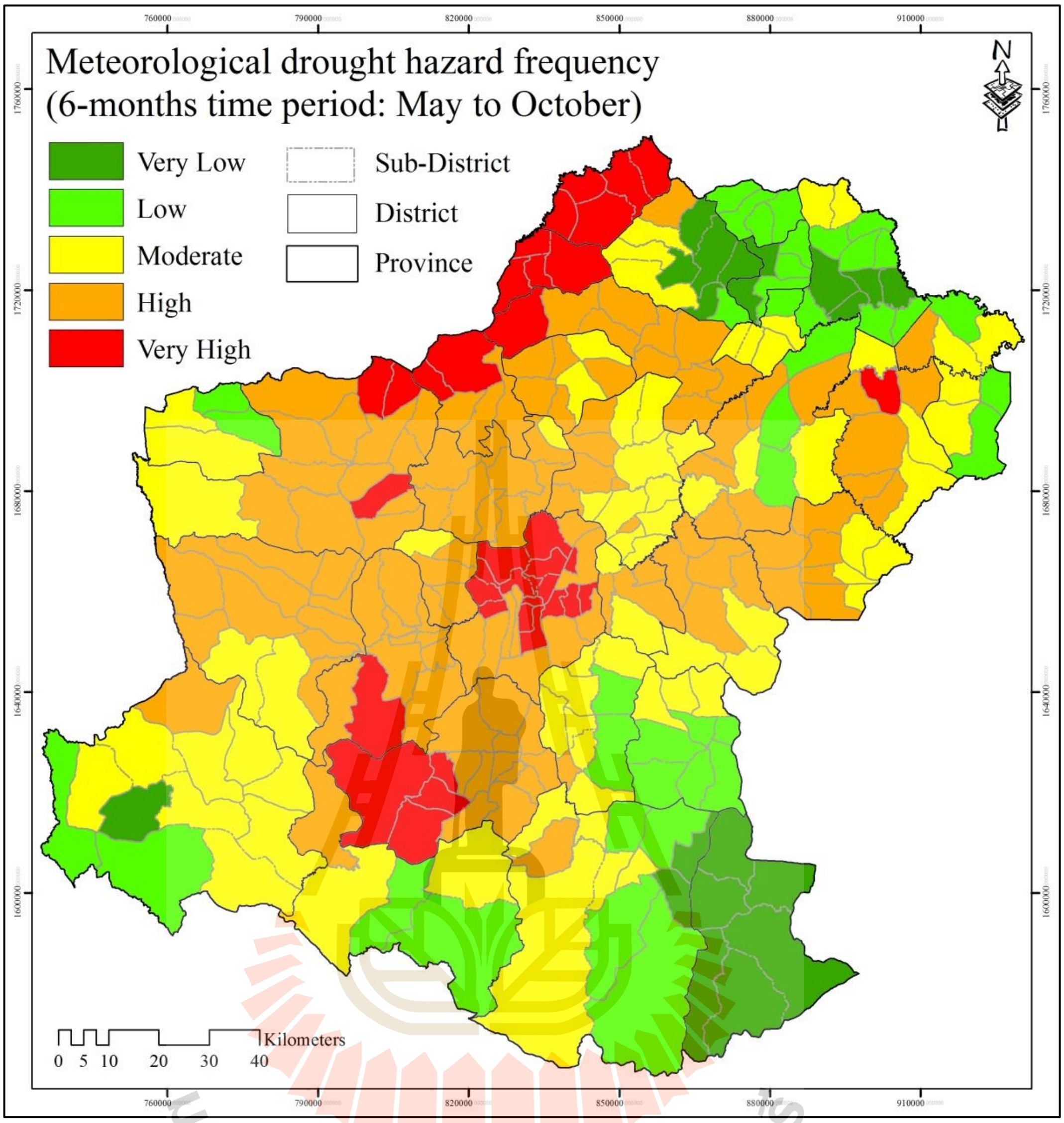


Figure 5.18 Distribution of meteorological drought hazard frequency classification of SPI-6m10 period (May, June, July, August, September and October).

Table 5.8 Percentage of meteorological drought hazard frequency classification of SPI-6m10 period (May, June, July, August, September and October) at district level.

District	Meteorological drought hazard frequency (% of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	0	0	0	0	100
Bua Lai	0	100	0	0	0
Bua Yai	45.2	6.6	36.5	11.8	0
Chakkarat	0	0	42.9	57.1	0
Chaloem Phrakiat	0	0	44.2	55.8	0
Chok Chai	0	33.5	62.6	3.9	0
Chum Phuang	0	0	34.1	57.5	8.4
Dan Khun Thot	0	0	18.6	69.9	11.5
Huai Thalaeng	0	0	30.5	69.5	0
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	32.5	67.5	0
Khom Thale So	0	0	22.6	77.4	0
Khon Buri	5.6	45.3	44.4	4.7	0
Khong	0	0	0	84.0	16.0
Lam Thamen Chai	0	50.9	49.1	0	0
Mueang Nakhon Ratchasima	0	0	0	54.0	46.0
Mueang Yang	0	26.3	48.5	25.2	0
Non Daeng	0	21.2	78.8	0	0
Non Sung	0	0	70.2	29.8	0
Non Thai	0	0	4.4	95.6	0
Nong Bunnak	0	69.0	31.1	0	0
Pak Chong	6.2	24.5	59.8	9.5	0
Pak Thong Chai	0	0	0	55.3	44.7
Phimai	0	27.2	27.7	45.1	0
Phra Thong Kham	0	0	0	54.0	46.0
Prathai	33.4	49.0	17.6	0	0
Sida	39.6	60.4	0	0	0
Sikhio	0	0	28.1	71.9	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	0	79.3	20.7
Tepharak	0	33.5	66.5	0	0
Wang Nam Khiao	0	43.5	42.0	14.5	0

In summary, percentage of meteorological drought hazard frequency classification of 3 SPI periods at provincial level is compared in Table 5.9. According to meteorological drought hazard frequency classification at provincial level, the most dominant class of all 3 periods (SPI-3m7, SPI-3m10, and SPI-6m10) at provincial level is high and very high drought hazard frequency and covers area of 39.9%, 26.10%, and 45.40% of the study area, respectively. Meanwhile very low and low drought hazard frequency of 3 periods covers area of 25.60%, 42.80%, and 25.00% and moderate drought hazard frequency of 3 periods covers area of 34.50%, 31.10%, and 29.60% of areas, respectively. Thus, at provincial level, the long time period (6m10) drought hazard becomes more frequent than short time period (3m7 and 3m10) drought hazard. The frequency of drought infers the number of occurrence precipitation shortage event or deficit of water per time of season or year.

Table 5.9 Percentage of meteorological drought hazard frequency classification of SPI periods in Nakhon Ratchasima Province.

SPI period	**Meteorological drought hazard frequency (% of area)**				
	Very low	**Low**	**Moderate**	**High**	**Very high**
SPI-3M7	4.1	21.5	34.5	29.1	10.8
SPI-3M10	14.6	28.2	31.1	16.1	10
SPI-6M10	7.8	17.2	29.6	35.9	9.5

At district level, there are 6 districts including Ban Lueam, Chakkarat, Chok Chai, Dan Khun Thot, Kaeng Sanam Nang, Kham Sakae Saeng, Khom Thale So and Mueang Nakhon Ratchasima incur in high and very high of occurrence of drought hazard frequency class in every period. During 3 periods, high to very high drought hazard frequency is observed in western, northwestern, central and eastern districts. Thus, these areas are seriously affected from drought hazard frequency of all short term (3m7 and 3m10) and long term (6m10) periods.

In conclusion, the high and very high frequency of occurrence meteorological drought hazard in short time period illustrates that 3m7 period is more dominant than 3m10 period. The analysis of drought hazard frequency map with different SPI period is suitable to differentiate type of drought in short time period and it always applies to analyze meteorological drought. Meanwhile drought hazard frequency map with moderate period is used to detect meteorological or agricultural drought. However, to detect agricultural drought it requires selecting appropriate period that relates with crop calendar. For instance, growing season of rain fed paddy field in Nakhon Ratchasima province takes place in rainy season (May to October). Therefore, the appropriate time period of meteorological drought hazard frequency should include 3 time periods: (1) start of growing season (May, June and July), (2) end of growing season (August, September and October) and (3) whole range of growing period (May, June, July, August, September and October). Meanwhile, meteorological drought hazard frequency classification of inter-rainy season should consists of 2 time period: 3m7 (May, June and July) and 3m10 (August, September and October). While, meteorological drought hazard frequency classification of rainy season is 6m10 (May, June, July, August, September and October).

5.4 Meteorological drought hazard intensity assessment

Meteorological drought hazard intensity is considered as the degree of the precipitation deficiency and the severity of impact in duration of event that measures by SPI. When the SPI is less than or equal -1, it indicates drought condition. Therefore, meteorological drought hazard intensity is here summation of SPI values that less than or equal -1. Because some stations of rainfall could not be detected in all 41 years, so the sum of SPI (≤ -1) was divided by the total number of years to normalize value for intensity calculation. Consequently, meteorological drought hazard intensity is here represented by the mean value of SPI with multiplication of 100 (percent). After that, the derived value were interpolated using IDW technique and then reclassified using natural break method into 5 categories (very low, low, moderate, high and very high) with weight of 1, 2, 3, 4 and 5 respectively. Table 5.10 summarized statistical data of drought hazard intensity classification of 3 SPI periods. Segal and Dhakar (2016) stated that drought intensity indicates severity of rainfall deficit. The occurrence of drought condition applies time about 2 to 3 months until seasonal or years, though the intensity and spatial extent of event is destination or change from month to month or season to season (Wilhite and Buchanan-Smith, 2005). The results of meteorological drought hazard intensity assessment of 3 SPI periods are separately explained and discussed in the following sections.

Table 5.10 The drought hazard intensity index values and its weight of each SPI period.

Intensity class	Weight	Range of drought hazard intensity (%)		
		SPI-3M7	**SPI-3M10**	**SPI-6M10**
Very low	1	10.90-19.76	13.50-20.10	2.52-15.60
Low	2	19.76-23.28	20.10-23.07	15.60-20.08
Moderate	3	23.28-25.09	23.07-25.37	20.08-22.74
High	4	25.09-27.51	25.37-27.52	22.74-25.41
Very high	5	27.51-36.57	27.52-32.41	25.41-33.40

5.4.1 Meteorological drought hazard intensity assessment of SPI-3m7 period

Distribution of meteorological drought hazard intensity classification of SPI-3m7 period at sub-district/district level is displayed in Figure 5.19. The result at district level indicates that very low and low intensity of drought hazard are obviously found in 14 districts include Soeng Sang, Non Sung, Prathai, Nong Bunnak, Bua Yai, Phimai, Huai Thalaeng, Bua Lai, Chum Phuang, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, and Sida. On contrary, high and very high intensity of drought hazard are noticeably found in 13 districts include Mueang Nakhon Ratchasima, Ban Lueam, Chaloem Phrakiat, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Non Thai, Phra Thong Kham, Tepharak, Sikhio, Kham Sakae Saeng, Pak Chong, and Chok Chai. Meanwhile, moderate intensity of drought hazard apparently occurs in 5 districts include Sung Noen, Chakkarat, Pak Thong Chai, Khong, and Wang Nam Khiao. Details of meteorological drought hazard intensity classification of SPI-3m7 period at district level is summarized in Table 5.11.

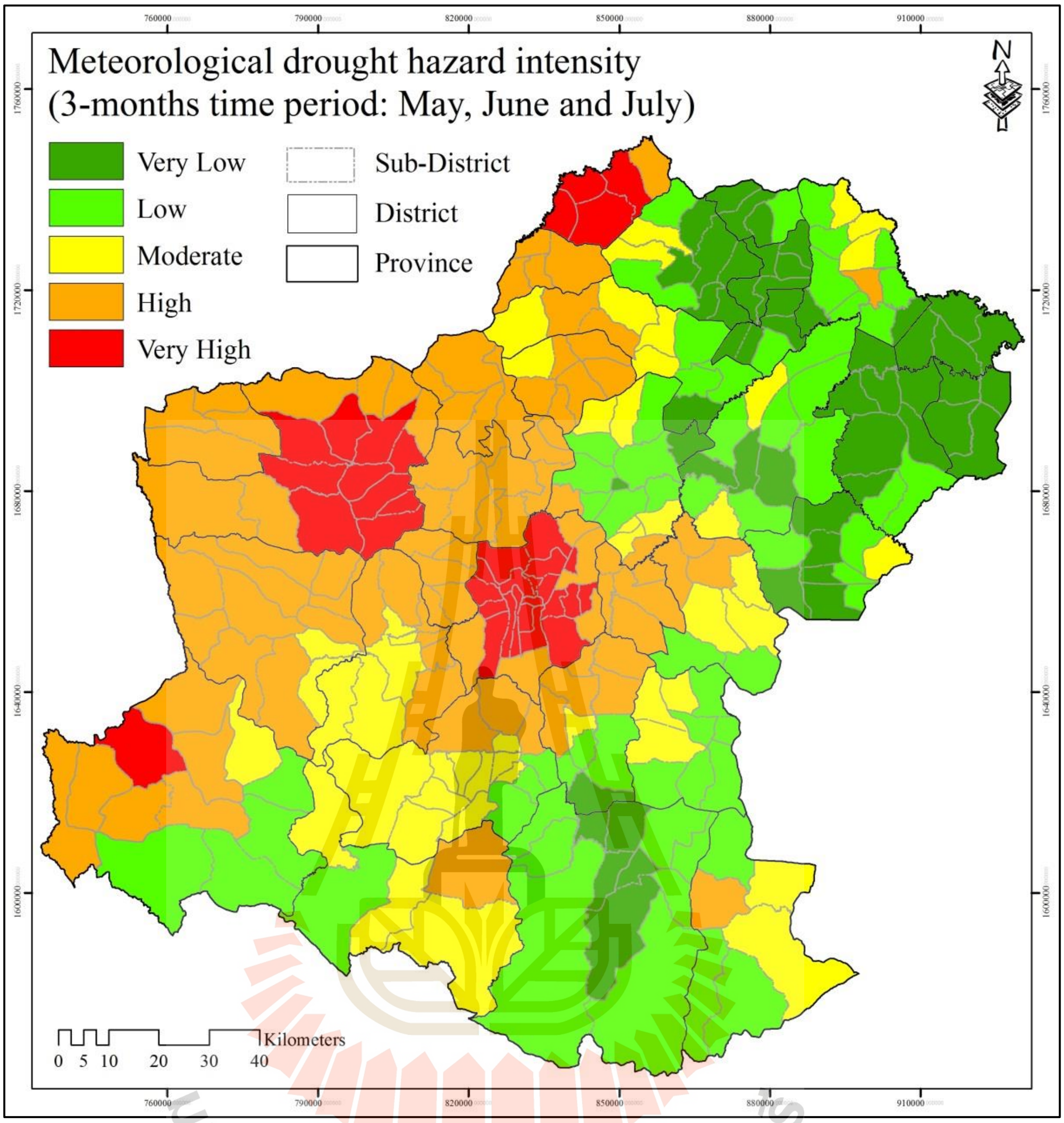


Figure 5.19 Distribution of meteorological drought hazard intensity classification of SPI-3m7 period (May, June and July).

Table 5.11 Percentage of meteorological drought hazard intensity classification of SPI-3m7 period (May, June and July) at district level.

District	Meteorological drought hazard intensity (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	100	0
Bua Lai	69.7	30.3	0	0	0
Bua Yai	51.8	29.5	18.8	0	0
Chakkarat	0	27.9	42.2	29.9	0
Chaloem Phrakiat	0	0	0	100	0
Chok Chai	11.2	30.3	4.9	53.6	0
Chum Phuang	77.3	22.7	0	0	0
Dan Khun Thot	0	0	0	49.5	50.5
Huai Thalaeng	54.4	35.3	10.3	0	0
Kaeng Sanam Nang	0	0	0	19.7	80.3
Kham Sakae Saeng	0	0	17.4	82.7	0
Khom Thale So	0	0	0	100	0
Khon Buri	20.7	79.3	0	0	0
Khong	10	28.3	42.2	19.5	0
Lam Thamen Chai	100	0	0	0	0
Mueang Nakhon Ratchasima	0	0	0	34.1	66.0
Mueang Yang	100	0	0	0	0
Non Daeng	72.6	27.4	0	0	0
Non Sung	7.2	58.3	25.0	9.5	0
Non Thai	0	0	0	100	0
Nong Bunnak	0	63.4	36.6	0	0
Pak Chong	0	39.6	6.6	45.5	8.3
Pak Thong Chai	0	14.1	61.4	24.5	0
Phimai	20.4	67.0	12.6	0	0
Phra Thong Kham	0	0	0	100	0
Prathai	13.2	58.8	21.7	6.4	0
Sida	100	0	0	0	0
Sikhio	0	0	9.0	91.0	0
Soeng Sang	0	49.0	39.6	11.5	0
Sung Noen	0	0	51.6	48.5	0
Tepharak	0	0	0	100	0
Wang Nam Khiao	0	24.4	58.0	17.6	0

5.4.2 Meteorological drought hazard intensity assessment of SPI-3m10 period

Distribution of meteorological drought hazard intensity classification of SPI-3m10 period at sub-district/district level is displayed in Figure 5.20. The result at district level indicates that very low and low intensity of drought hazard apparently occurs in 10 districts include Pak Chong, Khon Buri, Lam Thamen Chai, Non Thai, Sida, Pak Thong Chai, Prathai, Mueang Yang, Wang Nam Khiao, and Soeng Sang. On contrary, high and very high intensity of drought hazard are obviously found in 19 districts include Ban Lueam, Chaloem Phrakiat, Chok Chai, Kaeng Sanam Nang, Kham Sakae Saeng, Khom Thale So, Khong, Nong Bunnak, Dan Khun Thot, Mueang Nakhon Ratchasima, Chakkarat, Non Sung, Tepharak, Chum Phuang, Sung Noen, Non Daeng, Bua Yai, Phra Thong Kham, and Phimai. Meanwhile, moderate intensity of drought hazard noticeably occurs in 3 districts include Bua Lai, Sikhio, and Huai Thalaeng. Details of meteorological drought hazard intensity classification of SPI-3m10 period at district level is summarized in Table 5.12.

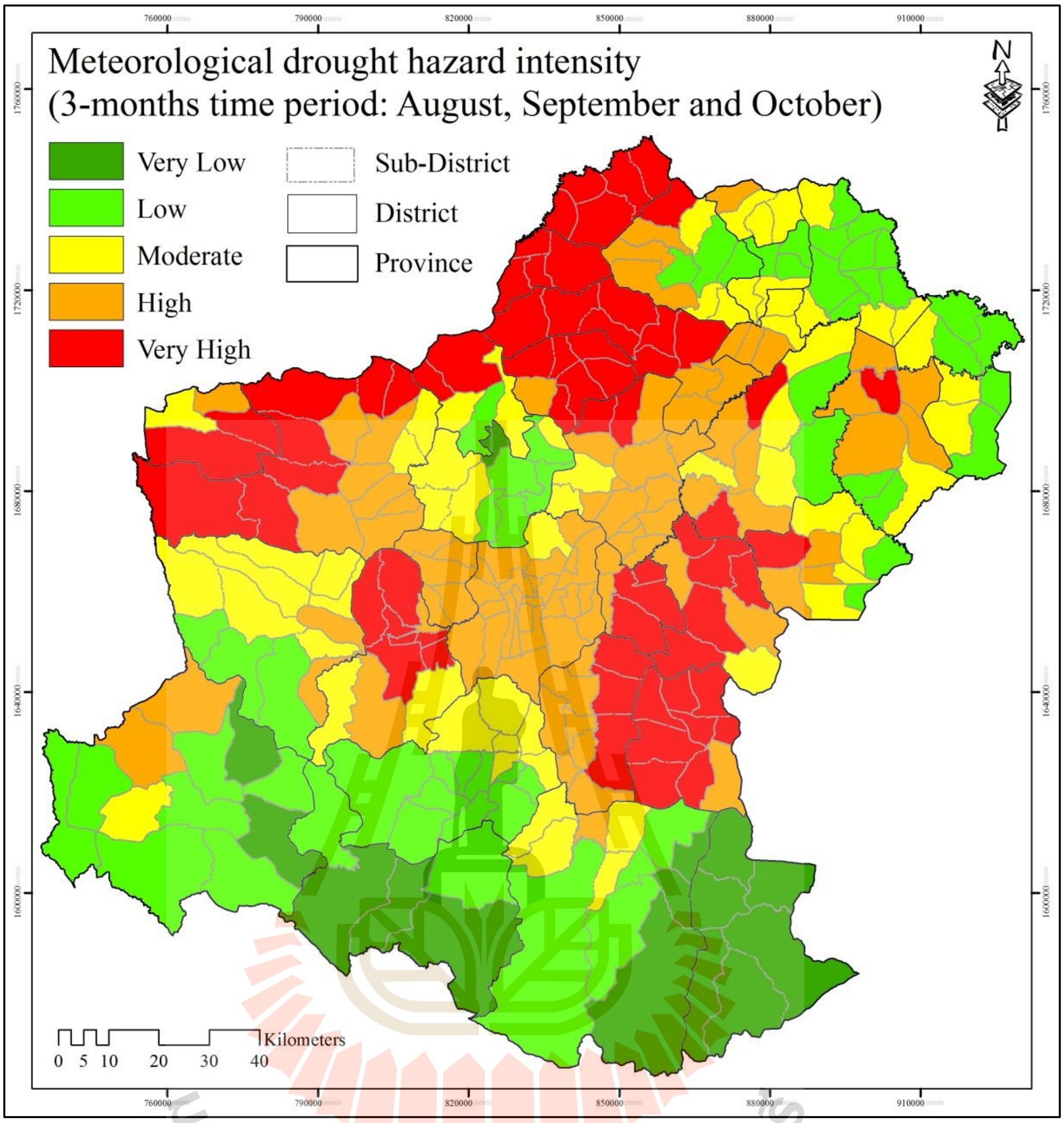


Figure 5.20 Distribution of meteorological drought hazard intensity classification of SPI-3m10 period (August, September and October).

Table 5.12 The percentage of meteorological drought hazard intensity classification of SPI-3m10 period (August, September and October) at district level.

Districts	Meteorological drought hazard intensity (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	0	100
Bua Lai	0	0	76.6	23.5	0
Bua Yai	0	30.1	21.7	36.5	11.8
Chakkarat	0	0	13.0	25.1	62.0
Chaloem Phrakiat	0	0	0	21.4	78.6
Chok Chai	0	0	0	53.6	46.4
Chum Phuang	0	14.4	15.0	62.2	8.4
Dan Khun Thot	0	0	6.6	35.2	58.3
Huai Thalaeng	0	14.5	43.5	26.9	15.1
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	0	15.4	84.6
Khom Thale So	0	0	0	100	0
Khon Buri	30.6	52.4	15.1	1.9	0
Khong	0	0	0	25.5	74.5
Lam Thamen Chai	0	50.9	49.1	0	0
Mueang Nakhon Ratchasima	0	0	7.9	92.1	0
Mueang Yang	0	74.8	25.2	0	0
Non Daeng	0	0	40.8	59.2	0
Non Sung	0	0	14.2	71.3	14.5
Non Thai	5.0	47.7	47.4	0	0
Nong Bunnak	0	0	0	15.0	85.0
Pak Chong	15.0	61.0	6.2	17.8	0
Pak Thong Chai	0	68.0	32.0	0	0
Phimai	0	26.9	32.2	28.3	12.6
Phra Thong Kham	0	18.4	35.6	0	46.0
Prathai	0	68.2	31.9	0	0
Sida	0	56.2	43.8	0	0
Sikhio	0	34.1	55.6	10.3	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	30.9	23.1	45.9
Tepharak	0	0	18.1	13.7	68.2
Wang Nam Khiao	68.0	32.1	0	0	0

5.4.3 Meteorological drought hazard intensity assessment of SPI-6m10 period

Distribution of meteorological drought hazard intensity classification of SPI-6m10 period at sub-district/district level is displayed in Figure 5.21. The result at district level indicates that very low and low intensity of drought hazard apparently occurs in 7 districts include Sida, Nong Bunnak, Prathai, Bua Yai, Mueang Yang, Soeng Sang, and Tepharak. On contrary, high and very high intensity of drought hazard are obviously found in 12 districts include Chaloem Phrakiat, Khom Thale So, Mueang Nakhon Ratchasima, Non Thai, Pak Thong Chai, Phra Thong Kham, Sung Noen, Non Sung, Huai Thalaeng, Khong, Dan Khun Thot, and Khon Buri. Meanwhile, moderate intensity of drought hazard noticeably occurs in 13 districts include Ban Lueam, Sikhio, Chok Chai, Kham Sakae Saeng, Chum Phuang, Chakkarat, Kaeng Sanam Nang, Non Daeng, Phimai, Wang Nam Khiao, Bua Lai, Lam Thamen Chai, and Pak Chong. Details of meteorological drought hazard intensity classification of SPI-6m10 period at district level is summarized in Table 5.13.

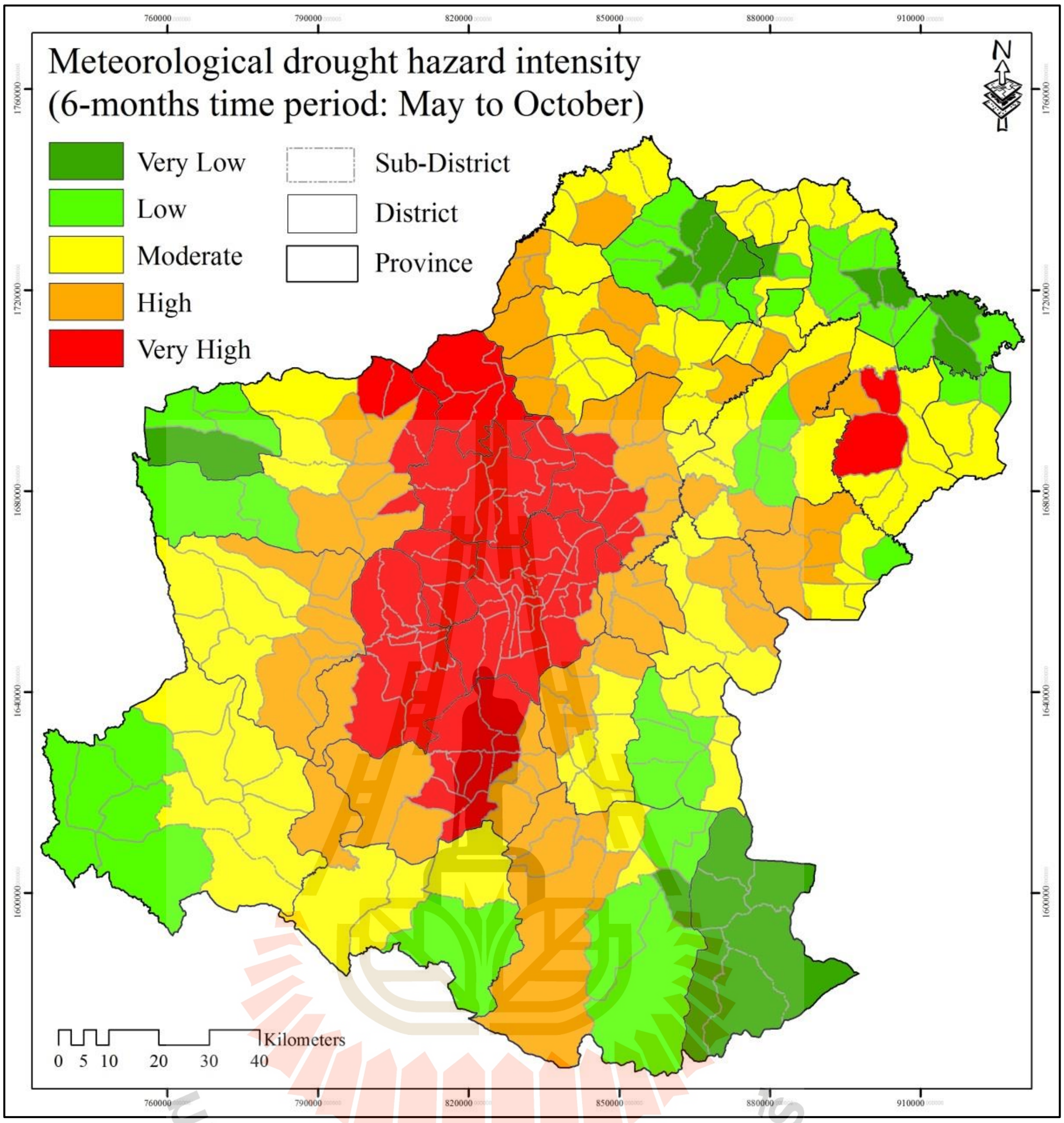


Figure 5.21 Distribution of meteorological drought hazard intensity classification of SPI-6m10 period (May, June, July, August, September and October).

Table 5.13 The percentage of meteorological drought hazard intensity classification of SPI-6m10 period (May to October) at district level.

Districts	Meteorological drought hazard intensity (% of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	0	0	50.7	49.3	0
Bua Lai	0	0	100	0	0
Bua Yai	39.6	60.4	0	0	0
Chakkarat	0	0	62.3	37.7	0
Chaloem Phrakiat	0	0	0	89.2	10.8
Chok Chai	0	0	54.3	45.7	0
Chum Phuang	0	0	58.7	9.5	31.9
Dan Khun Thot	0	27.4	23.5	33.5	15.7
Huai Thalaeng	0	10.3	32.3	57.5	0
Kaeng Sanam Nang	0	0	68.4	31.6	0
Kham Sakae Saeng	0	0	57.6	42.4	0
Khom Thale So	0	0	0	0	100
Khon Buri	2.9	44.2	5.5	47.4	0
Khong	0	0	48.6	51.4	0
Lam Thamen Chai	0	34.7	65.3	0	0
Mueang Nakhon Ratchasima	0	0	0	4.6	95.4
Mueang Yang	49.7	50.3	0	0	0
Non Daeng	0	21.2	51.5	27.4	0
Non Sung	0	0	6.2	54.9	38.9
Non Thai	0	0	0	0	100
Nong Bunnak	0	60.5	39.5	0	0
Pak Chong	0	46.6	53.4	0	0
Pak Thong Chai	0	0	0	56.5	43.5
Phimai	0	23.0	52.4	24.6	0
Phra Thong Kham	0	0	0	0	100
Prathai	14.2	55.2	30.6	0	0
Sida	17.3	39.6	43.1	0	0
Sikhio	0	0	51.6	48.4	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	0	15.0	85.0
Tepharak	48.4	51.6	0	0	0
Wang Nam Khiao	0	31.0	54.5	14.5	0

In summary, percentage of meteorological drought hazard intensity classification of 3 SPI periods at provincial level is compared in Table 5.14. Intensity is considerate the degree of the precipitation deficiency and the severity of impact in duration of event that measured by using the variation from normal condition. According to meteorological drought hazard intensity classification at provincial level, the most dominant class of all 3 periods (SPI-3m7, SPI-3m10, and SPI-6m10) at provincial level is high and very high drought hazard intensity and covers area of 40.50%, 44.00%, and 42.6% of areas, respectively. Meanwhile very low and low drought hazard intensity of 3 periods covers area of 42.00%, 38.00%, and 27.90% and moderate drought hazard intensity of 3 periods covers area of 17.50%, 18.00%, and 29.50% of the study area, respectively. Thus, the short time period of 3m10 (August, September and October) drought hazard becomes more intensity than 3m7 and 6m10 periods. In other words, the end of growing season (3m10) is affected by drought hazard intensity at extreme severity level and the early warning of severity of drought should be recommended in this period.

Table 5.14 Percentage of meteorological drought hazard intensity classification of each SPI period by each class in Nakhon Ratchasima Province.

SPI period	Meteorological drought hazard intensity (% of area)				
	Very low	Low	Moderate	High	Very high
SPI-3M7	13.6	28.4	17.5	32.6	7.9
SPI-3M10	12.5	25.5	18	21.9	22.1
SPI-6M10	7.7	20.2	29.5	25.1	17.5

At district level, there are 5 districts including Chaloem Phrakiat, Dan Khun Thot, Khom Thale So, Mueang Nakhon Ratchasima and Phra Thong Kham incur in high and very high of drought hazard intensity class occurrence in every period. Herewith, high to very high drought hazard intensity is obviously found in western, northwestern, and central districts. Thus, these areas are affected from drought hazard intensity of all short term (3m7 and 3m10) and long term (6m10) periods.

In conclusion, the high and very high intensity of meteorological drought hazard occurrence at short time period illustrates that 3m10 time period is dominant and occurs in western, northwestern, and eastern part of province as inter-rainy season. Meanwhile, long time period of 6m10 is dominant and occurs in western and central part of province as rainy season.

5.5 Drought exposure hazard assessment

Drought exposure hazard for agricultural drought vulnerability is assessed by combination of meteorological drought hazard frequency and intensity of 3 SPI periods. Drought exposure hazard is here divided into 5 scales: very low, low, moderate, high and very high using natural break method. The very low drought exposure hazard is resulting lower vulnerability while very high drought exposure hazard is resulting higher vulnerability. In addition, each time periods of drought exposure hazard illustrates the different characteristics of rainfall deficit, frequency of drought and severity of drought in the study area. The results of drought exposure hazard assessment of 3 SPI periods are separately described and discussed in the following section.

5.5.1 Drought exposure hazard classification of SPI-3m7 period

Distribution of drought exposure hazard classification of SPI-3m7 period at sub-district and district levels is presented in Figure 5.22. The result at district level indicates that combination of very low and low drought exposure hazard apparently occurs in 8 districts include Bua Lai, Phimai, Huai Thalaeng, Bua Yai, Lam Thamen Chai, Mueang Yang, Non Daeng, and Sida. On contrary, combination of high and very high drought exposure hazard is obviously found in 15 districts include Khom Thale So, Dan Khun Thot, Kham Sakae Saeng, Mueang Nakhon Ratchasima, Nong Bunnak, Phra Thong Kham, Tepharak, Sikhio, Kaeng Sanam Nang, Sung Noen, Chok Chai, Non Thai, Ban Lueam, Chakkarat, and Chaloem Phrakiat. Meanwhile, moderate drought exposure hazard noticeably occurs in 9 districts include Soeng Sang, Wang Nam Khiao, Khong, Prathai, Chum Phuang, Non Sung, Pak Thong Chai, Khon Buri, and Pak Chong. Details of drought exposure hazard classification of SPI-3m7 period at district level is summarized in Table 5.15.

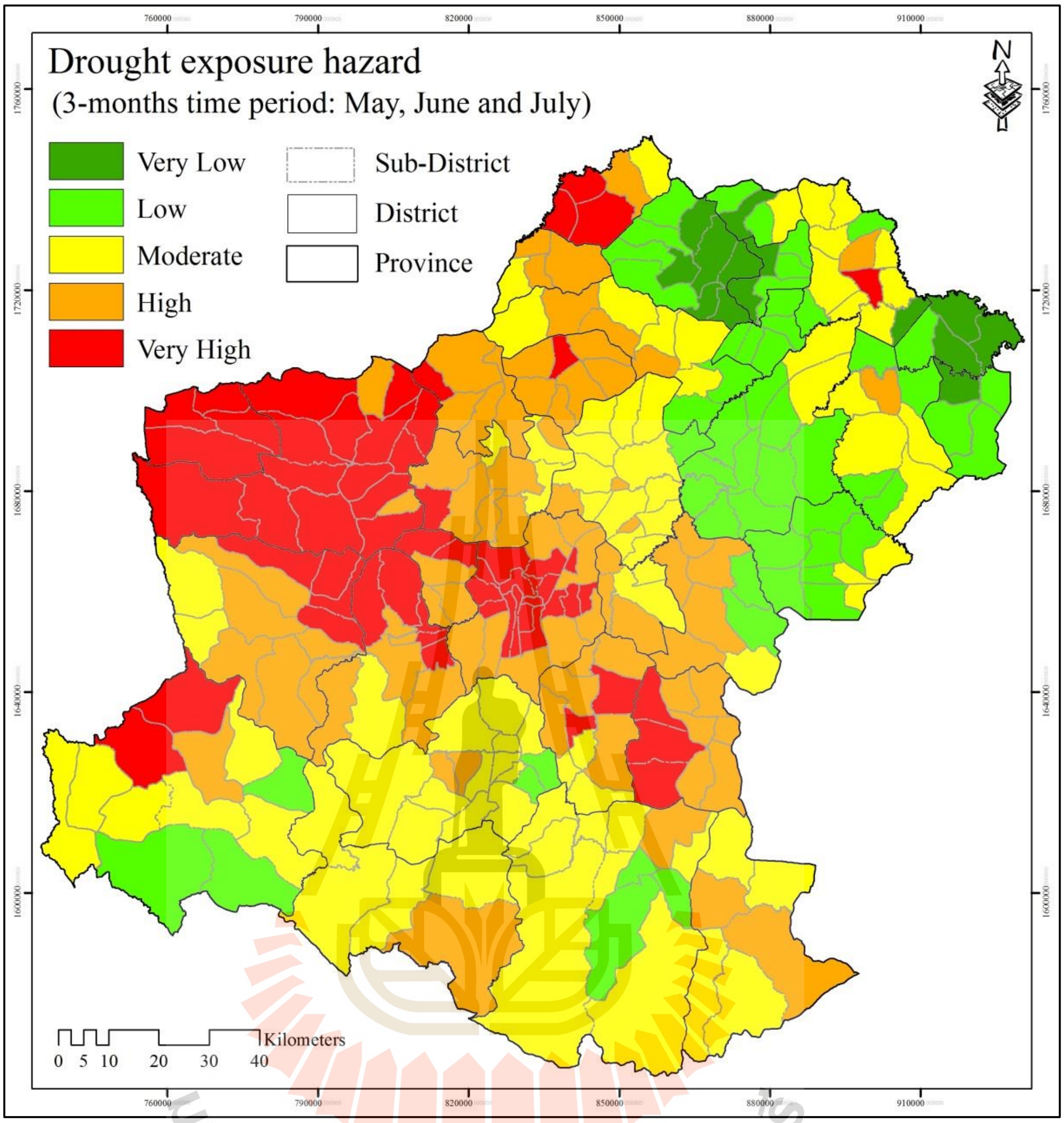


Figure 5.22 Distribution of drought exposure hazard classification of SPI-3m7 (May, June and July).

Table 5.15 Percentage of drought exposure hazard classification of SPI-3m7 period (May, June and July) at district level.

District	Drought exposure hazard (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	22.4	77.6	0
Bua Lai	25.0	44.7	30.3	0	0
Bua Yai	51.8	48.3	0	0	0
Chakkarat	0	24.6	13.0	62.4	0
Chaloem Phrakiat	0	0	45.2	54.8	0
Chok Chai	0	0	20.8	61.6	17.6
Chum Phuang	0	33.6	58.0	8.4	0
Dan Khun Thot	0	0	0	5.9	94.1
Huai Thalaeng	0	81.4	18.6	0	0
Kaeng Sanam Nang	0	0	19.7	20.8	59.5
Kham Sakae Saeng	0	0	0	91.2	8.8
Khom Thale So	0	0	0	61.7	38.4
Khon Buri	0	15.4	78.9	5.7	0
Khong	0	19.1	55.0	26.0	0
Lam Thamen Chai	18.4	81.6	0	0	0
Mueang Nakhon Ratchasima	0	0	0	56.9	43.1
Mueang Yang	74.8	25.2	0	0	0
Non Daeng	0	100	0	0	0
Non Sung	0	6.2	86.4	7.4	0
Non Thai	0	0	21.5	70.2	8.3
Nong Bunnak	0	0	0	56.2	43.8
Pak Chong	0	31.2	44.1	7.0	17.8
Pak Thong Chai	0	6.1	87.6	6.3	0
Phimai	0	79.2	20.8	0	0
Phra Thong Kham	0	0	0	90.5	9.5
Prathai	6.6	12.9	66.1	8.0	6.4
Sida	39.6	60.4	0	0	0
Sikhio	0	0	18.0	59.3	22.6
Soeng Sang	0	0	60.4	39.6	0
Sung Noen	0	0	20.7	46.7	32.6
Tepharak	0	0	0	0	100
Wang Nam Khiao	0	0	69.0	31.0	0

5.5.2 Drought exposure hazard classification of SPI-3m10 period

Distribution of drought exposure hazard classification of SPI-3m10 period at sub-district and district levels is presented in Figure 5.23. The result at district level indicates that combination of very low and low drought exposure hazard apparently occurs in 7 districts including Huai Thalaeng, Pak Chong, Non Daeng, Soeng Sang, Wang Nam Khiao, Sikhio, and Prathai. On contrary, combination of high and very high drought exposure hazard is obviously found in 16 districts including Kham Sakae Saeng, Ban Lueam, Kaeng Sanam Nang, Chaloem Phrakiat, Chakkarat, Sung Noen, Khom Thale So, Phra Thong Kham, Dan Khun Thot, Mueang Nakhon Ratchasima, Bua Yai, Khong, Chum Phuang, Tepharak, Chok Chai, and Lam Thamen Chai. Meanwhile, moderate drought exposure hazard noticeably occurs in 9 districts including Pak Thong Chai, Nong Bunnak, Non Sung, Bua Lai, Phimai, Sida, Khon Buri, Mueang Yang, and Non Thai. Details of drought exposure hazard classification of SPI-3m10 period at district level is summarized in Table 5.16.

In addition, very high drought exposure hazard zones at district level can be observed in the western and northwestern part, moderate to high of drought exposure hazard scatters in all part while very low to low drought exposure hazard zones situate in the southern and northern part.

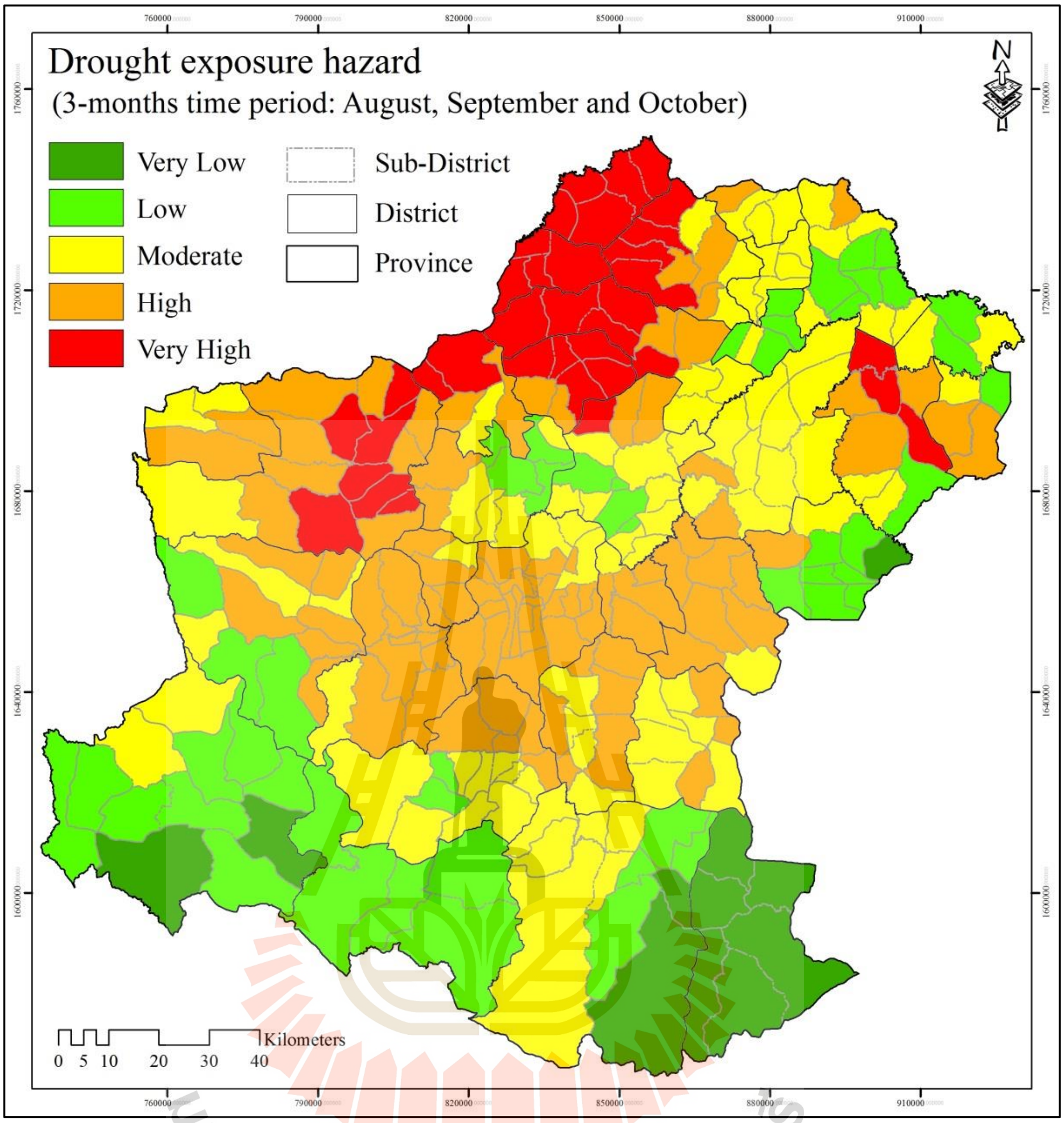


Figure 5.23 Distribution of drought exposure hazard classification of SPI-3m10 (August, September and October).

Table 5.16 Percentage of drought exposure hazard classification of SPI-3m10 period (August, September and October) at district level.

District	Drought exposure hazard (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	0	100
Bua Lai	0	0	76.6	23.5	0
Bua Yai	0	0	24.2	27.5	48.2
Chakkarat	0	0	13.0	87.0	0
Chaloem Phrakiat	0	0	10.8	89.2	0
Chok Chai	0	0	34.6	65.4	0
Chum Phuang	0	15.0	14.4	43.1	27.6
Dan Khun Thot	0	0	18.6	48.2	33.3
Huai Thalaeng	10.3	59.2	15.5	15.1	0
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	0	25.1	75.0
Khom Thale So	0	0	15.8	84.2	0
Khon Buri	27.9	20.9	51.2	0	0
Khong	0	0	25.5	20.2	54.3
Lam Thamen Chai	0	16.3	18.4	65.3	0
Mueang Nakhon Ratchasima	0	0	19.3	80.7	0
Mueang Yang	0	49.7	50.3	0	0
Non Daeng	0	84.7	15.3	0	0
Non Sung	0	19.8	54.4	19.3	6.5
Non Thai	0	34.4	38.6	27.0	0
Nong Bunnak	0	0	73.2	26.8	0
Pak Chong	24.4	57.8	17.8	0	0
Pak Thong Chai	0	7.6	62.4	29.9	0
Phimai	0	0	88.7	11.4	0
Phra Thong Kham	0	0	18.4	35.6	46.0
Prathai	0	47.1	45.6	7.3	0
Sida	0	0	100	0	0
Sikhio	0	40.1	20.1	39.8	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	15.0	85.0	0
Tepharak	0	0	31.8	68.2	0
Wang Nam Khiao	0	100	0	0	0

5.5.3 Drought exposure hazard classification of SPI-6m10 period

Distribution of drought exposure hazard classification of SPI-6m10 period at sub-district and district levels is presented in Figure 5.24. The result at district level indicates that combination of very low and low drought exposure hazard obviously occurs in 10 districts including Bua Lai, Bua Yai, Khon Buri, Lam Thamen Chai, Nong Bunnak, Prathai, Sida, Soeng Sang, Tepharak, and Wang Nam Khiao. On contrary, combination of high and very high drought exposure hazard is noticeably found in 17 districts including Ban Lueam, Chakkarat, Chaloem Phrakiat, Chok Chai, Dan Khun Thot, Huai Thalaeng, Kaeng Sanam Nang, Khom Thale So, Khong, Mueang Nakhon Ratchasima, Non Sung, Non Thai, Pak Thong Chai, Phimai, Phra Thong Kham, Sikhio, and Sung Noen. Meanwhile, moderate drought exposure hazard noticeably occurs in 5 districts include Chum Phuang, Kham Sakae Saeng, Mueang Yang, Non Daeng, and Pak Chong. Details of drought exposure hazard classification of SPI-6m10 period at district level is summarized in Table 5.17.

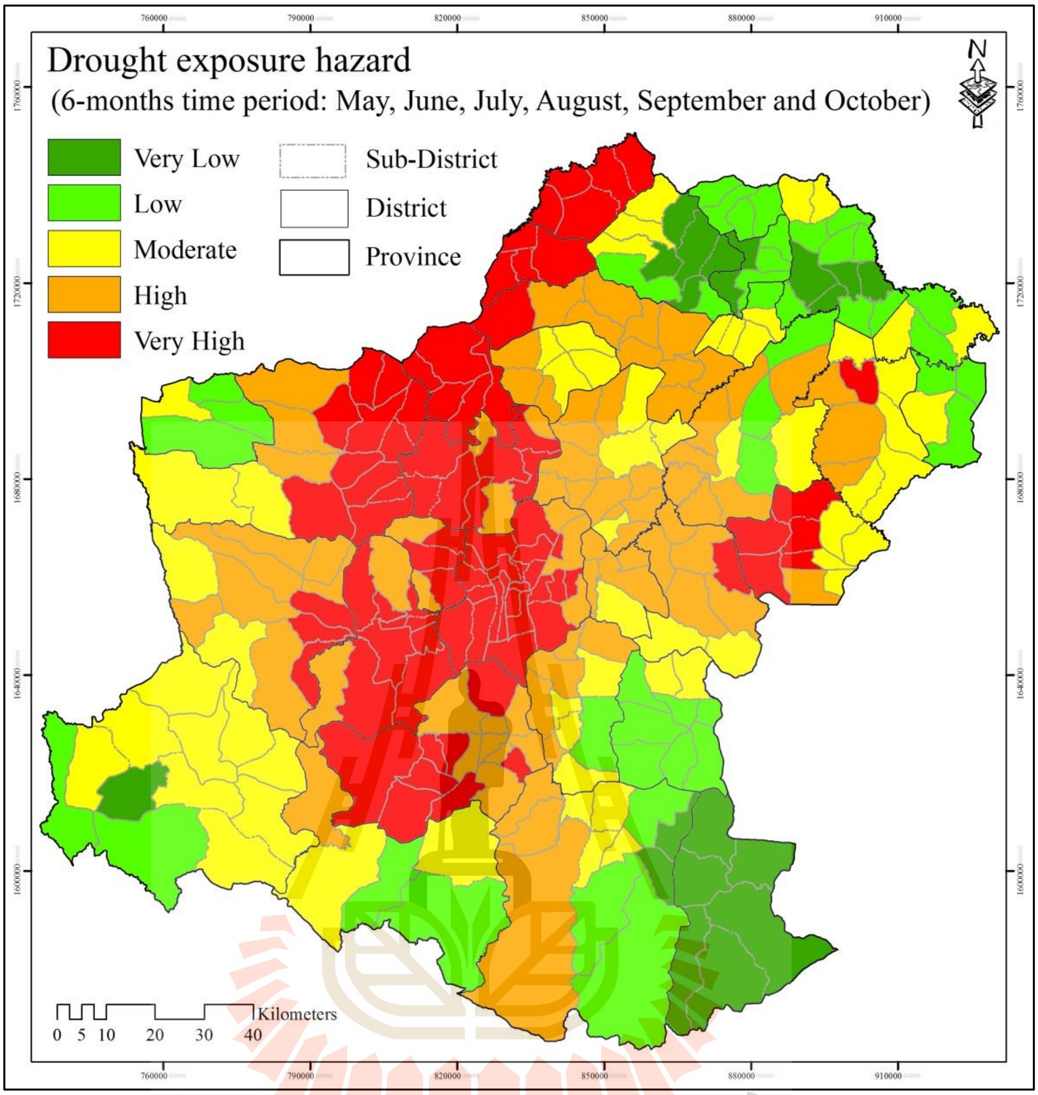


Figure 5.24 Distribution of drought exposure hazard classification of SPI-6m10 (May, June, July, August, September and October) time periods

Table 5.17 Percentage of drought exposure hazard classification of SPI-6m10 period (May to October) at district level.

District	Drought exposure hazard (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	0	100
Bua Lai	0	100	0	0	0
Bua Yai	45.2	24.3	30.5	0	0
Chakkarat	0	0	27.9	62.6	9.5
Chaloem Phrakiat	0	0	33.4	66.6	0
Chok Chai	0	20.8	34.5	44.7	0
Chum Phuang	0	0	51.9	39.7	8.4
Dan Khun Thot	0	0	27.4	23.5	49.2
Huai Thalaeng	0	0	30.5	12.0	57.5
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	57.6	42.4	0
Khom Thale So	0	0	0	35.6	64.4
Khon Buri	5.6	41.5	10	43.0	0
Khong	0	0	0	84.0	16.0
Lam Thamen Chai	0	69.3	30.7	0	0
Mueang Nakhon Ratchasima	0	0	0	16.0	84.0
Mueang Yang	0	49.7	50.3	0	0
Non Daeng	0	21.2	78.8	0	0
Non Sung	0	0	34.3	65.8	0
Non Thai	0	0	0	20.5	79.5
Nong Bunnak	0	80.1	19.9	0	0
Pak Chong	6.2	24.5	69.3	0	0
Pak Thong Chai	0	0	0	35.1	64.9
Phimai	0	27.2	22.1	50.7	0
Phra Thong Kham	0	0	0	0	100
Prathai	33.4	49.0	17.6	0	0
Sida	39.6	60.5	0	0	0
Sikhio	0	0	23.3	62.3	14.4
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	0	28.1	71.9
Tepharak	0	81.9	18.1	0	0
Wang Nam Khiao	0	43.5	42.0	14.5	0

Summary

The application of different time scale of SPI can apply to each drought types. Particularly, short-time scale of SPI (weeks and months) is suitable for meteorological or agricultural drought (Guttman., 1999; Quiring and Ganesh., 2010). Stagge et al. (2015) recommended that SPI is predominant meteorological drought indices used in Europe. Moreover, Xiaoqian et al. (2013) stated that SPI was a simple indicator of exposure to drought at different time scales with spatial homogeneity. In the same way, Sehgal and Dhakar (2016) studied drought exposure in term of frequency and intensity of SPI over the 56 years period. Similarly, Shahid and Behrawan (2008) investigated the spatial extend, temporal extend and severity of drought hazard by used SPI for 3 and 6 month time periods that indicated drought in short and medium time scale. While, Murthy et al. (2014, 2015a) used four parameters: (1) total season rainfall, (2) total season rainy days, (3) sowing period rainfall and (4) sowing period rainy periods to represent drought exposure. Meanwhile, Murthy et al. (2015b) used two parameters: (1) total season rainfall and (2) total season rainy days, representing the exposure component. Pei et al. (2016) stated that the mainly factor of exposure is significant related to degree of drought. It consisted of annual precipitation and forest coverage. Besides, Li et al. (2015) used the relative moisture index (RMI) as meteorological drought in order to identify exposure to drought. Kim et al. (2015) used the effective drought index (EDI) for calculated drought hazard.

According to drought exposure hazard classification, the most dominant class of all 3 periods (SPI-3m7, SPI-3m10, and SPI-6m10) at province level is high and very high drought exposure hazard and covers area of 43.60%, 39.20%, and 49.50%, respectively. Meanwhile very low and low drought exposure hazard of 3 periods covers area of 20.40%, 31.00%, and 26.40% and moderate drought exposure hazard of 3 periods covers area of 36.00%, 29.80%, and 24.00%, respectively (Figure 5.25). Thus, at provincial level, it can be concluded that drought exposure hazard mostly occurs at high and very high level of all 3 time periods: 3m7, 3m10, and 6m10.

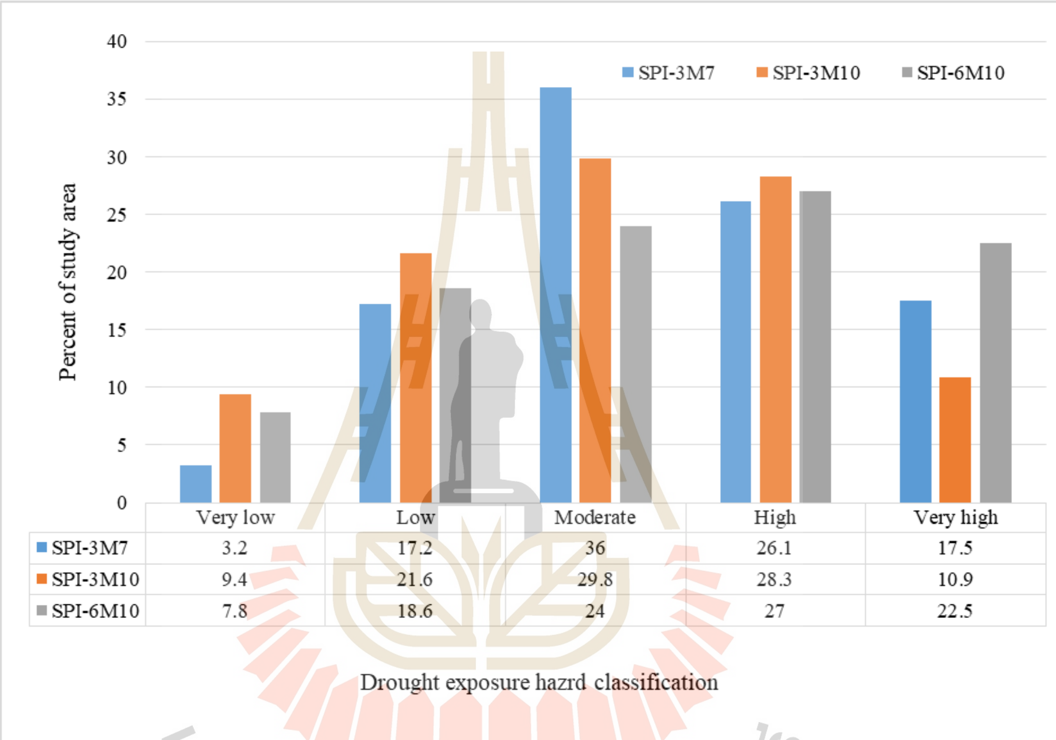


Figure 5.25 Percentage of drought exposure hazard classification of 3 periods.

The distribution pattern of high and very high drought exposure hazard classes of 3 periods are similar. However, percentage of high and very high drought exposure hazard of SPI-6m10 period is slightly higher than other periods. There are 9 districts including Chakkarat, Chaloem Phrakiat, Chok Chai, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Mueang Nakhon Ratchasima, Phra Thong Kham, and Sung Noen incur high and very high drought exposure hazard in every period.

On contrary, distribution pattern of very low and low drought exposure hazard of 3 periods are dissimilar. None of districts always incurs very low and low drought exposure hazard in all 3 periods. The pattern of very low and low drought exposure hazard of 3 periods randomly distribute in 16 districts including Bua Lai, Bua Yai, Huai Thalaeng, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, Nong Bunnak, Pak Chong, Phimai, Prathai, Sida, Sikhio, Soeng Sang, Tepharak and Wang Nam Khiao.

Likewise, distribution pattern of moderate drought exposure hazard of 3 periods is also dissimilar. None of districts always incur moderate drought exposure hazard for all 3 periods. The pattern of moderate drought exposure hazard class of 3 periods randomly occurs in 16 districts including Bua Lai, Chum Phuang, Kham Sakae Saeng, Khon Buri, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Pak Chong, Pak Thong Chai, Prathai, Sida, Soeng Sang and Wang Nam Khiao.

Drought exposure hazard classification is here derived from the combination between meteorological drought hazard frequency and intensity. It shows that drought exposure hazard classification relates to meteorological drought hazard frequency of 6m10 period as rainy season that the most extreme drought occurrence in area while 3m7 period is the most extreme drought occurrence in area as inter-rainy season (start of rainy season). Moreover, 6m10 period is mostly occurrence in all time period and characteristics of drought that consist of spatial, frequency and intensity indicates the affected rainy season drought. For inter-rainy season of drought exposure hazard assessment, 3m7 period (May, June and July) is suitable for detect meteorological drought while 6m10 period (May to October) is suitable for agricultural drought in rainy season.

5.6 Validation of drought exposure hazard assessment

In this study, the derived economic crop yield (paddy field, cassava, and maize) variation based on coefficient variation (CV) from high and very high levels were used to validate drought exposure hazard classification using coincident matrix. Distribution of economic crop yield variation of CV classification during 2011 and 2015 is displayed in Figure 5.26 while results of validation of drought exposure hazard assessment of 3 periods (SPI-3m7, SPI-3m10 and SPI-6m10) are reported in Tables 5.18 to 5.20, respectively.

Table 5.18 Comparison between drought exposure hazard classification of SPI-3m7 period and economic crop yield variation of CV classification.

Economic crop yield variation	**Drought exposure hazard (% of area)**				
	VL	**L**	**M**	**H**	**VH**
(high and very high)	7.34	11.03	19.53	30.73	31.37

Table 5.19 Comparison between drought exposure hazard classification of SPI-3m10 period and economic crop yield variation of CV classification.

Economic crop yield variation	**Drought exposure hazard (% of area)**				
	VL	**L**	**M**	**H**	**VH**
(high and very high)	0.00	9.10	25.36	29.48	36.06

Table 5.20 Comparison between drought exposure hazard classification of SPI-6m10 period and economic crop yield variation of CV classification.

Economic crop yield variation (high and very high)	Drought exposure hazard (% of area)				
	VL	L	M	H	VH
	8.72	11.64	17.60	24.12	37.92

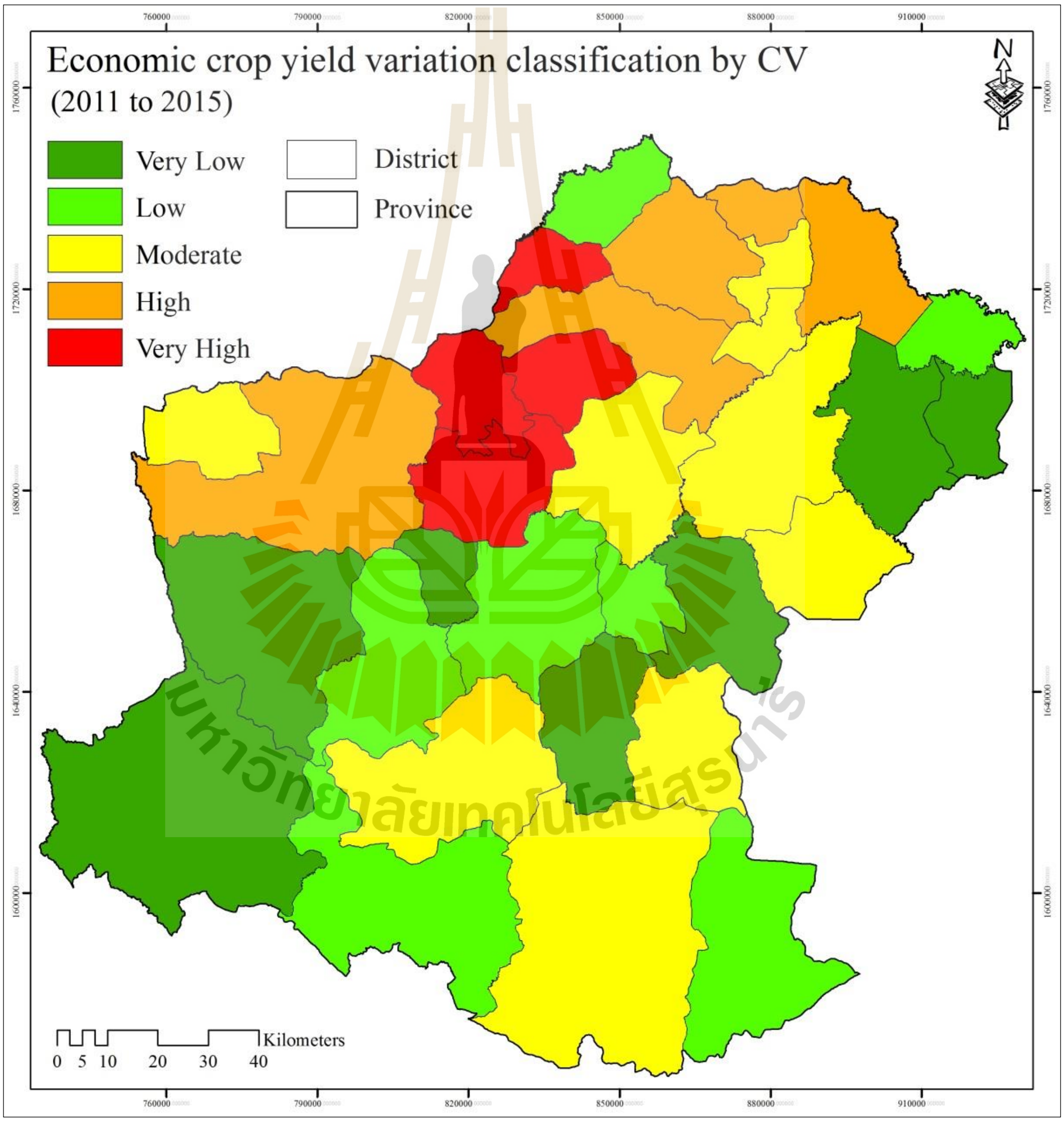


Figure 5.26 Distribution of economic crop yield variation of CV classification during 2011 and 2015.

As results, it can be observed that high economic crop yield variation is found in Bua Lai, Bua Yai, Dan Khun Thot, Kong, and Prathai district while very high economic crop yield variation situates in Ban Lueam, Kham Sakae Saeng, Non Thai, and Phra Thong Kham districts.

For validation, it was found that high and very high drought exposure hazard classes of 3 periods (SPI-3m7, SPI-3m10 and SPI-6m10) are consistent with high and very high economic crop yield variations which represent area of drought effect on crop yield about 62.10%, 65.54% and 62.04%, respectively. These percentages are greater than additional percentage from very low, low, and moderate drought exposure hazard classes. Thus, the classifications of drought exposure hazard of 3 periods are acceptable.

CHAPTER VI

AGRICULTURAL DROUGHT SENSITIVITY ASSESSMENT

This chapter presents results of the first objectives focusing on agricultural drought sensitivity assessment as component of agricultural drought vulnerability analysis. A main result consists of (1) overall agricultural drought sensitivity assessment and its validation and (2) annual agricultural drought sensitivity assessment and its validation (See Figures 3.5 and 3.7). Both overall and annual drought sensitivity assessment used four common input data. However, all factors are determined as average time scale and applies to construct overall agricultural drought sensitivity index as describing in detail in Chapter IV while all factors from specific year are applied as independent variables and they are linear regressed with overall agricultural drought sensitivity index to identify significant factors on agricultural drought sensitivity using CART of CUBIST software.

6.1 Overall agricultural drought sensitivity assessment

Under this component, rating of individual factors is assigned based literature reviews while weighting of all factors will analyzed according to knowledge and experience from experts using questionnaire. Because of factors of agricultural drought sensitivity have different unit and range of data, therefore there are crucial standardized. Thus, weight and rating of factors are normalized into the same standard before SAW operation. After that the derived agricultural drought sensitivity index is reclassified into 5 classes (VL, L, M, H and VH) using natural break method.

Table 6.1 summarizes normalized rating value of influential factors on agricultural drought sensitivity, while average weighting values of influential factors on agricultural drought sensitivity providing by experts were normalized using standardized rank value (Eq. 3.3) is presented in Table 6.2. Herewith, factor maps for agricultural drought sensitivity assessment is displayed again in Figure 6.1.

In addition, overall agricultural drought sensitivity index is generated using Eq. 6.1 with Map Algebra function under Spatial Analyst Tools of ESRI ArcMap. Herein, SPI and SPEI of 3 periods (3m7, 3m10, and 6m10) as dynamic factors are separately applied to generate 3 overall agricultural drought sensitivity indices and classification. In principle, 3 time scales (3m7, 3m10, and 6m10) plays an important role on agricultural drought sensitivity which directly relates vegetation phenology.

Table 6.1 Normalized rating value of influential factors for agricultural drought sensitivity classification.

Factors	Drought sensitivity level				
	VL	**L**	**M**	**H**	**VH**
Agricultural drought frequency	1	1.5	2	2.5	3
Agricultural drought intensity	1	1.5	2	2.5	3
SPI	1	1.5	2	2.5	3
SPEI	1	1.5	2	2.5	3
Land use	1	1.5	2	2.5	3
Soil drainages	1	1.5	2	2.5	3
Agricultural irrigation area	1	n. a	n. a	n. a	3
Slope	1	1.5	2	2.5	3
Elevation	1	1.5	2	2.5	3
Distance to river	1	1.5	2	2.5	3
Drainage density	1	n. a	2	n. a	3
Agricultural occupation	1	1.5	2	2.5	3
Economic crop production	1	1.5	2	2.5	3
Population density	1	1.5	2	2.5	3

Table 6.2 Average and normalized weighting of each factor by experts.

Factors	**Average weighting**	**Normalized weighting**
Agricultural drought frequency	4.20	0.904
Agricultural drought intensity	4.13	0.870
SPI	3.80	0.711
SPEI	4.40	1.000
LULC	3.53	0.581
Soil drainages	3.47	0.552
Agricultural irrigation area	3.60	0.615
Slope	3.33	0.485
Elevation	2.80	0.230
Distance to river	3.53	0.581
Drainage density	3.40	0.519
Agricultural occupation	3.20	0.422
Economic crop production	3.33	0.485
Population density	2.53	0.100

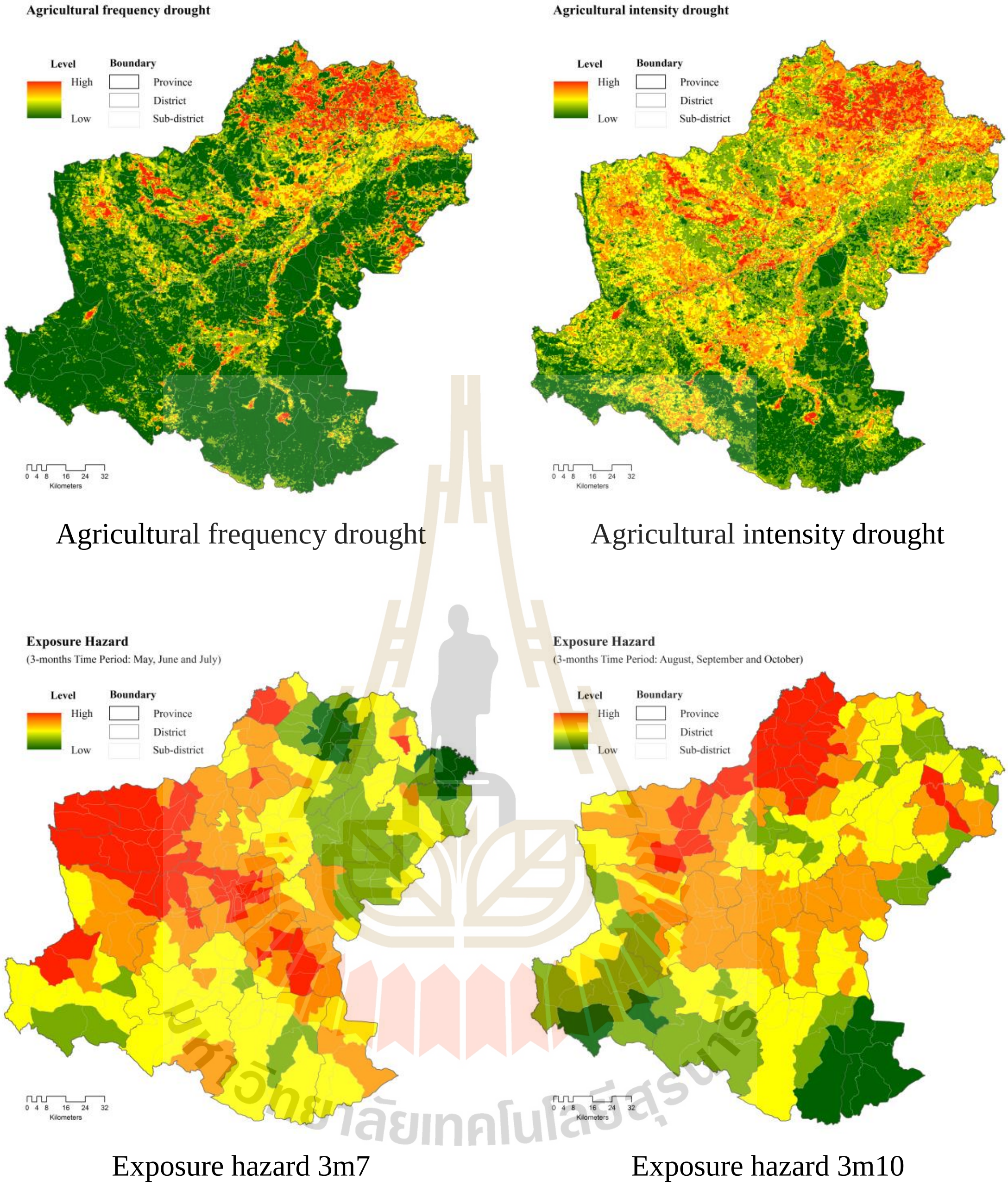


Figure 6.1 Factor maps for agricultural drought sensitivity assessment.

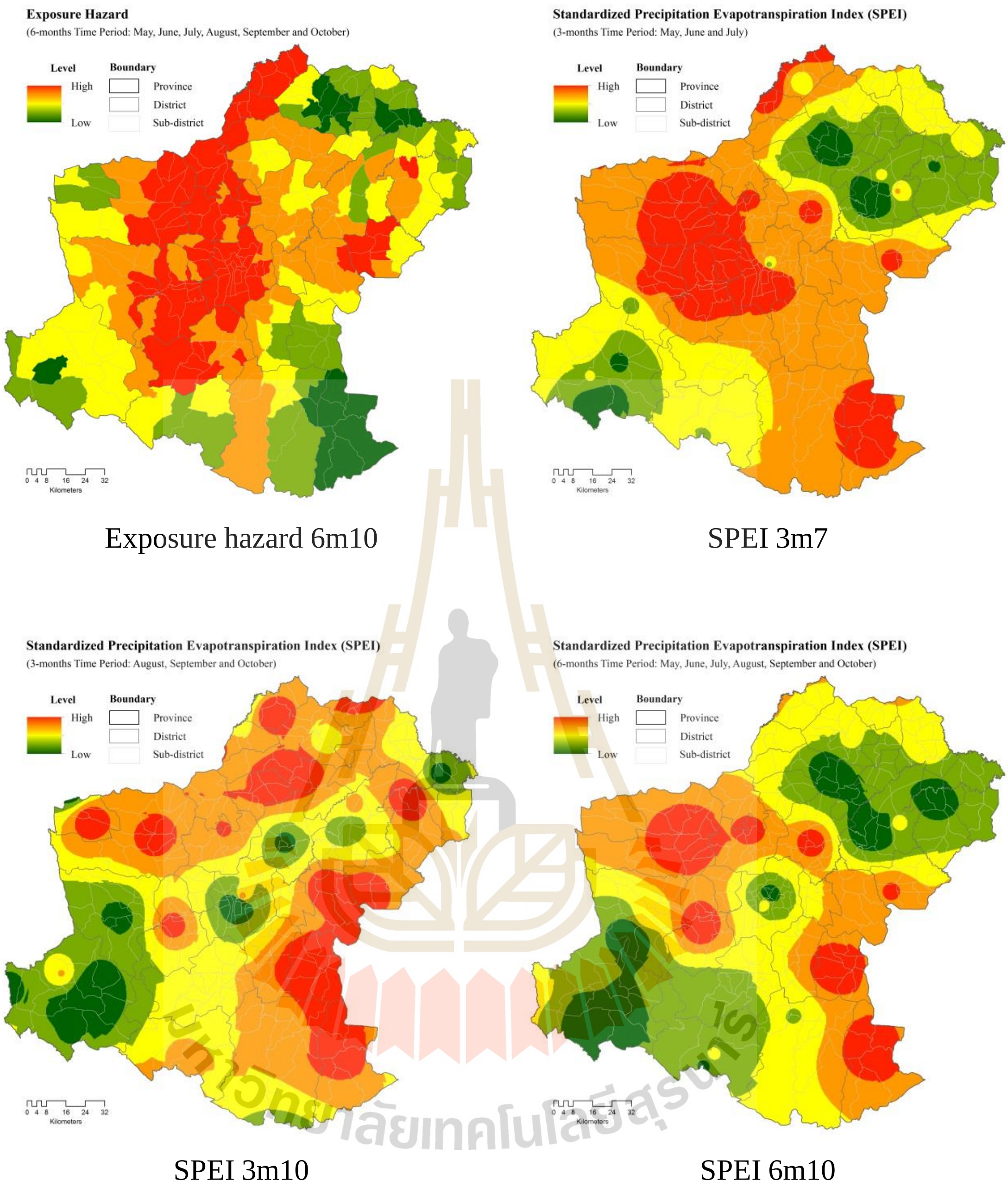
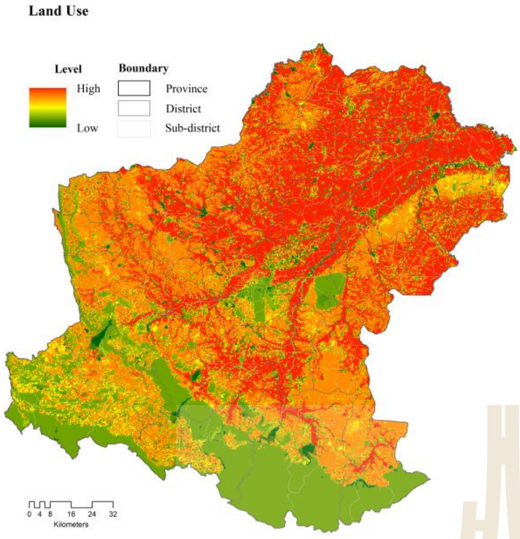
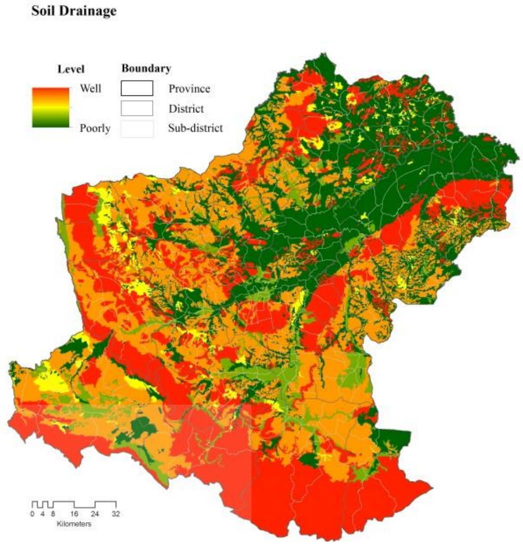


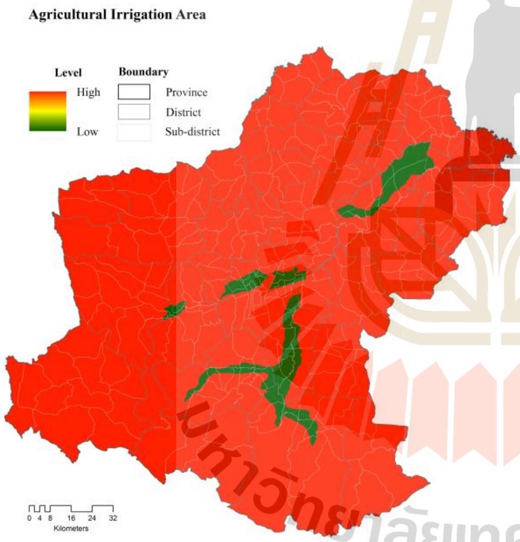
Figure 6.1 (Continued).



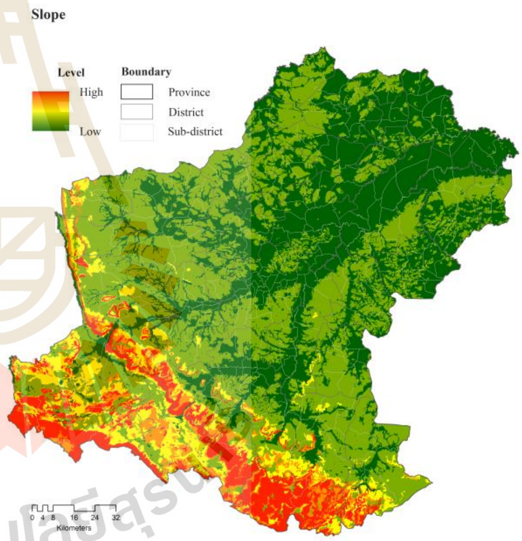
Land use



Soil drainage

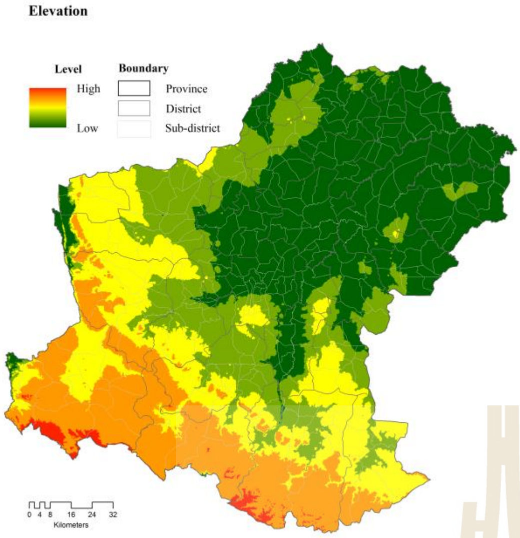


Agricultural irrigation area

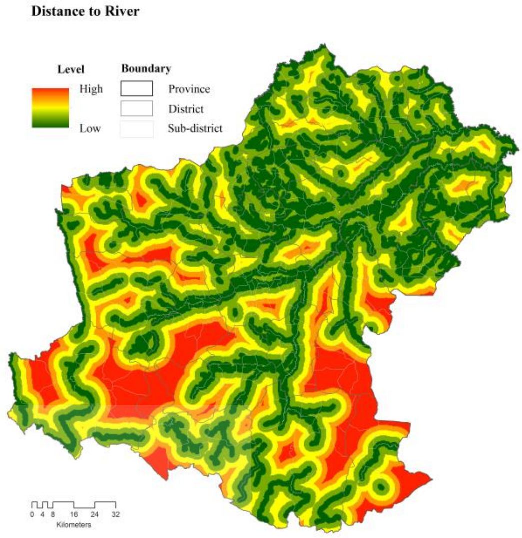


slope

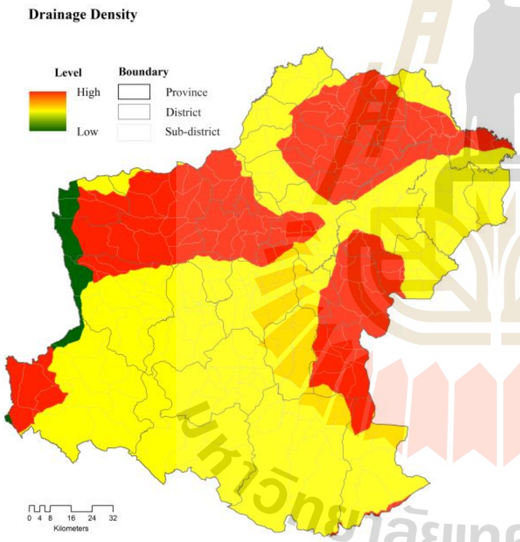
Figure 6.1 (Continued).



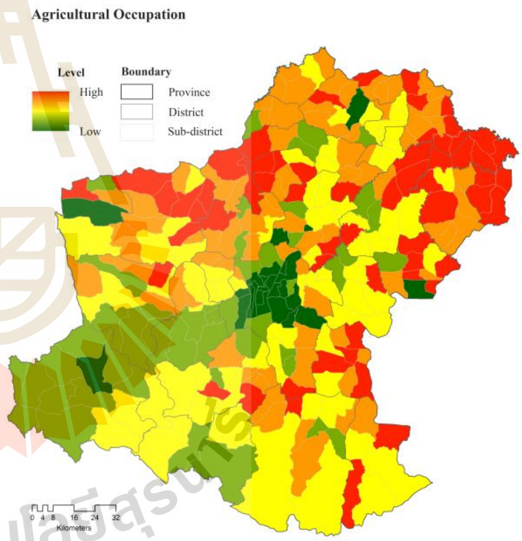
Elevation



Distance to river

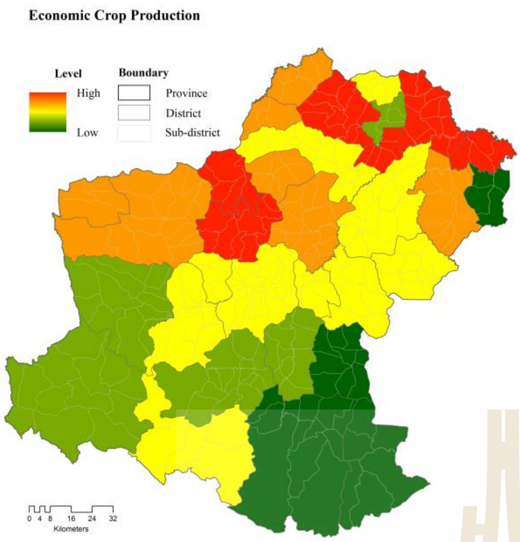


Drainage density

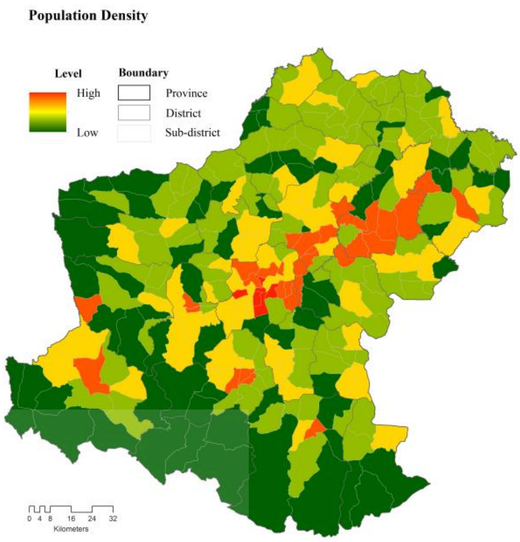


Agricultural occupation

Figure 6.1 (Continued).



Economic crop production



Population density

Figure 6.1 (Continued).

$$Y = 0.904*X1 + 0.870*X2 + 0.711*X3 + 1.000*X4 + 0.581*X5 + 0.552*X6 + 0.615*X7 + 0.485*X8 + 0.230*X9 + 0.581*X10 + 0.519*X11 + 0.422*X12 + 0.485*X13 + 0.100*X14 \quad (6.1)$$

where, Y is overall agricultural drought sensitivity (OADS),

X1 is agricultural drought frequency,

X2 is agricultural drought intensity,

X3 is SPI of 3m7, 3m10, and 6m10 periods,

X4 is average SPEI of 3m7, 3m10, and 6m10 periods,

X5 is land use,

X6 is soil drainage,

X7 is agricultural irrigation area,

X8 is slope,

X9 is elevation,

X10 is distance to river,

X11 is drainage density,

X12 is agricultural occupation,

X13 is economic crop production, and

X14 is population density.

Refer to Table 6.2, it can be observed that top three relative high important factors for overall agricultural drought sensitivity assessment from expert's opinion are SPEI (climate condition), agricultural drought frequency and intensity (vegetation condition). In contrast, top three relative low important factors are population density (socioeconomic condition), elevation (physical condition) and agricultural occupation (socioeconomic condition). Results of overall agricultural drought sensitivity assessment and its validation of 3 periods are separately described and discussed in the following section.

6.1.1 Overall agricultural drought sensitivity of 3m7 period

Distribution of overall agricultural drought sensitivity classification of 3m7 period (May, June, and July) is displayed in Figure 6.2. Meanwhile, percentage of overall agricultural drought sensitivity classification of 3m7 period at provincial and district levels are reported in Table 6.3 and Table 6.4, respectively. Comparison of overall agricultural drought sensitivity classification of 3m7 period at district level is displayed in Figure 6.3.

Table 6.3 Percentage of overall agricultural drought sensitivity classification of 3m7 period at provincial level.

Period (months)	Overall agricultural drought sensitivity (% of area)				
	Very low	Low	Moderate	High	Very high
3M7	10.10	26.45	30.20	23.30	9.96

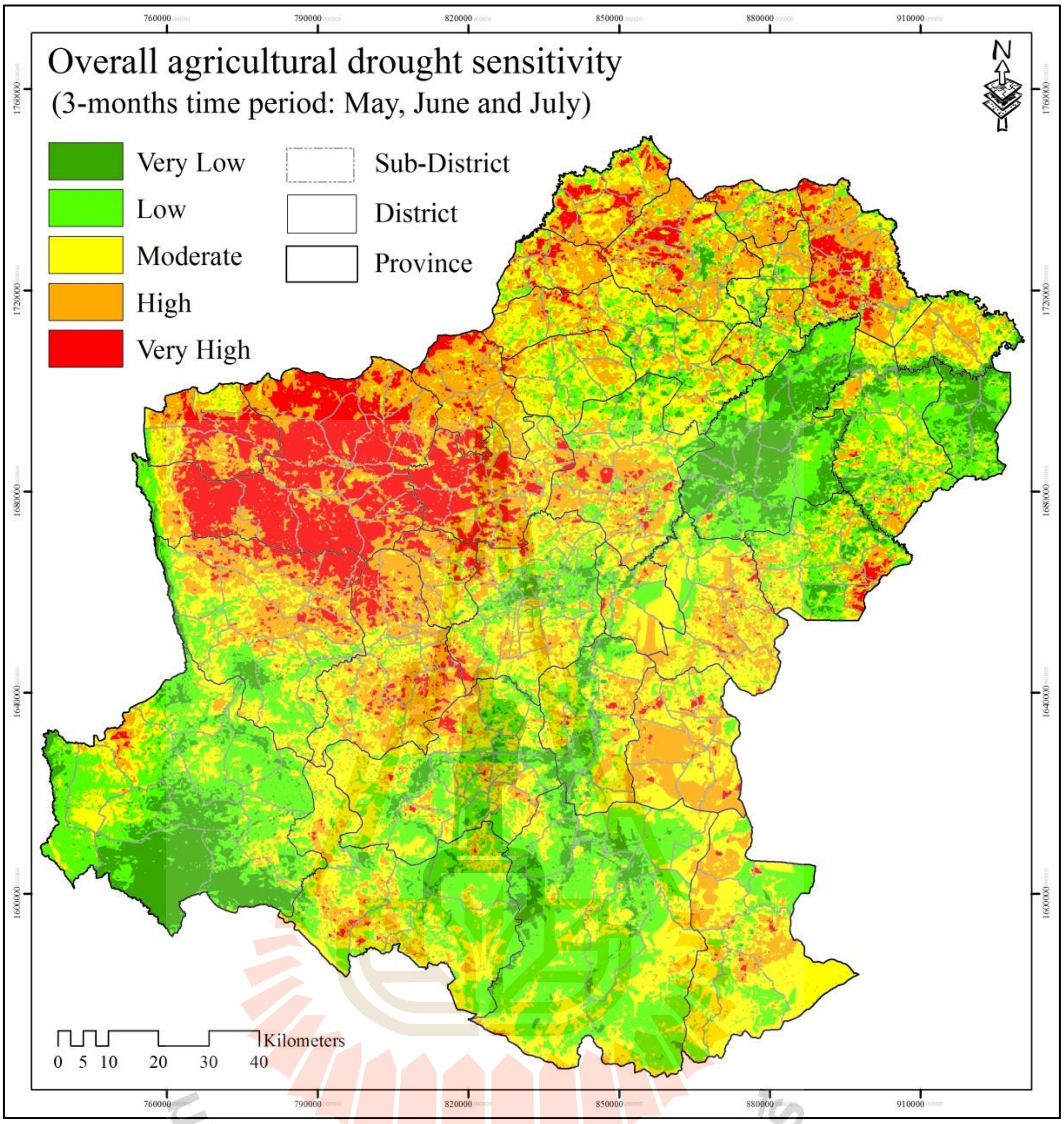


Figure 6.2 Distribution of overall agricultural drought sensitivity classification of 3m7 period.

Table 6.4 Percentage of overall agricultural drought sensitivity classification of 3m7 period at district level.

Districts	Overall agricultural drought sensitivity (% of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	0.10	8.62	32.30	47.24	11.73
Bua Lai	1.47	12.29	23.98	52.32	9.94
Bua Yai	3.48	8.31	26.99	48.62	12.60
Chakkarat	0.91	14.83	50.89	31.09	2.29
Chaloem Phrakiat	6.29	27.00	45.42	20.22	1.07
Chok Chai	16.95	26.40	39.90	15.71	1.05
Chum Phuang	15.69	39.33	31.25	13.08	0.65
Dan Khun Thot	0.39	2.25	4.61	29.11	63.64
Huai Thalaeng	12.54	34.27	30.45	18.51	4.23
Kaeng Sanam Nang	0.18	7.72	29.34	42.80	19.96
Kham Sakae Saeng	1.02	23.07	52.16	22.53	1.22
Khom Thale So	0.59	5.74	27.93	48.95	16.78
Khon Buri	9.75	57.80	30.20	2.21	0.04
Khong	5.60	21.47	45.72	25.14	2.08
Lam Thamen Chai	45.51	45.97	8.02	0.50	0.00
Mueang Nakhon Ratchasima	8.01	27.04	39.63	22.83	2.48
Mueang Yang	11.45	14.48	43.12	30.67	0.28
Non Daeng	5.66	25.37	31.93	34.58	2.46
Non Sung	5.24	21.82	35.15	33.21	4.58
Non Thai	0.01	3.10	16.66	37.75	42.48
Nong Bunnak	0.09	5.28	42.51	49.03	3.10
Pak Chong	32.06	45.73	18.83	3.08	0.30
Pak Thong Chai	8.94	36.53	40.92	12.19	1.42
Phimai	54.01	39.35	5.73	0.81	0.10
Phra Thong Kham	0.00	0.65	15.16	66.59	17.59
Prathai	1.57	8.10	21.31	47.71	21.31
Sida	8.78	20.09	39.47	31.55	0.11
Sikhio	4.24	21.94	31.71	30.75	11.36
Soeng Sang	0.35	23.99	56.00	18.76	0.90
Sung Noen	0.17	5.47	29.08	52.58	12.70
Tepharak	0.32	3.71	20.33	39.80	35.84
Wang Nam Khiao	3.67	42.30	41.31	11.76	0.96

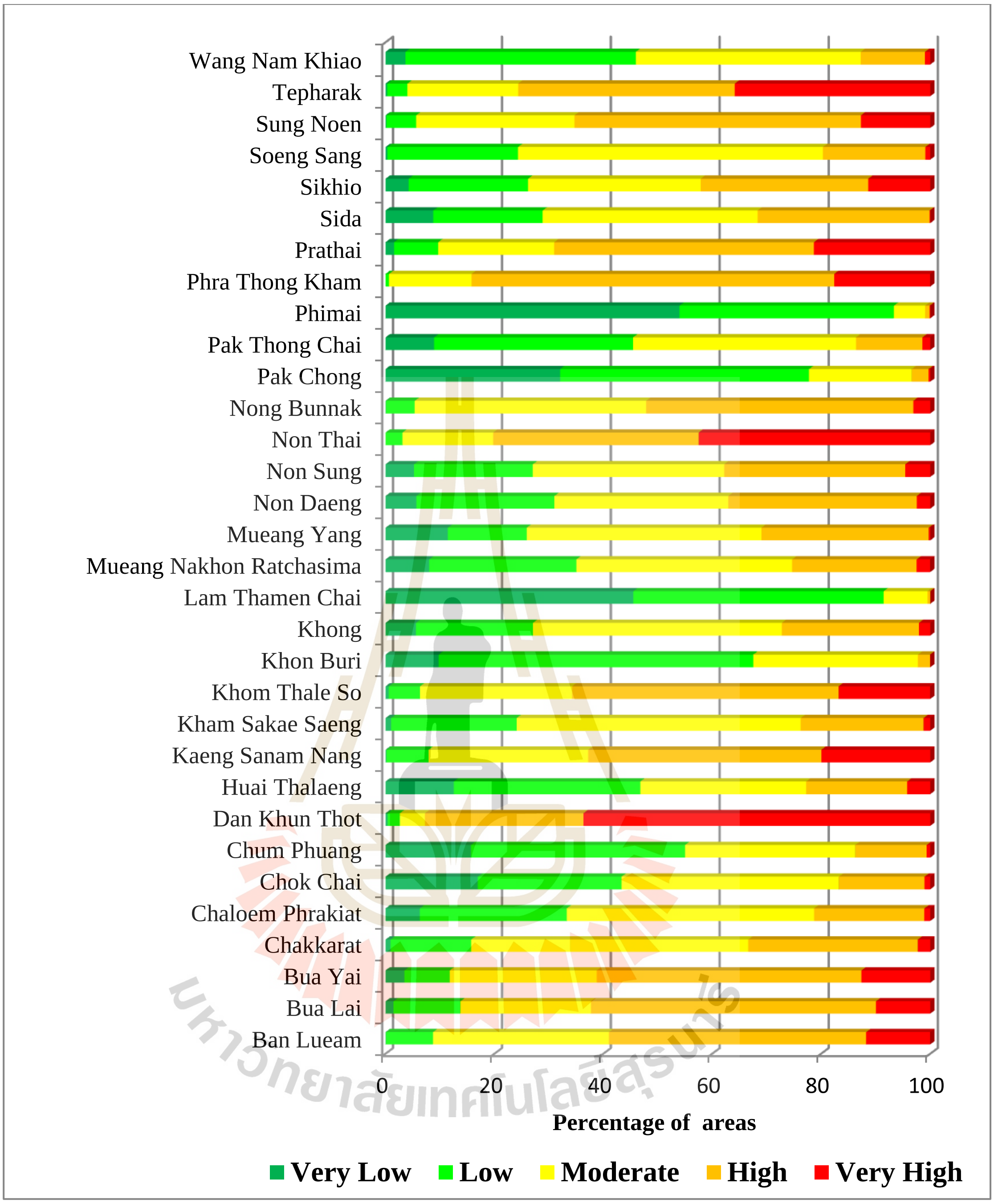


Figure 6.3 Comparison of overall agricultural drought sensitivity classification of 3m7 period at district level.

As results, at provincial level, it is found that about 36.55% of the total area is very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 33.26% of the total area while moderate agricultural drought sensitivity class covers area of 30.20% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 9 districts including Chok Chai, Chum Phuang, Huai Thalaeng, Khon Buri, Lam Thamen Chai, Pak Chong, Pak Thong Chai, Phimai, and Wang Nam Khiao. On contrary, combination of high and very high agricultural drought sensitivity is dominant at 15 districts including Ban Lueam, Bua Lai, Bua Yai, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, Sikhio, Sung Noen, and Tepharak. Meanwhile, moderate agricultural drought sensitivity is mostly found in 8 districts including Chakkarat, Chaloem Phrakiat, Kham Sakae Saeng, Khong, Mueang Nakhon Ratchasima, Mueang Yang, Sida, and Soeng Sang.

In addition, overall agricultural drought sensitivity classification of 3m7 period is validated by comparison with an accumulate drought effected area on agricultural crops during 2012 to 2015 (Figure 6.4) as result shown in Table 6.5. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 47.03%. This percentage is greater than moderate agricultural drought sensitivity class that covers area of 30.11% or very low and low agricultural drought sensitivity classes that cover area of 22.86%. Meanwhile, ROC value, which determines best fit of model, provides relatively high value of 0.891. The ROC value indicates a perfect fit. Therefore, the validation of overall agricultural drought sensitivity of 3m7 period can be acceptable.

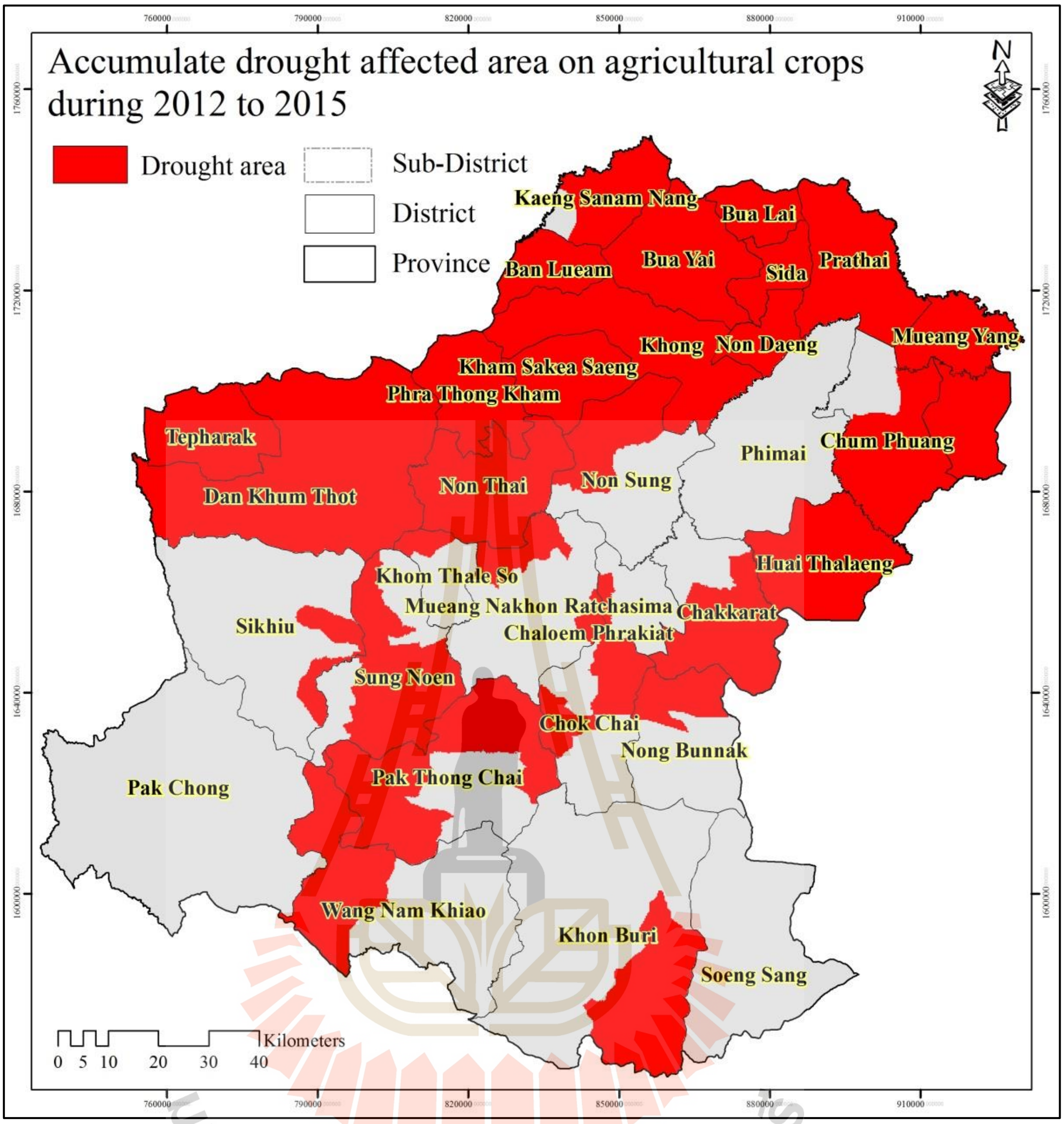


Figure 6.4 Distribution of accumulate drought effected areas on agricultural crops from 2012, 2014, and 2015.

Table 6.5 Comparison between overall agricultural drought sensitivity classification of 3m7 period and drought effected areas on agricultural crops.

	Overall agricultural drought sensitivity classification of 3m7 period (% of area)				
Drought effected areas	**VL**	**L**	**M**	**H**	**VH**
	4.92	17.94	30.11	30.03	17.00

6.1.2 Overall agricultural drought sensitivity of 3m10 period

Distribution of overall agricultural drought sensitivity classification of 3m10 period (August, September and October) is displayed in Figure 6.5. Meanwhile, percentage of overall agricultural drought sensitivity classification of 3m10 period at provincial and district levels are reported in Table 6.6 and Table 6.7, respectively. Comparison of overall agricultural drought sensitivity classification of 3m10 period at district level is displayed in Figure 6.6.

Table 6.6 Percentage of overall agricultural drought sensitivity classification of 3m10 period at provincial level.

Period (months)	Overall agricultural drought sensitivity (% of area)				
	Very low	Low	Moderate	High	Very high
3m10	13.62	26.81	25.41	22.83	11.33

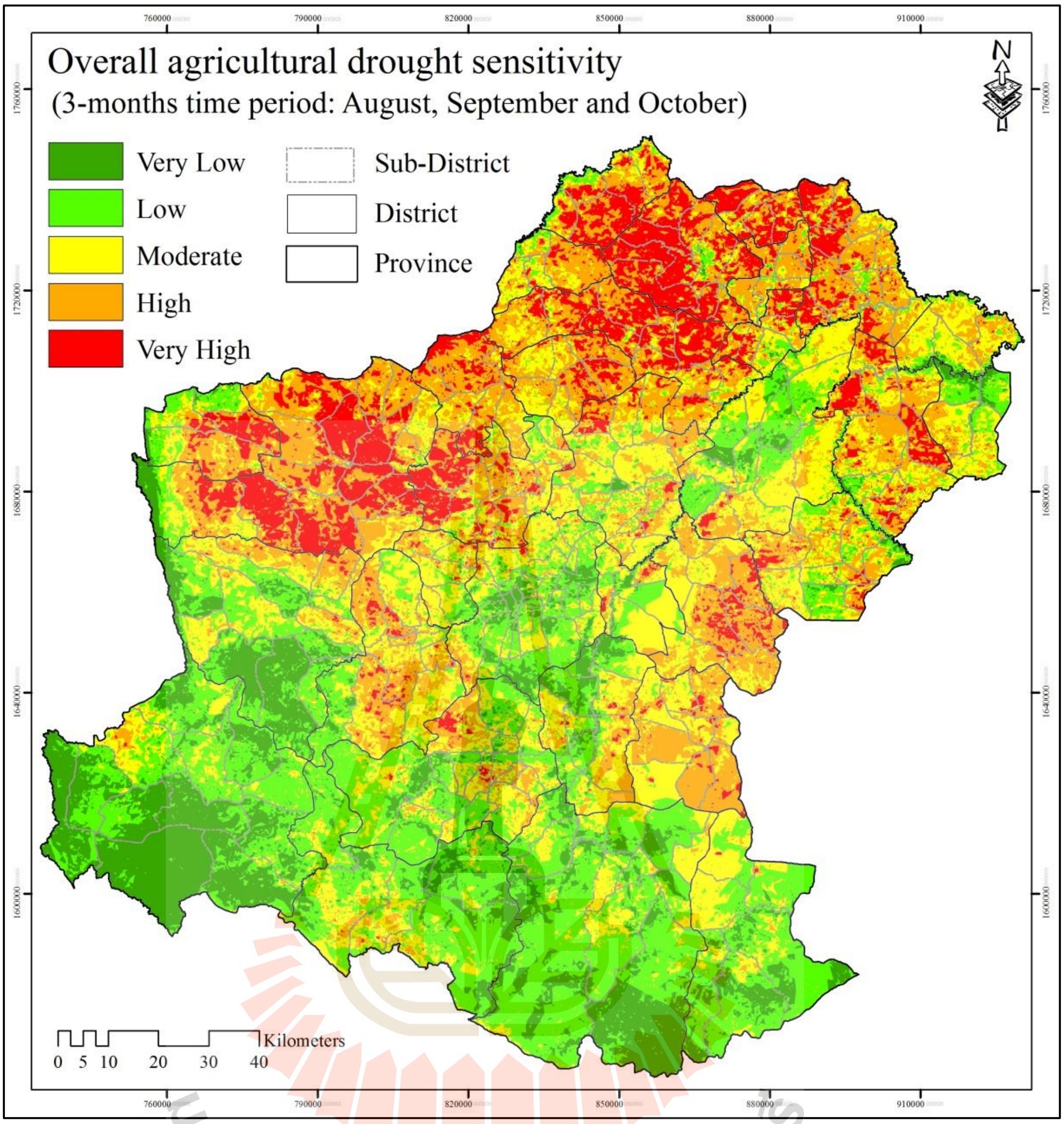


Figure 6.5 Distribution of overall agricultural drought sensitivity classification of 3m10 period.

Table 6.7 Percentage of overall agricultural drought sensitivity classification of 3m10 period at district level.

Districts	Overall agricultural drought sensitivity (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.86	8.56	32.64	46.56	11.38
Bua Lai	0.04	0.92	10.72	33.82	54.51
Bua Yai	0.46	2.67	6.66	30.02	60.19
Chakkarat	0.17	2.12	32.63	51.66	13.42
Chaloem Phrakiat	6.46	28.19	53.90	9.11	2.34
Chok Chai	17.84	28.97	34.70	17.19	1.30
Chum Phuang	1.48	9.08	28.79	41.01	19.63
Dan Khun Thot	2.70	3.65	13.99	41.32	38.33
Huai Thalaeng	4.31	20.21	38.44	31.32	5.72
Kaeng Sanam Nang	0.43	8.40	14.05	37.63	39.48
Kham Sakae Saeng	0.00	1.59	28.96	51.97	17.48
Khom Thale So	4.21	20.92	51.15	20.96	2.76
Khon Buri	28.48	56.60	14.21	0.70	0.00
Khong	0.06	1.71	16.56	44.09	37.58
Lam Thamen Chai	12.34	30.54	39.35	17.00	0.77
Mueang Nakhon Ratchasima	19.43	42.34	30.77	6.88	0.58
Mueang Yang	5.63	14.60	52.36	26.83	0.59
Non Daeng	1.61	11.13	26.68	33.76	26.83
Non Sung	2.09	14.35	45.79	32.20	5.57
Non Thai	0.22	7.56	27.09	38.26	26.88
Nong Bunnak	0.00	3.32	40.23	51.50	4.95
Pak Chong	52.52	37.32	9.06	1.07	0.04
Pak Thong Chai	7.97	46.78	31.17	12.29	1.79
Phimai	8.16	32.26	46.23	12.01	1.34
Phra Thong Kham	0.00	0.37	17.28	59.59	22.76
Prathai	0.32	4.94	16.98	49.55	28.21
Sida	0.53	7.15	18.02	64.77	9.53
Sikhio	29.67	32.57	25.20	11.53	1.04
Soeng Sang	17.84	56.04	24.55	1.44	0.13
Sung Noen	2.48	17.85	39.44	34.96	5.26
Tepharak	3.79	22.01	20.06	31.76	22.39
Wang Nam Khiao	16.33	58.47	21.16	3.90	0.13

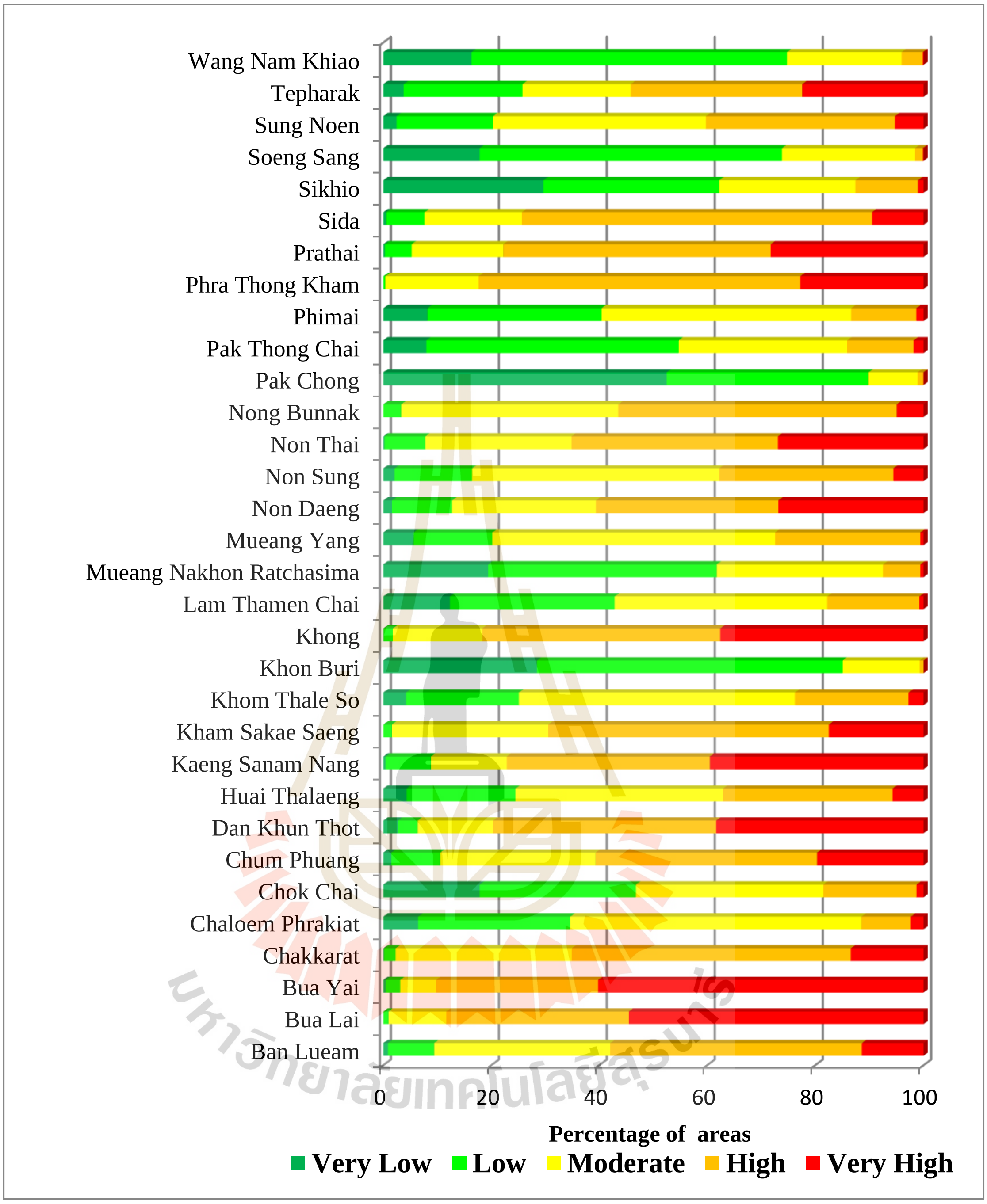


Figure 6.6 Comparison of overall agricultural drought sensitivity classification of 3m10 period at district level.

As results, at provincial level, it is found that about 40.43% of the total area is very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 34.16% of the total area while moderate agricultural drought sensitivity class covers area of 25.41% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 9 districts including Chok Chai, Khon Buri, Lam Thamen Chai, Mueang Nakhon Ratchasima, Pak Chong, Pak Thong Chai, Sikhio, Soeng Sang, and Wang Nam Khiao. On contrary, combination of high and very agricultural drought sensitivity is dominant in 17 districts including Ban Lueam, Bua Lai, Bua Yai, Chakkarat, Chum Phuang, Dan Khun Thot, Kaeng Sanam Nang, Kham Sakae Saeng, Khong, Non Daeng, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, Sida, Sung Noen, and Tepharak. Meanwhile, moderate agricultural drought sensitivity is mostly found in 6 districts including Chaloem Phrakiat, Huai Thalaeng, Khom Thale So, Mueang Yang, Non Sung, and Phimai.

Furthermore, overall agricultural drought sensitivity classification of SPI-3m10 period is validated by comparison with drought effected area on agricultural crops during 2012 to 2015 (see Figure 6.4) as result shown in Table 6.8. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 54.93%. Meanwhile, ROC value provides very high value of 0.923. The ROC value indicates a perfect fit. Thus, the validate result of overall agricultural drought sensitivity of SPI-3m10 period can be acceptable.

Table 6.8 Comparison between overall agricultural drought sensitivity classification of 3m10 and drought effected area on agricultural crops.

Drought effected area	Overall agricultural drought sensitivity classification of 3m10 (% of area)				
	VL	**L**	**M**	**H**	**VH**
	5.35	14.84	24.87	34.49	20.44

6.1.3 Overall agricultural drought sensitivity of 6m10 period

Distribution of overall agricultural drought sensitivity classification of 6m10 period is displayed in Figure 6.7. Meanwhile, percentage of overall agricultural drought sensitivity classification of 6m10 period at provincial and district levels are reported in Table 6.9 and Table 6.10, respectively. Comparison of overall agricultural drought sensitivity classification of 6m10 period at district level is displayed in Figure 6.8.

Table 6.9 Percentage of overall agricultural drought sensitivity classification of 6m10 period at provincial level.

Period (months)	Overall agricultural drought sensitivity (% of area)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
6M10	13.7	26.92	26.77	22.64	9.97

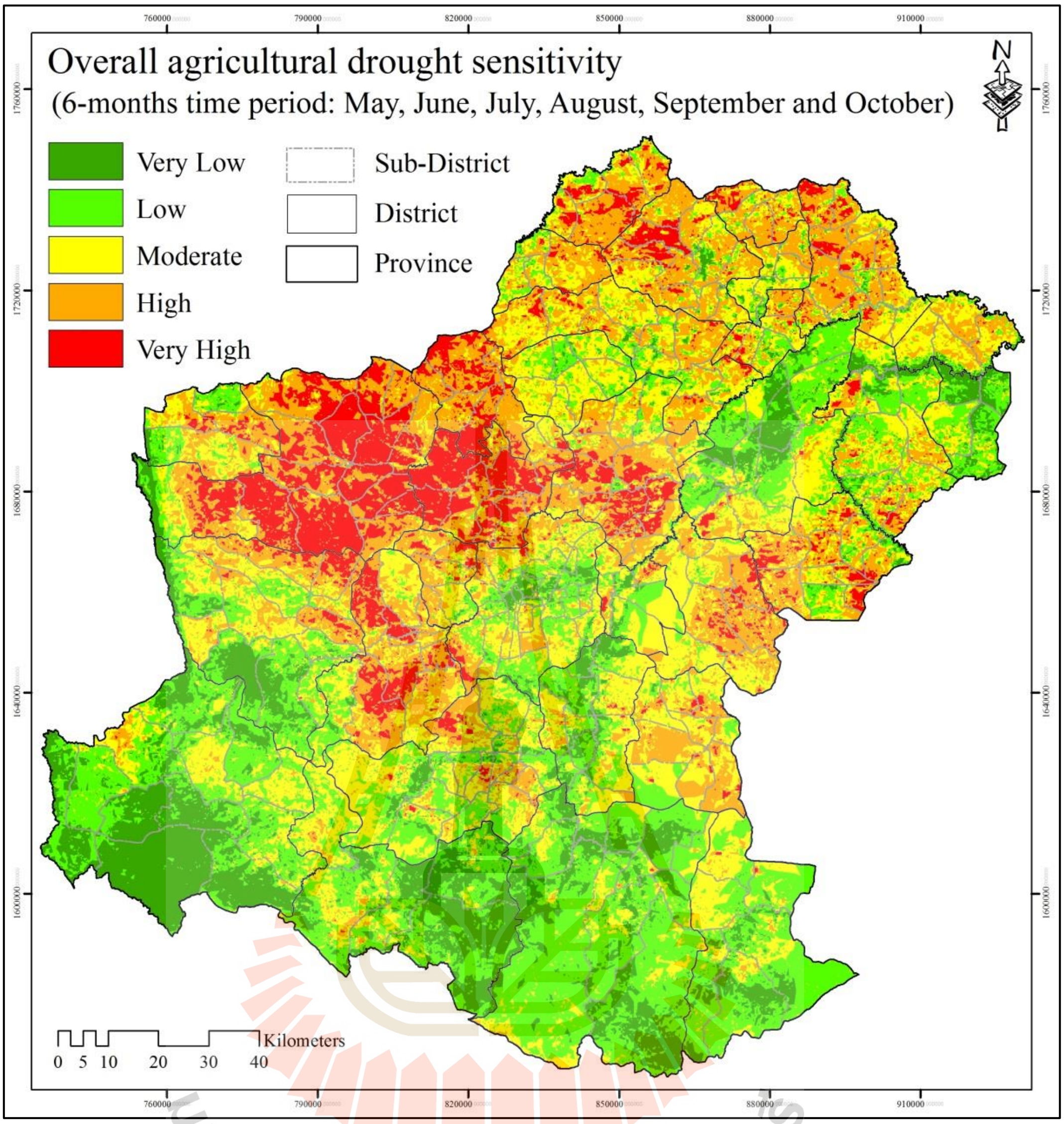


Figure 6.7 Distribution of overall agricultural drought sensitivity classification of 6m10 period.

Table 6.10 Percentage of overall agricultural drought sensitivity classification of 6m10 period at district level.

Districts	**Overall agricultural drought sensitivity (% of area)**				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	1.21	13.71	36.77	43.18	5.13
Bua Lai	0.44	6.81	26.55	54.39	11.82
Bua Yai	2.83	7.04	26.97	48.78	14.37
Chakkarat	0.27	5.20	42.25	43.57	8.71
Chaloem Phrakiat	8.14	28.92	49.75	10.71	2.48
Chok Chai	19.89	34.71	36.92	8.01	0.48
Chum Phuang	9.58	30.53	35.18	21.12	3.60
Dan Khun Thot	2.11	2.78	7.88	35.42	51.81
Huai Thalaeng	3.36	13.42	30.21	40.54	12.47
Kaeng Sanam Nang	0.30	8.22	20.27	50.51	20.71
Kham Sakae Saeng	2.50	27.12	59.05	11.06	0.27
Khom Thale So	1.35	8.43	34.16	46.79	9.27
Khon Buri	24.41	62.80	12.21	0.57	0.02
Khong	2.59	11.28	40.58	40.72	4.83
Lam Thamen Chai	32.96	44.48	20.50	2.05	0.02
Mueang Nakhon Ratchasima	9.34	30.63	38.68	18.71	2.63
Mueang Yang	7.34	11.57	46.26	34.31	0.52
Non Daeng	3.55	19.22	33.20	36.78	7.24
Non Sung	1.47	7.89	25.48	44.60	20.55
Non Thai	0.00	1.02	10.88	34.26	53.84
Nong Bunnak	0.29	12.93	45.96	37.89	2.94
Pak Chong	45.14	37.84	15.41	1.58	0.03
Pak Thong Chai	5.98	32.51	44.13	15.01	2.37
Phimai	20.87	41.81	29.78	6.54	1.00
Phra Thong Kham	0.00	0.08	6.28	58.64	35.00
Prathai	1.74	7.96	26.00	52.29	12.00
Sida	8.02	17.37	45.45	28.83	0.33
Sikhio	17.26	28.59	28.15	20.84	5.16
Soeng Sang	14.25	57.20	26.32	2.10	0.12
Sung Noen	0.94	8.56	29.43	40.18	20.89
Tepharak	4.80	21.40	32.20	34.43	7.17
Wang Nam Khiao	35.94	41.21	19.69	3.08	0.08

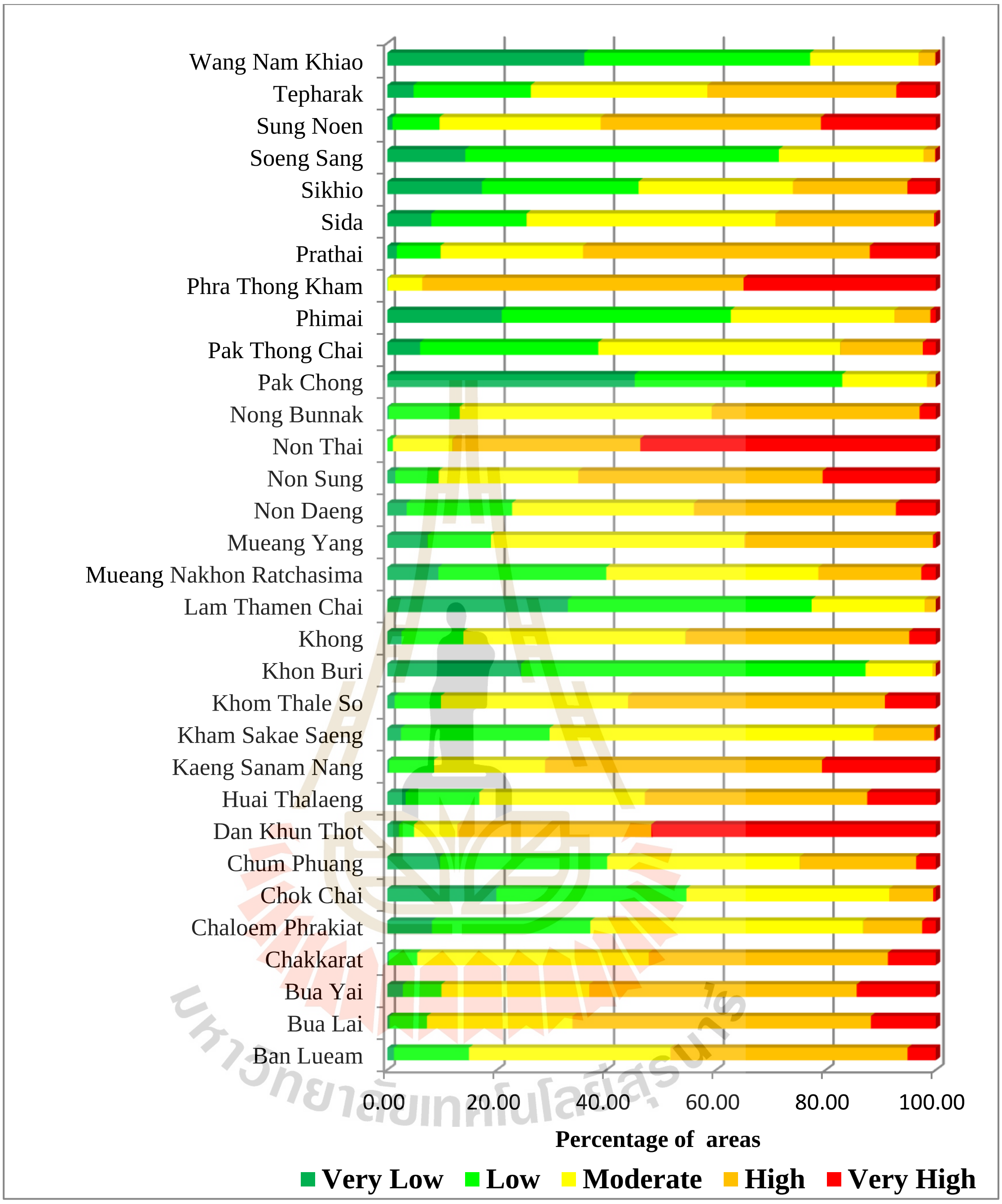


Figure 6.8 Comparison of overall agricultural drought sensitivity of 6m10 period at district level.

As results, at provincial level, it is found that about 40.62% of the total area is very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 32.61% of the total area while moderate agricultural drought sensitivity class covers area of 26.77% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 10 districts including Chok Chai, Chum Phuang, Khon Buri, Lam Thamen Chai, Mueang Nakhon Ratchasima, Pak Chong, Phimai, Sikhio, Soeng Sang, and Wang Nam Khiao. On contrary, combination of high and very agricultural drought sensitivity is dominant in 16 districts including Ban Lueam, Bua Lai, Bua Yai, Chakkarat, Dan Khun Thot, Huai Thalaeng, Kaeng Sanam Nang, Khom Thale So, Khong, Non Daeng, Non Sung, Non Thai, Phra Thong Kham, Prathai, Sung Noen, and Tepharak. Meanwhile, moderate agricultural drought sensitivity is mostly found in 6 districts including Chaloem Phrakiat, Kham Sakae Saeng, Mueang Yang, Nong Bunnak, Pak Thong Chai, and Sida.

Furthermore, overall agricultural drought sensitivity classification of 6m10 is validated by comparison with accumulate drought effected area on agricultural crops during 2012 to 2015 (see Figure 6.4) as result shown in Table 6.11. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 47.30%. This percentage is greater than moderate agricultural drought sensitivity that cover area of 30.11% or very low and low agricultural drought sensitivity that cover area of 22.86%. Meanwhile, ROC value provides very high value of 0.912. The ROC value indicates a perfect fit. Thus, the validate result of overall agricultural drought sensitivity classification of SPI-6m10 period can be acceptable.

Table 6.11 Comparison between overall agricultural drought sensitivity classification of 6m10 period and drought effected area on agricultural crops.

	Overall agricultural drought sensitivity classification of 6m10 (% of area)				
Drought effected area	**VL**	**L**	**M**	**H**	**VH**
	4.92	17.94	30.11	30.03	17.00

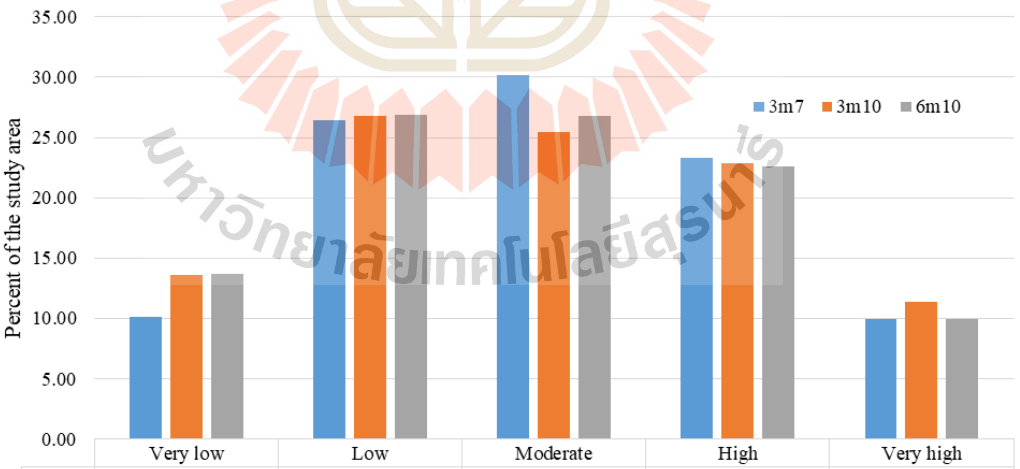
Summary

Overall agricultural drought sensitivity assessment is assessed using weighting linear combination of vegetation (agricultural drought frequency and agricultural drought intensity), climate (SPI and SPEI), physical (land use, soil drainages, agricultural irrigation area, slope, elevation, distance to river and drainage density) and socio-economic factors (agricultural occupation, economic crop production, and population density). Herein, overall agricultural drought sensitivity classification with 3 periods (3m7, 3m10, and 6m10) was implemented according to dynamic data of climate factors (SPI and SPEI).

As mentioned earlier, all selected factors on overall agricultural drought sensitivity factors were reviewed from the existing research work. For example, Pei et al. (2016) stated that sensitivity was related with the sensitive degree of the agricultural system structure and population structure. The factor of sensitivity consists of population density, proportion of agricultural population, proportion of agricultural GDP, food yield per unit area and per capita arable land. While, Murthy et al. (2014, 2015a) used four parameters: (1) season's integrated NDVI, (2) season's maximum NDVI, (3) August NDVI and (4) cropping pattern. Murthy et al. (2015b) used season's integrated NDVI for analysis sensitivity components. While, Sehgal and Dhakar (2016) stated that the main factor of agricultural drought sensitivity impact consists of (1) water holding capacity of soil, (2) agricultural drought frequency and (3) agricultural drought intensity.

In this study, overall agricultural drought sensitivity assessment used significant factors in four conditions (vegetation, climate, physical and socioeconomic) to assess agricultural drought and lead to more understanding, accuracy, and efficiency for mitigation and prevention affected from agricultural drought.

According to overall agricultural drought sensitivity classification, the most dominant class of 3 periods (3m7, 3m10, and 6m10) at province level is very low and low and covers area of 36.55%, 40.43%, and 40.62%, respectively. Meanwhile, high and very high overall agricultural drought sensitivity of 3 periods covers area of 33.26%, 34.16%, and 32.61% and moderate overall agricultural drought sensitivity of 3 periods covers area of 30.20%, 25.41%, and 26.77%, respectively (Figure 6.9).



	Very low	Low	Moderate	High	Very high
3m7	10.10	26.45	30.20	23.30	9.96
3m10	13.62	26.81	25.41	22.83	11.33
6m10	13.70	26.92	26.77	22.64	9.97

Figure 6.9 Percentage of overall agricultural drought sensitivity classification of 3 periods.

At district level, there are 11 districts including Ban Lueam, Bua Lai, Bua Yai, Dan Khun Thot, Kaeng Sanam Nang, Non Daeng, Non Thai, Phra Thong Kham, Prathai, Sung Noen, and Tepharak always incur at high and very high overall agricultural drought sensitivity in every period. At the same time, there are 5 districts including Chok Chai, Khon Buri, Lam Thamen Chai, Pak Chong, and Wang Nam Khiao always incur at very low and low overall agricultural drought sensitivity in every period. Meanwhile, there are 2 districts including Chaloem Phrakiat and Mueang Yang always incur at moderate overall agricultural drought sensitivity in every period. On contrary, there are 14 districts including Chakkarat, Chok Chai, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khom Thale So, Khong, Lam Thamen Chai, Mueang Nakhon Ratchasima, Non Daeng, Non Sung, Pak Thong Chai, Sida, Sikhio, Soeng Sang, and Sung Noen have different overall agricultural drought sensitivity levels among 3 periods.

Furthermore, combination of high and very high overall agricultural drought sensitivity classification of 3 periods (3m7, 3m10, and 6m10) are consistent with an accumulate drought effected area on agricultural crops during 2012 to 2015 about 47.03%, 54.93%, and 47.30%, respectively. Likewise, ROC values for best fit test of overall agricultural drought sensitivity classification of 3 periods are 0.891, 0.923, and 0.912, respectively. Thus, the classification of overall agricultural drought sensitivity of 3 periods are acceptable.

6.2 Annual agricultural drought sensitivity assessment

Under this component, CART model was applied to derive annual agricultural drought sensitivity classification based on the derived overall agricultural drought sensitivity of 6m10 period as dependent variable and significant conditions on drought response including vegetation, climatic, physical and socioeconomic conditions as independent variables. Results of annual agricultural drought sensitivity classification of 3 periods (2012, 2014, and 2015) are separately described and discussed in the following section.

6.2.1 Annual agricultural drought sensitivity assessment in 2012

The optimum derived multiple linear regression equation that provides the lowest average error of 0.879, relative error of 0.51 and correlation coefficient of 0.82 creates annual agricultural drought sensitivity index of 2012 with following equation:

$$OADS = 7.068 + 1.51\ DD + 0.96\ LU + 1.73\ POPDEN + 1.71\ SPEI + 0.81\ DFR + 0.46\ SOIL \quad (6.2)$$

Where: OADS is overall agricultural drought sensitivity index,

DD is drainage density,

LU is land use in 2012,

POPDEN is population density in 2011

SPEI is SPEI in 2012

DFR is distance to river

SOIL is soil drainage,

According to Eq. 6.2, the six significant factors on overall agricultural drought sensitivity are drainage density, land use in 2012, population density in 2011, SPEI in 2012, distance to river, and soil drainage. Herewith, 8 influential factors include agricultural irrigation area, SOSA in 2012, PASG in 2012, agricultural occupation in 2011, SPI, elevation, slope, and economic crop production are excluded from the model. In addition, all of significant factors show positively relate with overall agricultural drought sensitivity of 6m10 period. Herewith, top three dominant factors which provide high coefficient value are population density in 2011, SPEI in 2012 and drainage density. The relationship between observed (real) data and predicted data with relevant statistics is displayed in Figure 6.10. Meanwhile, independent variables as factor maps for generating annual agricultural drought sensitivity assessment index in 2012 under Spatial Analyst Tools of ESRI ArcMap is demonstrated in Figure 6.11.

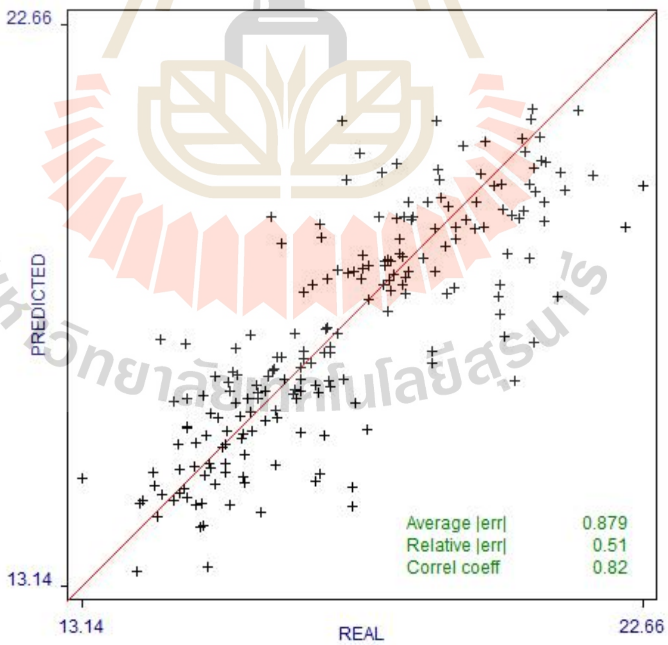
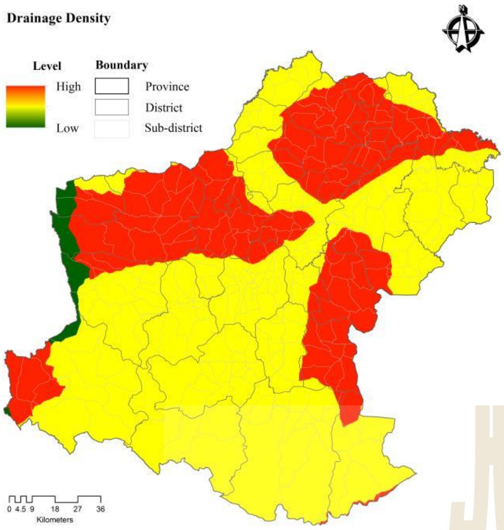
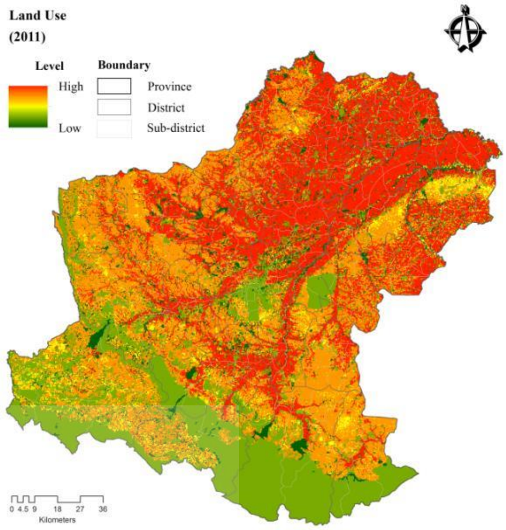


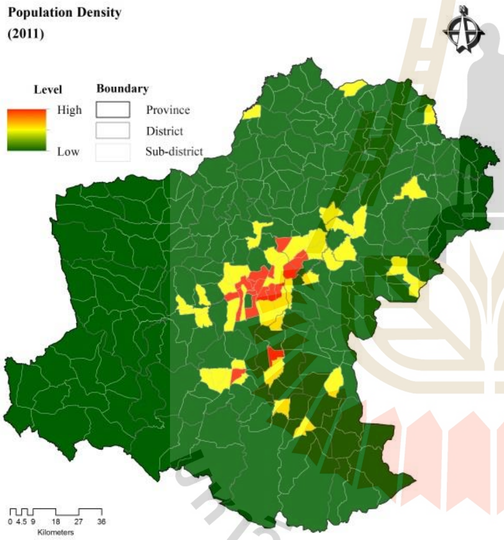
Figure 6.10 Relationship between original data and predicted data of overall agricultural drought sensitivity index model.



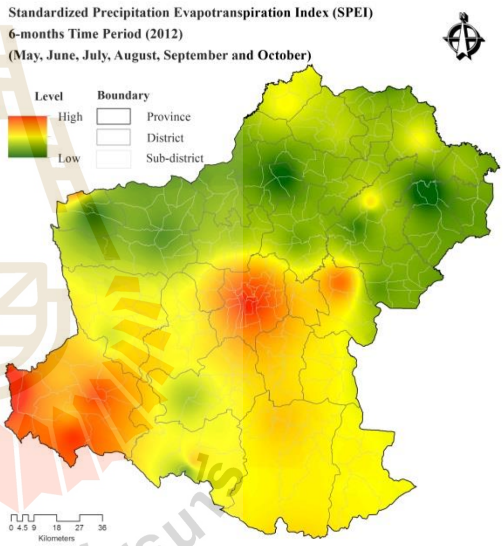
Drainage density



Land use (2011)

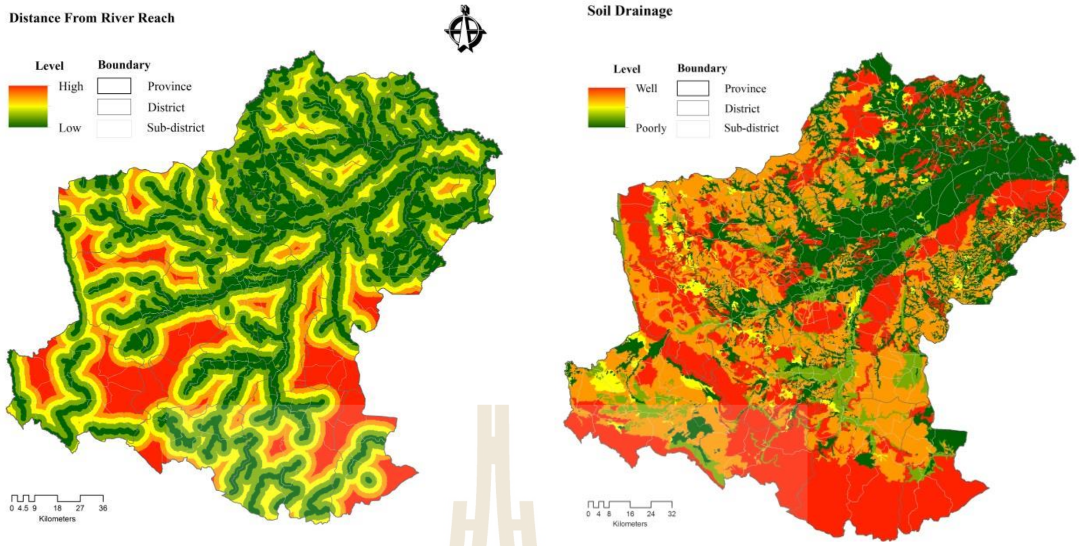


Population density (2011)



SPEI 6 months (May to October) 2012

Figure 6.11 Factor maps for generating annual agricultural drought sensitivity index in 2012.



Distance to river Soil drainage

Figure 6.11 (Continued).

Distribution of annual agricultural drought sensitivity classification in 2012 is displayed in Figure 6.12. Meanwhile, percentage of annual agricultural drought sensitivity in 2012 at provincial and district levels are reported in Table 6.12 and Table 6.13, respectively. Comparison of annual agricultural drought sensitivity classification in 2012 at district level is displayed in Figure 6.13.

Table 6.12 Percentage of annual agricultural drought sensitivity classification in 2012 at provincial level.

Annual agricultural drought sensitivity in 2012	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
	9.4	20.32	28.4	24.49	17.4

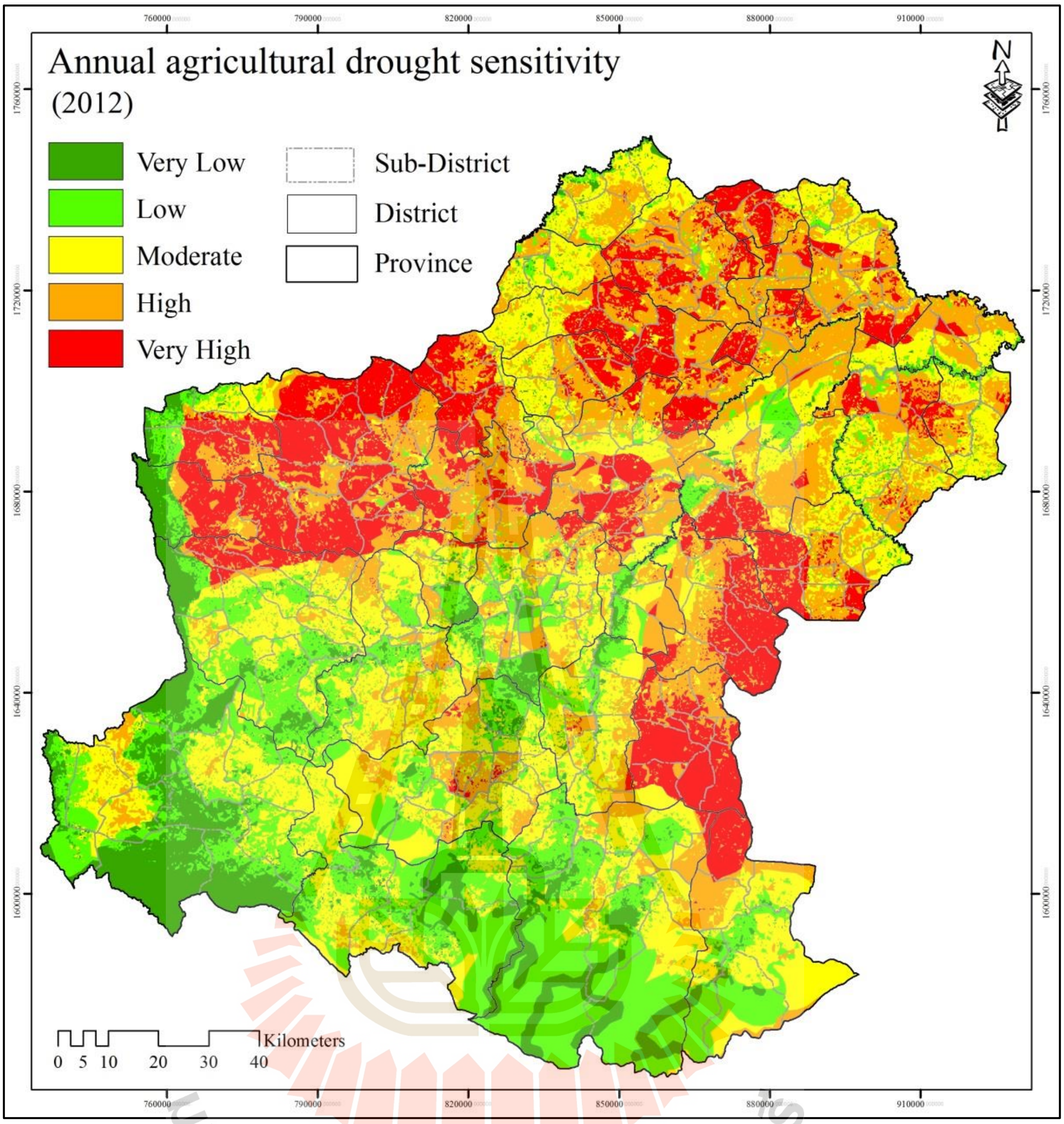


Figure 6.12 Distribution of annual agricultural drought sensitivity classification in 2012.

Table 6.13 Percentage of annual agricultural drought sensitivity classification in 2012 at district level.

Districts	Annual agricultural drought sensitivity (% of area)				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	1.86	15.09	54.01	27.59	1.45
Bua Lai	0.3	1.35	12.36	31.35	54.64
Bua Yai	0.18	3.15	15.38	51.87	29.42
Chakkarat	0.53	2.33	12.07	36.71	48.35
Chaloem Phrakiat	9.35	16.93	31.31	39.53	2.89
Chok Chai	6.07	21.3	52.52	18.48	1.63
Chum Phuang	2.21	11.49	35.57	38.59	12.13
Dan Khun Thot	5.42	2.65	5.77	28.08	58.07
Huai Thalaeng	0.64	4.4	27.61	35.95	31.41
Kaeng Sanam Nang	6.85	9.35	55.22	28.16	0.42
Kham Sakae Saeng	0.53	3.74	34.61	39.64	21.48
Khom Thale So	13.83	22.32	38.21	17.46	8.19
Khon Buri	17.52	52.67	23.33	5.71	0.77
Khong	0.47	2.65	22.56	35.96	38.36
Lam Thamen Chai	2.23	8.19	48.79	32.37	8.43
Mueang Nakhon Ratchasima	10.19	23.69	37.17	25.2	3.75
Mueang Yang	3.39	9.64	36.08	44.01	6.88
Non Daeng	0	2.32	7.54	51.93	38.21
Non Sung	0.71	3.7	24.08	44.43	27.08
Non Thai	0.21	4.97	12.84	52.27	29.71
Nong Bunnak	0	0.24	7.18	24.63	67.95
Pak Chong	41.17	31.5	23.58	3.75	0
Pak Thong Chai	5.74	24.94	49.63	18.26	1.44
Phimai	2.17	12.87	29.31	43.63	12.01
Phra Thong Kham	0.19	1.31	11.05	35.44	52.01
Prathai	0.54	4.33	31.29	45.41	18.43
Sida	0	4.25	5.96	72.31	17.48
Sikhio	13.33	32.21	35.15	9.67	9.64
Soeng Sang	3.92	29.82	40.45	15.89	9.92
Sung Noen	4.37	24.84	51.48	19.07	0.24
Tepharak	12	18.39	13.96	20.35	35.3
Wang Nam Khiao	15.59	49.32	33.32	1.77	0

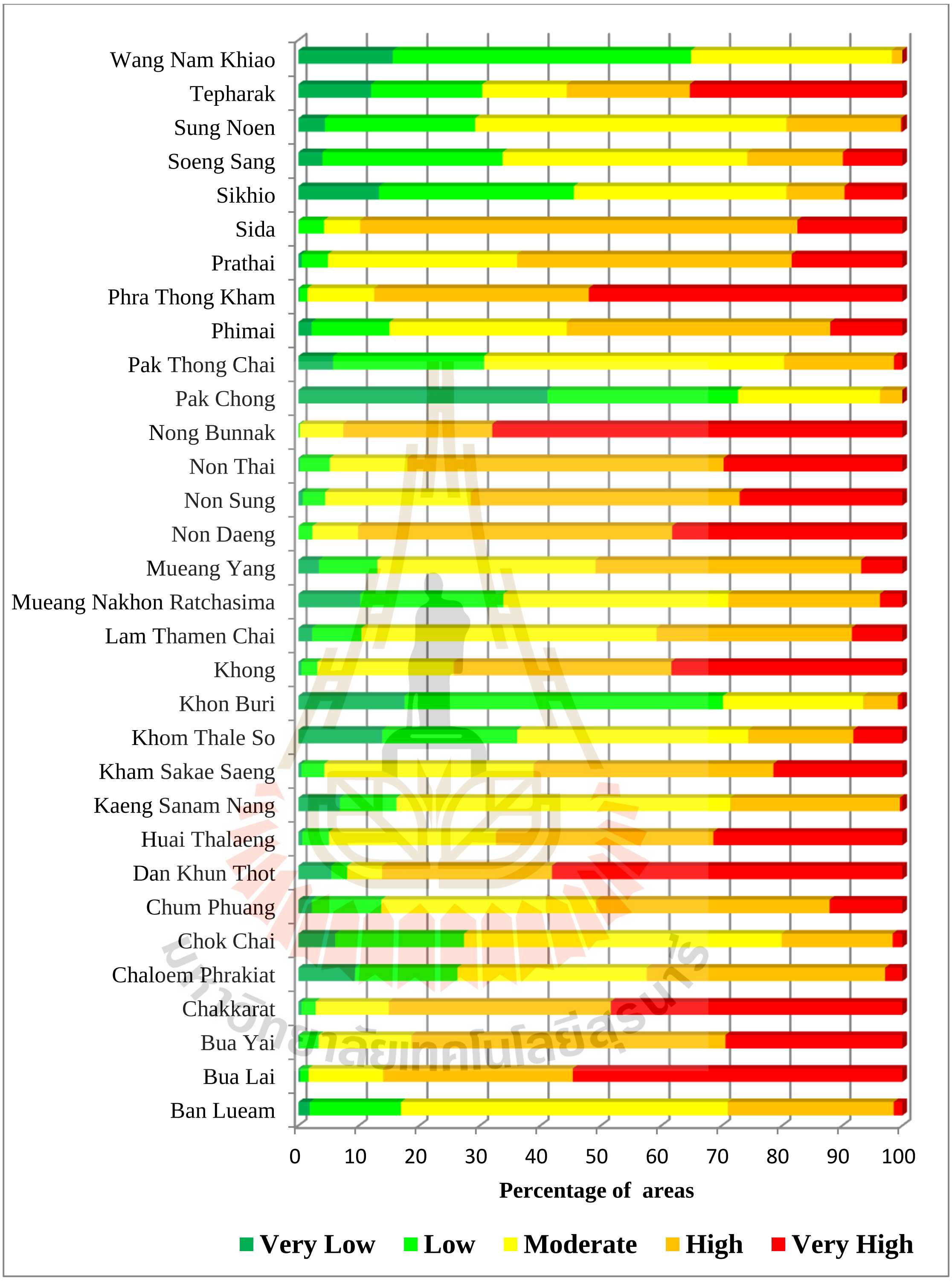


Figure 6.13 Comparison of annual agricultural drought sensitivity classification in 2012 at district level.

As results, at provincial level, it is found that about 29.72% of the total area is very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 41.89% of the total area while moderate agricultural drought sensitivity class covers area of 28.4% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 4 districts including Khon Buri, Pak Chong, Sikhio, and Wang Nam Khiao. On contrary, combination of high and very high agricultural drought sensitivity is dominant in 19 districts including Bua Lai, Bua Yai, Chakkarat, Chaloem Phrakiat, Chum Phuang, Dan Khun Thot, Huai Thalaeng, Kham Sakae Saeng, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phimai, Phra Thong Kham, Prathai, Sida, and Tepharak. Meanwhile, moderate agricultural drought sensitivity is mostly found in 9 districts including Ban Lueam, Chok Chai, Kaeng Sanam Nang, Khom Thale So, Lam Thamen Chai, Mueang Nakhon Ratchasima, Pak Thong Chai, Soeng Sang, and Sung Noen,

In addition, annual agricultural drought sensitivity classification in 2012 at district level can be interpreted in term of climate condition by regroup original classes into 3 classes: wet (VL and L), normal (M) and drought (H and VH) as shown in Figure 6.14.

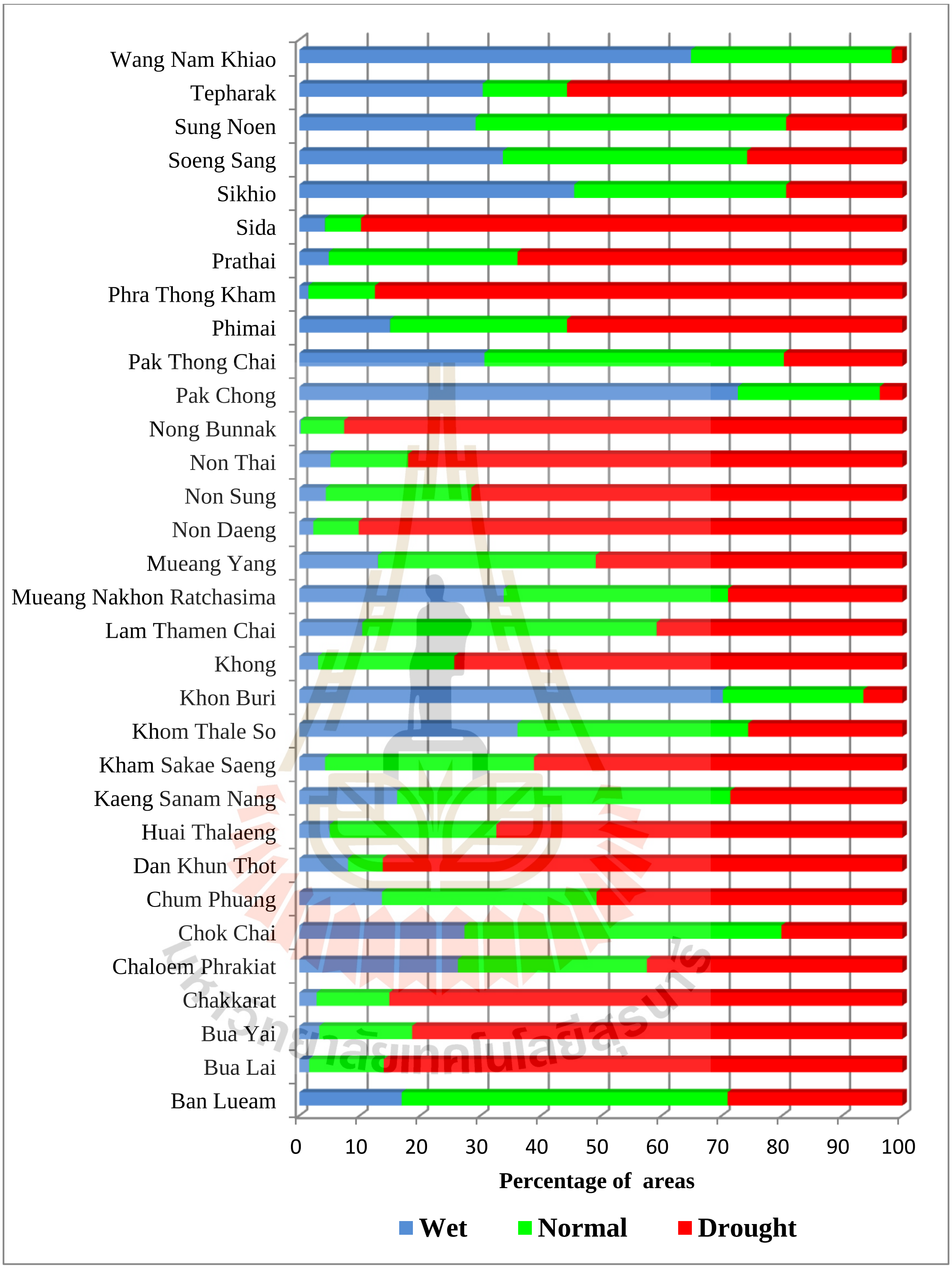


Figure 6.14 Comparison of annual agricultural drought sensitivity classification in 2012 by climate condition at district level.

Furthermore, annual agricultural drought sensitivity classification in 2012 is validated by comparison with drought effected area on agricultural crops in 2012 (Figure 6.15) using coincident matrix as result shown in Table 6.14. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 56.07%. This percentage is greater than combination of very low, low, and moderate agricultural drought sensitivity that only cover area of 43.93%. Meanwhile, ROC value provides relatively high value of 0.851. The ROC value indicates a perfect fit. Thus, the validation result of annual agricultural drought sensitivity classification in 2012 can be acceptable.

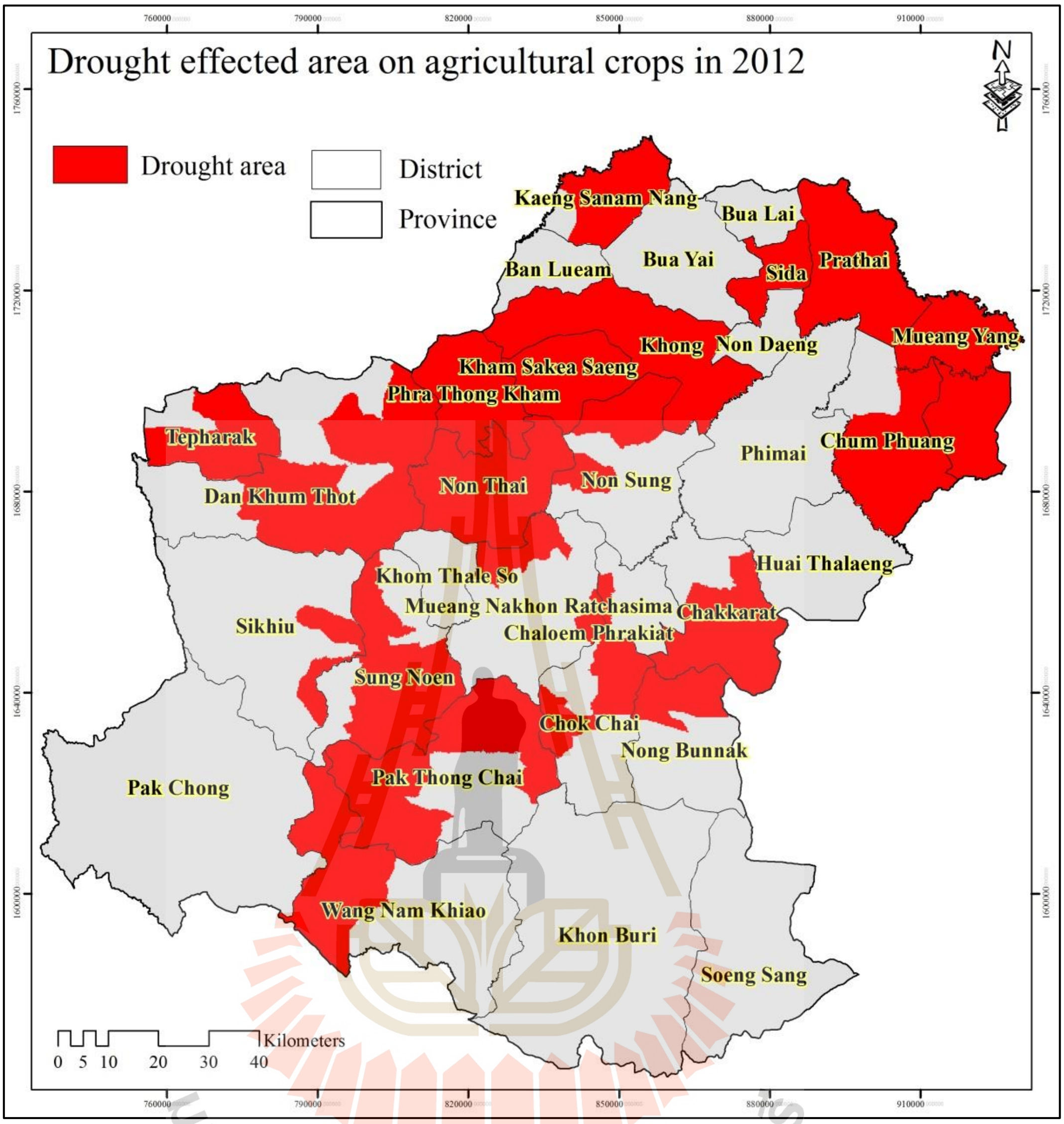


Figure 6.15 Distribution of drought effected area on agricultural crop in 2012.

Table 6.14 Comparison between annual agricultural drought sensitivity classification in 2012 and drought effected area on agricultural crops in 2012.

Drought effected area in 2012	**Annual agricultural drought sensitivity classification in 2012 (% of area)**				
	VL	**L**	**M**	**H**	**VH**
	2.98	11.33	29.63	33.17	22.90

6.2.2 Annual agricultural drought sensitivity assessment in 2014

The optimum derived multiple linear regression equation that provides the lowest average error of 0.714, relative error of 0.41 and correlation coefficient of 0.89 creates annual agricultural drought sensitivity index of 2014 with the following equation:

$$OADS = 9.376 - 1.21\ ELE + 0.87\ LU + 0.69\ SOIL + 0.84\ DFR - 0.67\ SPI + 0.37\ APR + 0.42\ IRR + 0.4\ DD + 0.31\ AOC + 0.44\ POPDEN - 0.41\ SPEI \quad (6.3)$$

Where: OADS is overall agricultural drought sensitivity index,

ELE is elevation,

LU is land use in 2015,

SOIL is soil drainage,

DFR is distance to river

SPI is SPI in 2014,

APR is agricultural economic crop production in 2014

IRR is agricultural irrigation area

DD is drainage density,

AOC is agricultural occupation in 2014,

POPDEN is population density in 2013

SPEI is SPEI 2014

According to Eq. 6.3, most of the pre-selected influential factors on overall agricultural drought sensitivity are included except slope, PASG in 2014, and SOSA in 2014.

In addition, most of significant factors show positively correlate with overall agricultural drought sensitivity except ELE, SPI and SPEI. Herewith, top three dominant factors which provide high coefficient value are elevation, land use in 2014, and distance to river. The relationship between observed (real) data and predicted data with relevant statistics is displayed in Figure 6.16. Meanwhile, independent variables as factor map for generating annual agricultural drought sensitivity index in 2014 is presented in Figure 6.17.

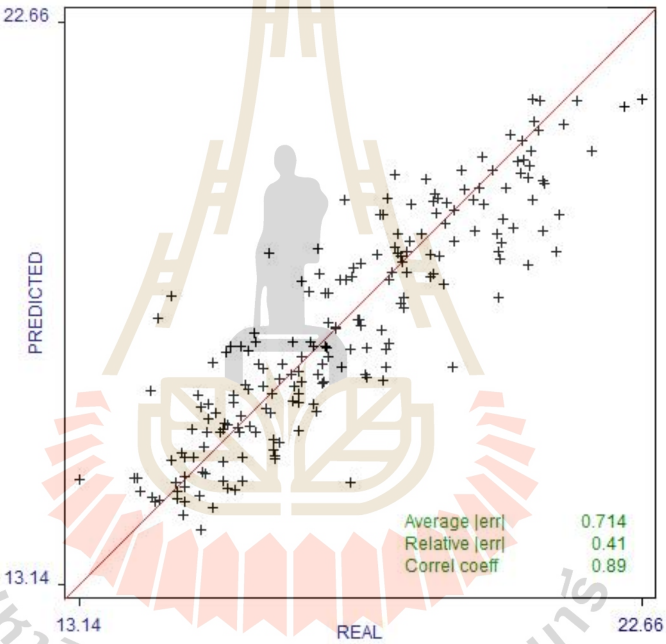


Figure 6.16 Relationship between original data and predicted data of overall agricultural drought sensitivity index model.

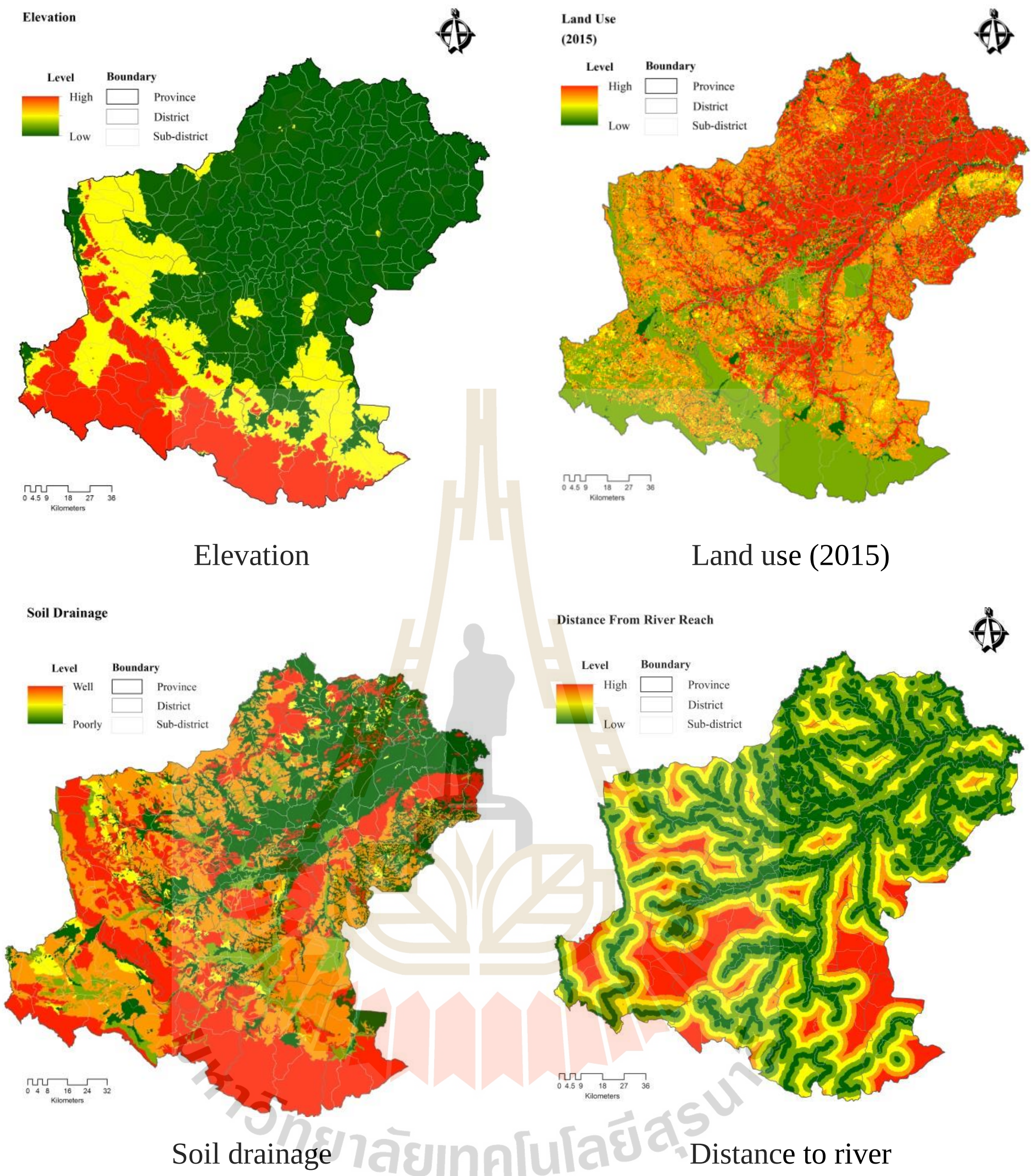
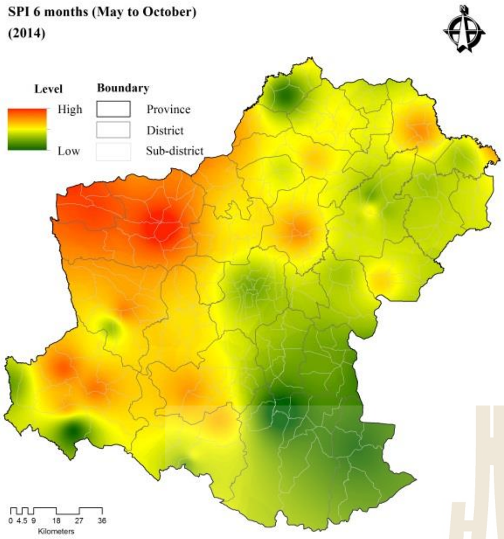
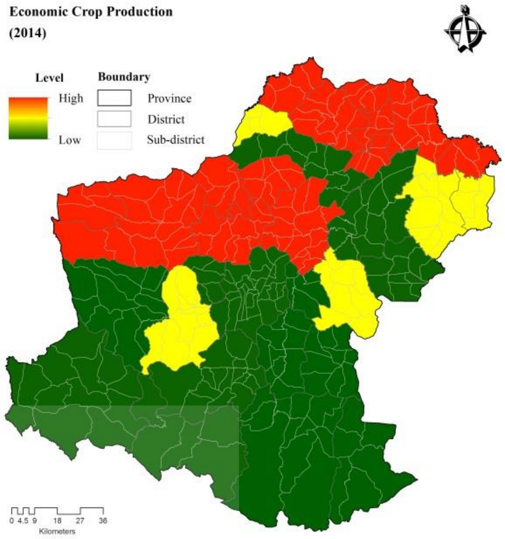


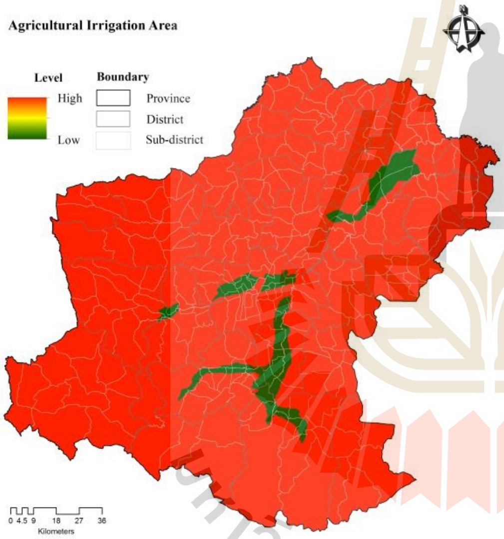
Figure 6.17 Factor maps for generating annual agricultural drought sensitivity index in 2014.



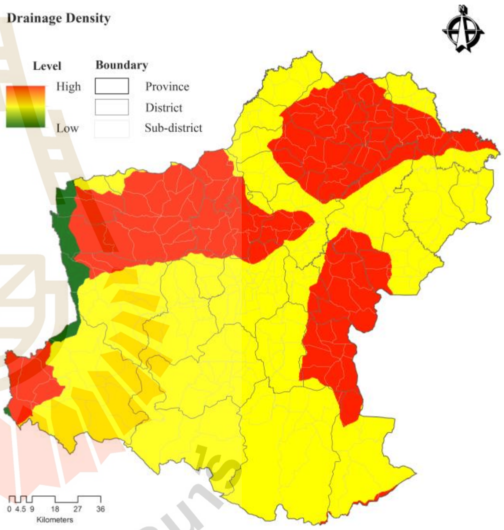
SPI 6 months (May to October) 2014



Economic crop production (2014)

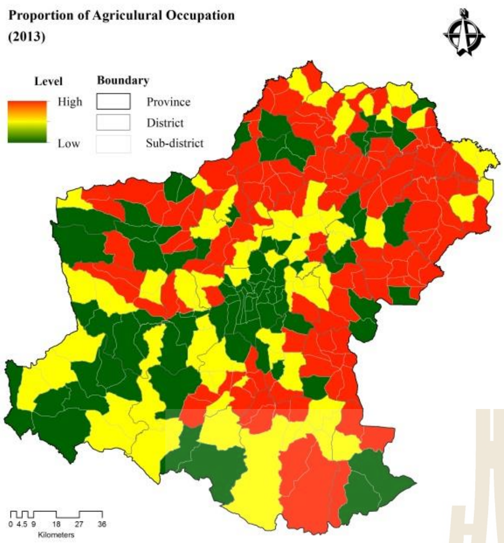


Agricultural irrigation area

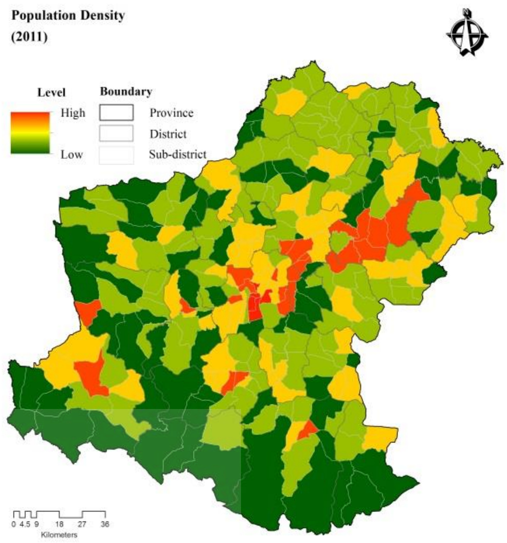


Drainage density

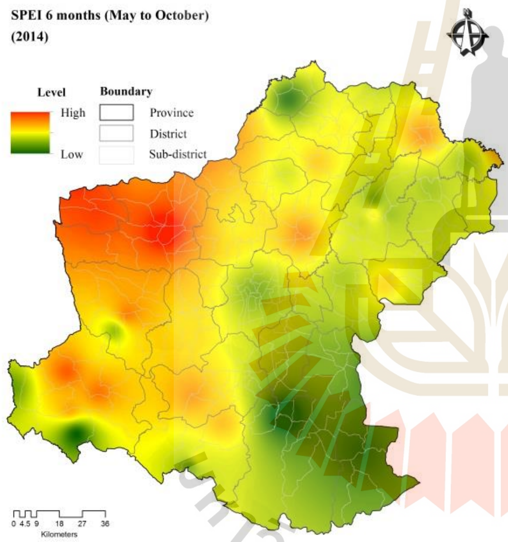
Figure 6.17 (Continued).



Proportion agricultural occupation (2013)



Population density (2013)



SPEI 6 months (May to October) (2014)

Figure 6.17 (Continued).

Distribution of annual agricultural drought sensitivity classification in 2014 is displayed in Figure 6.18. Meanwhile, percentage of annual agricultural drought sensitivity classification in 2014 at provincial and district levels are reported in Table 6.15 and Table 6.16, respectively. Comparison of annual agricultural drought sensitivity classification in 2014 at district level is displayed in Figure 6.19.

Table 6.15 Percentage of annual agricultural drought sensitivity in 2014 at provincial level.

Annual agricultural drought sensitivity in 2014	Percentage of areas (%)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
	11.47	18.38	24.86	29.27	16.02

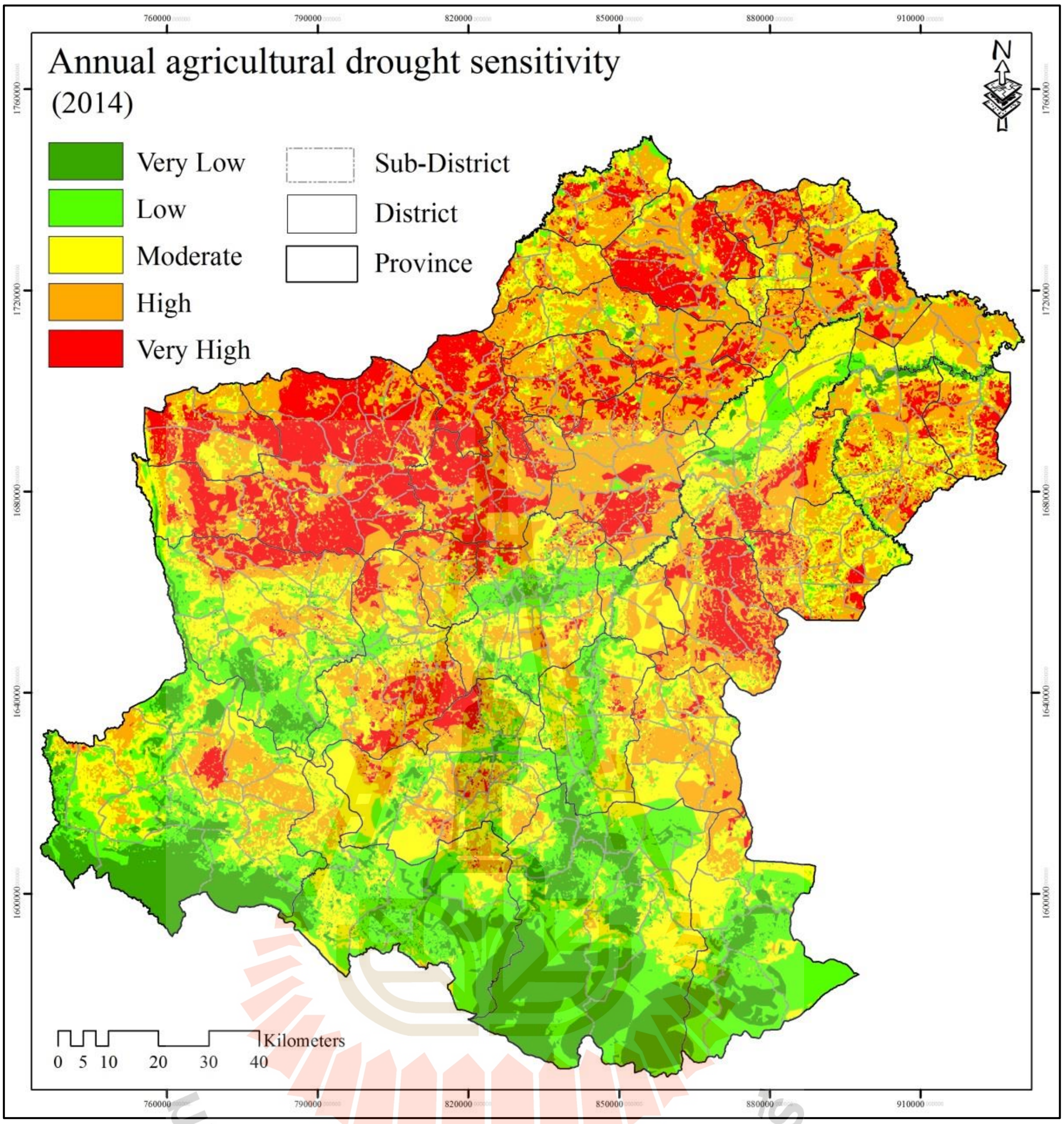


Figure 6.18 Distribution of annual agricultural drought sensitivity classification in 2014.

Table 6.16 Percentage of annual agricultural drought sensitivity classification in 2014 at district level.

Districts	Annual agricultural drought sensitivity (% of area)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.59	8.01	40.76	44.88	5.76
Bua Lai	0	2.37	7.25	54.2	36.18
Bua Yai	0.11	3.3	10.95	40.62	45.02
Chakkarat	0.27	2.24	14.57	43.26	39.66
Chaloem Phrakiat	6.79	14.99	46.95	30.25	1.02
Chok Chai	10.41	36.84	37.05	14.63	1.08
Chum Phuang	6.04	8.16	34.61	38.59	12.6
Dan Khun Thot	0.26	2.2	8.81	30.71	58.02
Huai Thalaeng	1.85	7.01	35.44	41.52	14.17
Kaeng Sanam Nang	1.07	8.54	22.74	49.23	18.42
Kham Sakae Saeng	0.15	3.44	12.46	57.69	26.27
Khom Thale So	1.3	8.08	24.55	48.2	17.87
Khon Buri	48.35	33.66	16.58	1.41	0
Khong	0.97	5.51	17	62.85	13.68
Lam Thamen Chai	3.21	4.89	28.7	41.94	21.26
Mueang Nakhon Ratchasima	8.44	28.43	32.2	24.89	6.04
Mueang Yang	4.08	8.87	33.01	52.24	1.8
Non Daeng	0.22	5.18	9.54	63.66	21.41
Non Sung	0.52	4.22	11.28	58.88	25.1
Non Thai	0	1.95	6.6	44.3	47.15
Nong Bunnak	0.24	6.43	39.66	50.18	3.49
Pak Chong	29.82	27.58	25.1	15.87	1.63
Pak Thong Chai	4.42	20.12	44.85	24.65	5.96
Phimai	5.4	15.98	44.98	23.27	10.37
Phra Thong Kham	0	0.38	4.62	32.64	62.36
Prathai	0.42	4.96	21.34	51.58	21.69
Sida	0.83	6.12	45.1	39.89	8.06
Sikhio	10.8	28.21	34.53	18.52	7.95
Soeng Sang	21.07	51.15	21.78	5.37	0.63
Sung Noen	1.27	11.06	30.1	38.2	19.37
Tepharak	0.08	2.32	19.95	41.77	35.89
Wang Nam Khiao	21.37	46.94	24.79	6.65	0.25

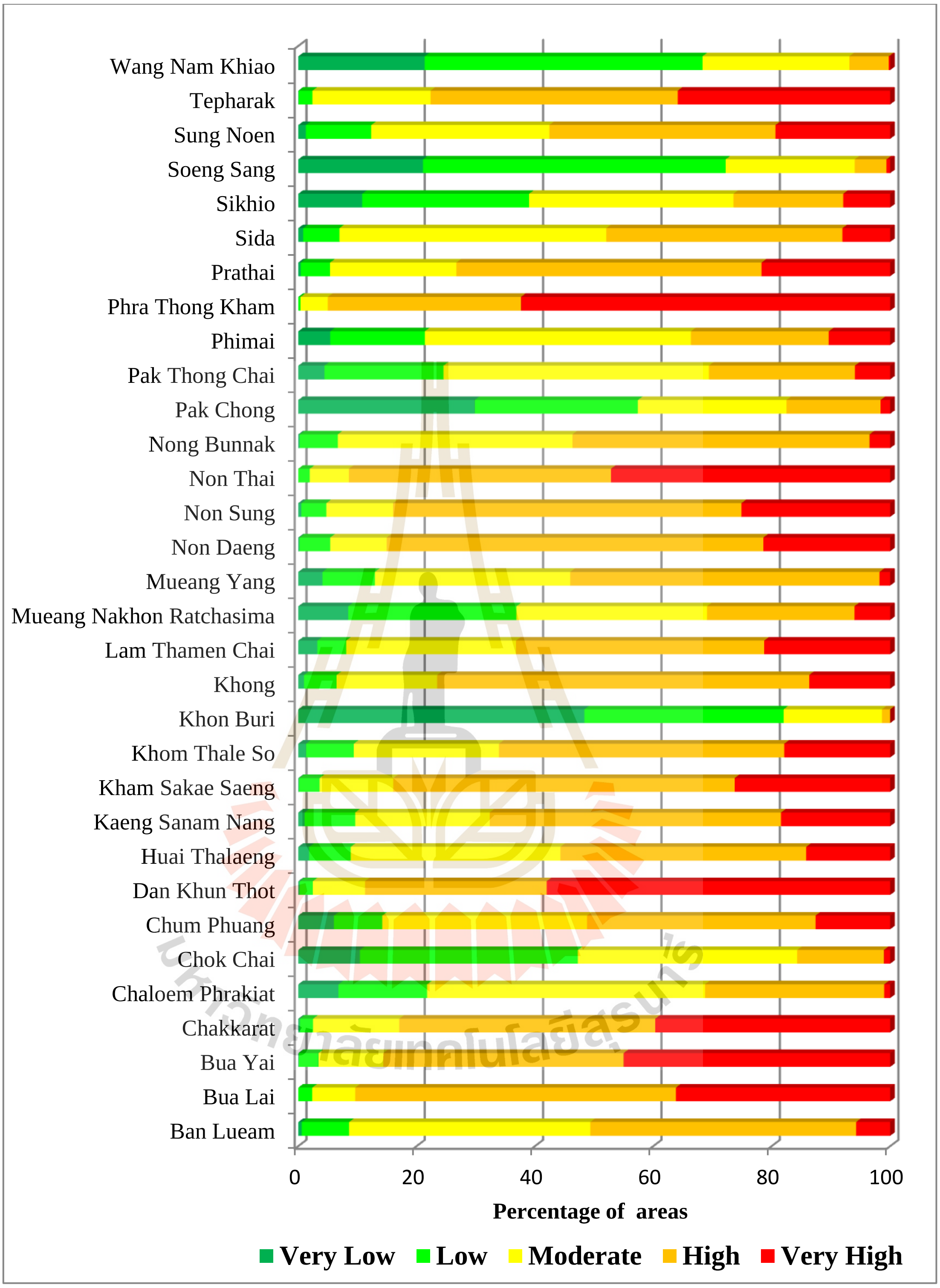


Figure 6.19 Comparison of annual agricultural drought sensitivity classification in 2014 at district level.

As results, at provincial level, it is found that about 29.85% of the total area are very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 45.29% of the total area while moderate agricultural drought sensitivity class covers area of 24.86% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 7 districts including Chok Chai, Khon Buri, Mueang Nakhon Ratchasima, Pak Chong, Sikhio, Soeng Sang, and Wang Nam Khiao. On contrary, combination of high and very high agricultural drought sensitivity is dominant in 22 districts including Ban Lueam, Bua Lai, Bua Yai, Chakkarat, Chum Phuang, Dan Khun Thot, Huai Thalaeng, Kaeng Sanam Nang, Kham Sakae Saeng, Khom Thale So, Khong, Lam Thamen Chai, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, Sida, Sung Noen, and Tepharak. Meanwhile, moderate agricultural drought sensitivity is mostly found in 3 districts including Chaloem Phrakiat, Pak Thong Chai, and Phimai.

In addition, annual agricultural drought sensitivity classification in 2014 at district level can be interpreted in term of climate condition by regroup original classes into 3 classes: wet (VL and L), normal (M) and drought (H and VH) as shown in Figure 6.20.

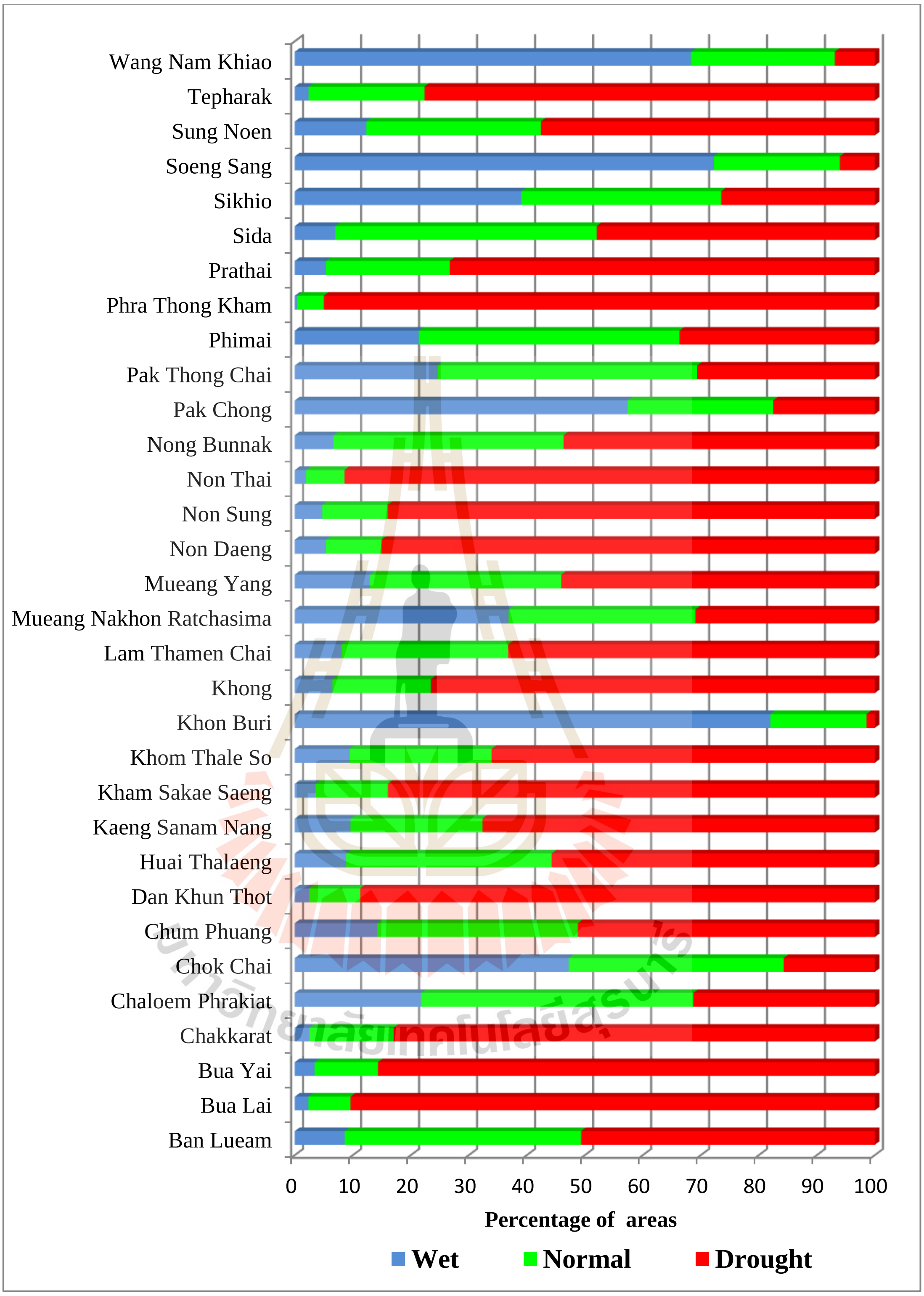


Figure 6.20 Comparison of annual agricultural drought sensitivity classification in 2014 by climate condition at district level.

Furthermore, annual agricultural drought sensitivity classification in 2014 is validated by comparison with drought effected area on agricultural crops in 2014 (Figure 6.21) as result shown in Table 6.17. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 78.67%. This percentage is greater than combination of very low, low, and moderate agricultural drought sensitivity classes that only cover area of 21.33%. Meanwhile, ROC value provides very high value of 0.898. The ROC value indicates a perfect fit. So, the validation result of annual agricultural drought sensitivity in 2014 can be acceptable.

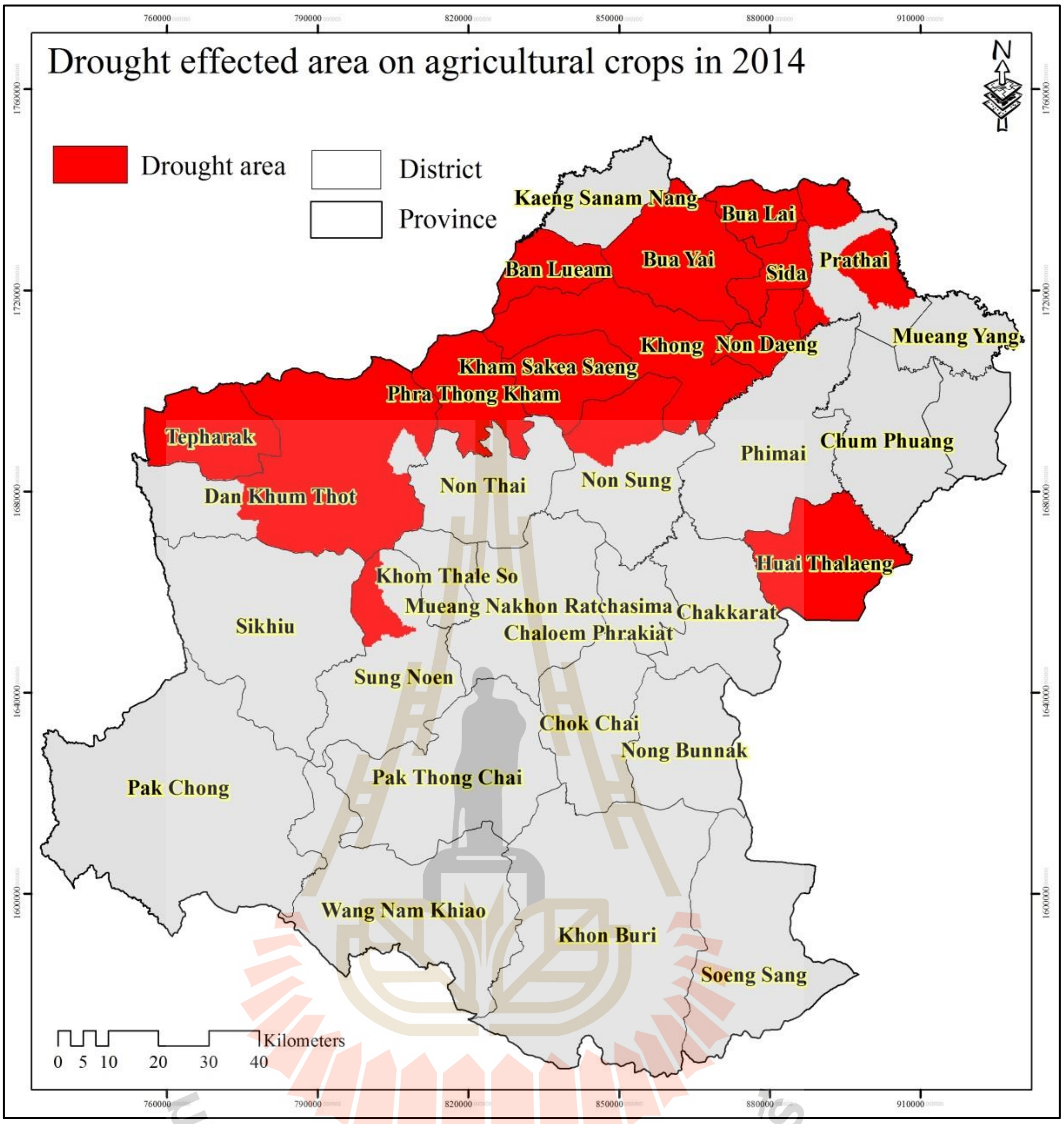


Figure 6.21 Distribution of drought effected area on agricultural crop in 2014.

Table 6.17 Comparison between annual agricultural drought sensitivity classification in 2014 and drought effected area on agricultural crops in 2014.

Drought effected area in 2014	Annual agricultural drought sensitivity classification in 2014 (% of area)				
	VL	**L**	**M**	**H**	**VH**
	0.50	4.14	16.69	43.70	34.97

6.2.3 Annual agricultural drought sensitivity assessment in 2015

The optimum derived multiple linear regression equation that provides the lowest average error of 0.789, relative error of 0.45 and correlation coefficient of 0.86 creates annual agricultural drought sensitivity index of 2015 with following equation:

$$OADS = 7.883 + 1.01\ DFR + 0.89\ LU + 1.31\ POPDEN + 0.98\ DD + 0.9\ APR - 0.82\ SPI + 0.5\ SOIL - 0.75\ ELE - 0.0044\ SOSA \quad (6.4)$$

Where: OADS is overall agricultural drought sensitivity index,

DFR	is distance to river,
LU	is land use in 2015,
POPDEN	is population density in 2015
DD	is drainage density,
APR	is agricultural economic crop production in 2015,
SPI	is SPI in 2015,
SOIL	is soil drainage,
ELE	is elevation,
SOSA	is SOSA in 2015

According to Eq. 6.4, the significant factors on overall agricultural drought sensitivity are distance to river, land use in 2015, population density in 2015, drainage density, economic crop production in 2015, SPI in 2015, soil, elevation, and SOSA in 2015. Herewith, 5 influential factors include agricultural occupation in 2015, agricultural irrigation area, PASG in 2015, SPEI 2015 and slope are excluded from the model.

In addition, five significant factors show positively correlate with overall agricultural drought sensitivity including distance to river, land use in 2015, population density in 2015, drainage density, and agricultural economic crop production in 2015 while four significant factors show positively correlate with overall agricultural drought sensitivity, namely SPI in 2015, soil, elevation, and SOSA in 2015. Herewith, top three dominant factors which provide high coefficient value are distance to river, population density in 2015, and drainage density. The relationship between observed (real) data and predicted data with relevant statistics is displayed in Figure 6.22. Meanwhile, independent variables as factor map for generating annual agricultural drought sensitivity index in 2015 is presented in Figure 6.23.

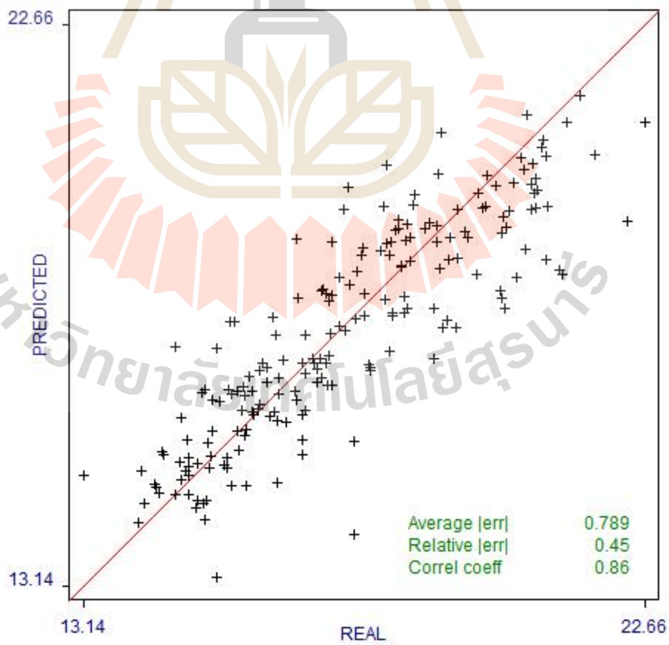


Figure 6.22 Relationship between original data and predicted data of overall agricultural drought sensitivity index model.

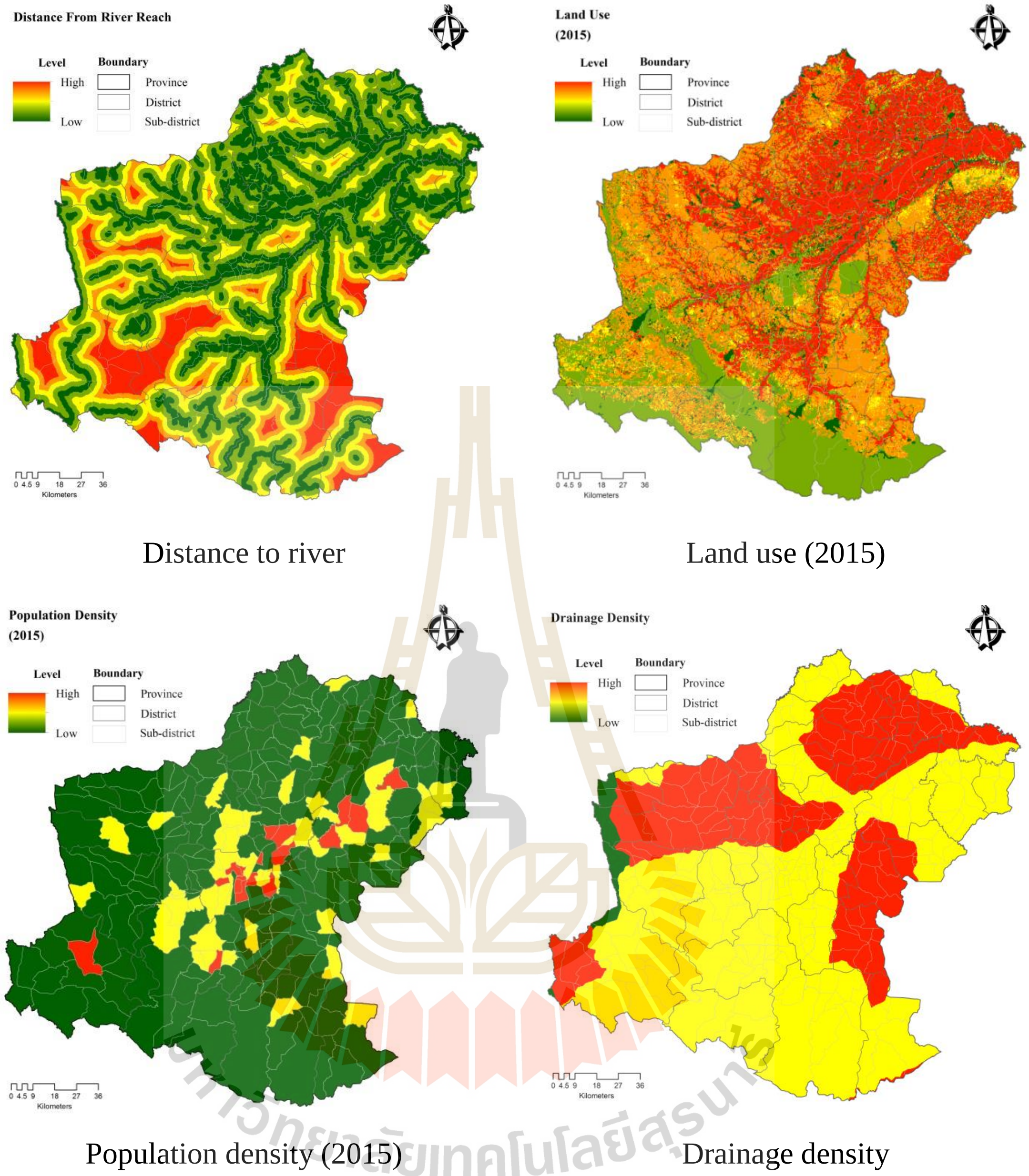
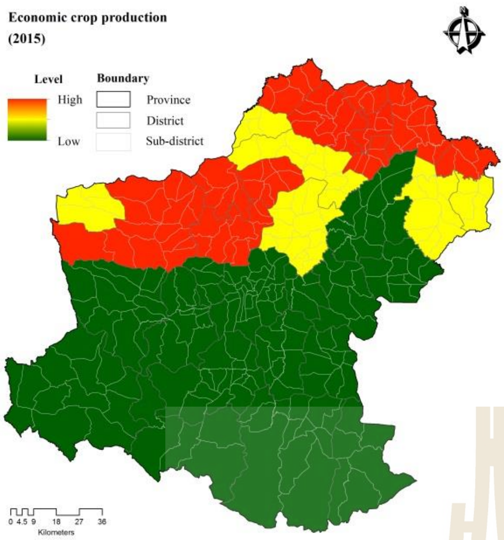
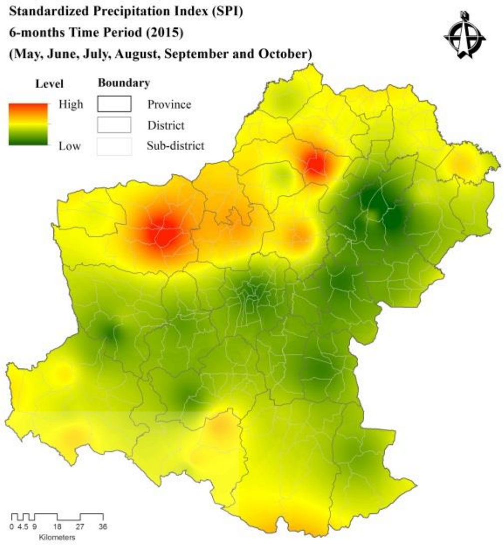


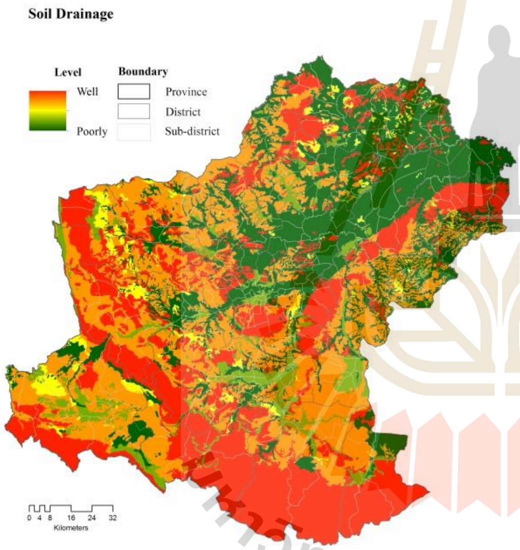
Figure 6.23 Factor maps for generating annual agricultural drought sensitivity index in 2015.



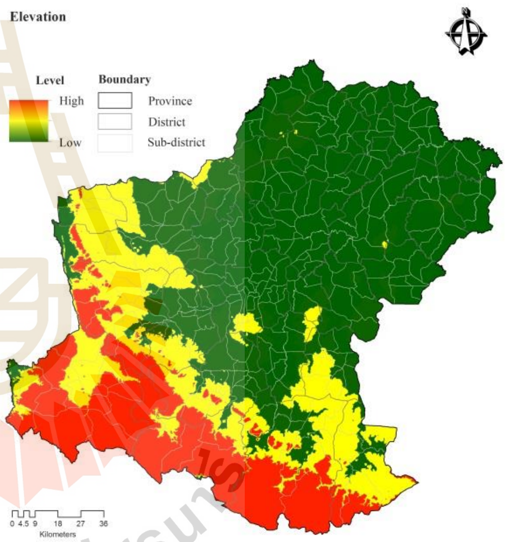
Economic crop production (2015)



SPI 6 months (May to October) (2015)

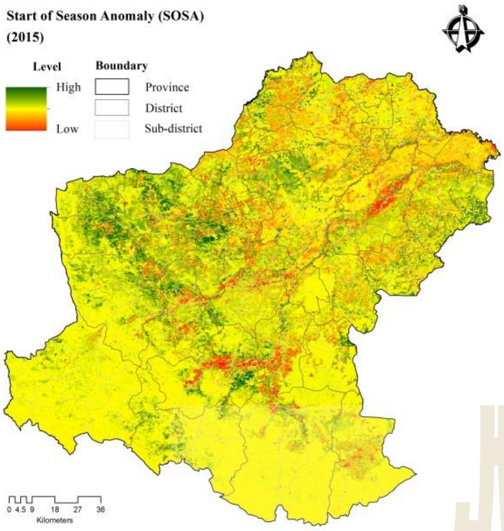


Soil drainage



Elevation

Figure 6.23 (Continued).



SOSA (2015)

Figure 6.23 (Continued).

Distribution of annual agricultural drought sensitivity classification in 2015 is displayed in Figure 6.24. Meanwhile, percentage of annual agricultural drought sensitivity classification in 2015 at provincial and district levels are reported in Table 6.18 and Table 6.19, respectively. Comparison of annual agricultural drought sensitivity classification in 2014 at district level is displayed in Figure 6.25.

Table 6.18 Percentage of annual agricultural drought sensitivity classification in 2015 at provincial level.

Annual agricultural drought sensitivity in 2015	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
	16.32	25.47	25.77	20.7	11.74

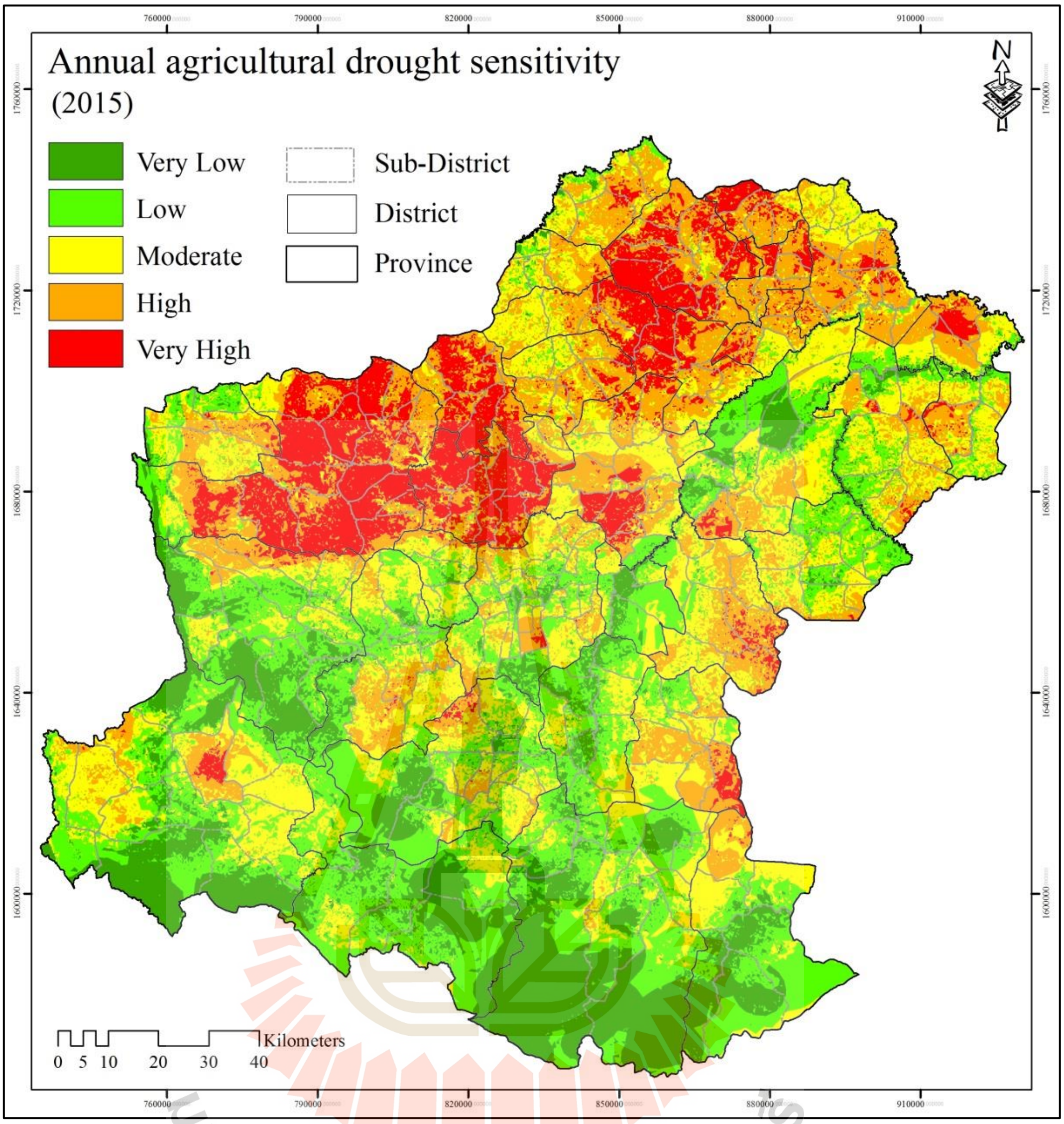


Figure 6.24 Distribution of annual agricultural drought sensitivity classification in 2015.

Table 6.19 Percentage of annual agricultural drought sensitivity classification in 2015 at district level.

Districts	**Annual agricultural drought sensitivity (% of area)**				
	Very Low	**Low**	**Moderate**	**High**	**Very High**
Ban Lueam	3.71	5.97	38.71	49.13	2.47
Bua Lai	0	0.58	5.73	30.46	63.23
Bua Yai	0	0.43	5.99	16.21	77.36
Chakkarat	1.87	10.16	36.69	48.56	2.72
Chaloem Phrakiat	23.5	45.42	28.93	2.15	0
Chok Chai	40.37	36.28	22.24	1.1	0
Chum Phuang	10.12	12.2	52.49	24.64	0.55
Dan Khun Thot	1.16	3.22	5.41	14.52	75.69
Huai Thalaeng	7.29	29.67	47.12	15.89	0.02
Kaeng Sanam Nang	0.01	9.37	11.11	65.92	13.59
Kham Sakae Saeng	0	2.81	7.1	67.92	22.17
Khom Thale So	11.74	17.96	49.17	19.86	1.27
Khon Buri	16.34	56.96	25.08	1.6	0.02
Khong	0.26	3.49	8.3	53.92	34.03
Lam Thamen Chai	3.47	8.7	36.83	50.68	0.31
Mueang Nakhon Ratchasima	41.01	30.92	24.66	3.38	0.03
Mueang Yang	1	7.66	8.19	49.71	33.45
Non Daeng	0.24	4.09	10.85	59.21	25.62
Non Sung	2.53	8.99	31.01	51.83	5.64
Non Thai	0.01	1.37	7.1	28.89	62.63
Nong Bunnak	0.67	6.3	39.15	53.26	0.62
Pak Chong	9.56	37.75	37.18	15.35	0.17
Pak Thong Chai	11.42	34.13	45.13	9.32	0
Phimai	21.18	47.58	30.19	1.05	0
Phra Thong Kham	0	0.07	4.31	15.47	80.15
Prathai	0.32	5.3	13.64	54.03	26.72
Sida	0	1.88	7.19	45.61	45.32
Sikhio	15.1	30.31	37.57	11.93	5.09
Soeng Sang	6.43	51.62	32.02	9.55	0.38
Sung Noen	7.87	23.59	44.84	22.93	0.77
Tepharak	2.32	9.07	23.77	50.53	14.31
Wang Nam Khiao	2.8	43.59	43.18	10.43	0

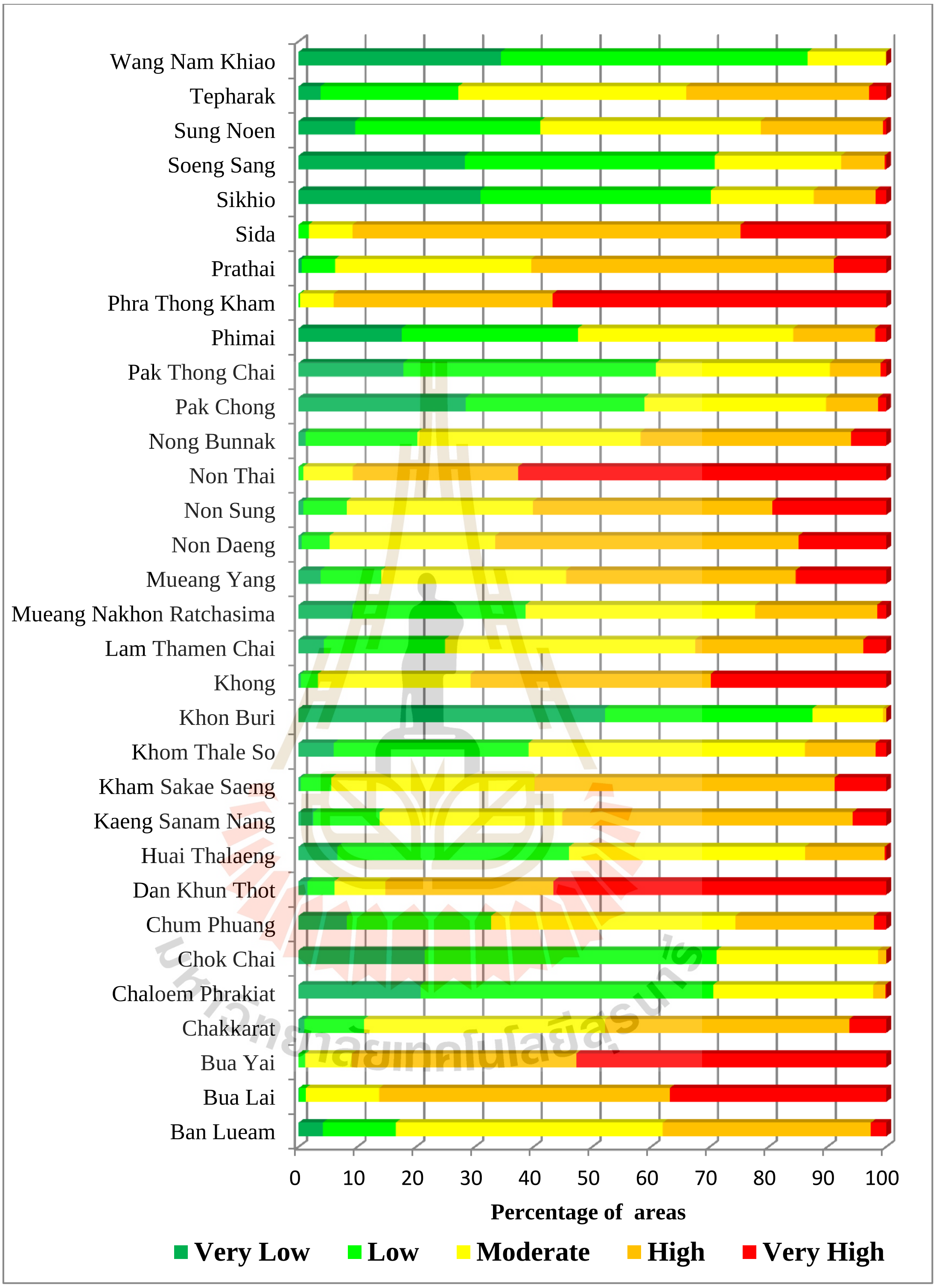


Figure 6.25 Comparison of annual agricultural drought sensitivity classification in 2015 at district level.

As results, at provincial level, it is found that about 41.79% of the total area is very low and low agricultural drought sensitivity but area of high and very high agricultural drought sensitivity is about 32.44% of the total area while moderate agricultural drought sensitivity covers area of 25.77% of the total area.

At district level, combination of very low and low agricultural drought sensitivity is dominant in 11 districts including Chaloem Phrakiat, Chok Chai, Huai Thalaeng, Khon Buri, Pak Chong, Pak Thong Chai, Phimai, Sikhio, Soeng Sang, Sung Noen, and Wang Nam Khiao. On contrary, combination of high and very high agricultural drought sensitivity is dominant in 15 districts including Bua Lai, Bua Yai, Chakkarat, Dan Khun Thot, Kaeng Sanam Nang, Kham Sakae Saeng, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, and Sida. Meanwhile, moderate agricultural drought sensitivity is mostly found in 4 districts including Ban Lueam, Chum Phuang, Khom Thale So, Lam Thamen Chai, Mueang Nakhon Ratchasima, and Tepharak.

In addition, annual agricultural drought sensitivity classification in 2015 at district level can be interpreted in term of climate condition by regroup original classes into 3 classes: wet (VL and L), normal (M) and drought (H and VH) as shown in Figure 6.26.

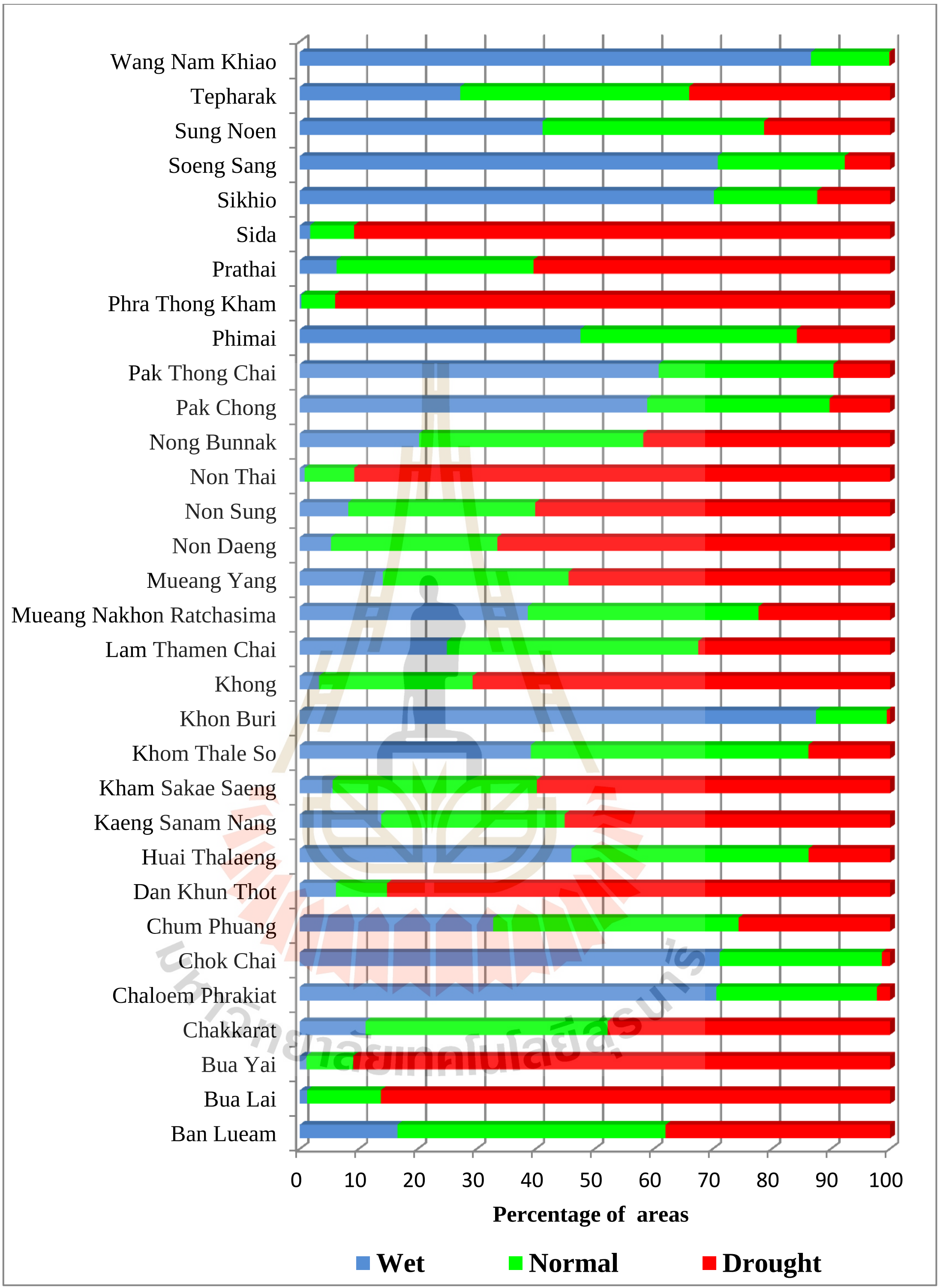


Figure 6.26 Comparison of annual agricultural drought sensitivity classification in 2014 by climate condition at district level.

Furthermore, annual agricultural drought sensitivity classification in 2015 is validated by comparison with drought effected area on agricultural crops in 2015 (Figure 6.27) as result shown in Table 6.20. It was found that combination of high and very high agricultural drought sensitivity is consistent with drought effected area on agricultural crops about 67.61%. This percentage is greater than combination of very low, low, and moderate agricultural drought sensitivity classes that only cover area of 32.39%. Meanwhile, ROC value provides very high value of 0.887. The ROC value indicates a perfect fit. So, the validation result of annual agricultural drought sensitivity in 2015 can be acceptable.

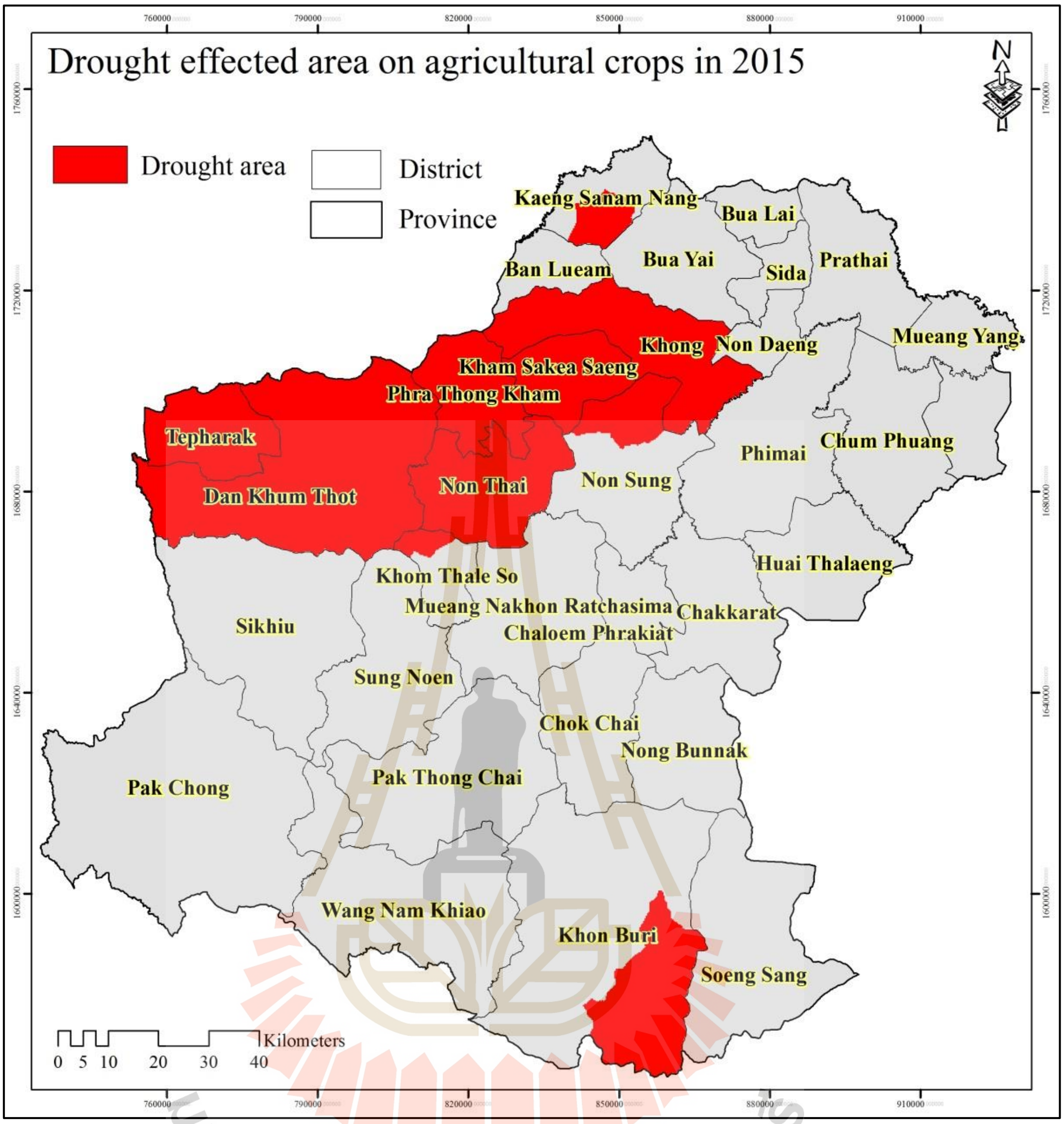


Figure 6.27 Distribution of drought effected area on agricultural crop in 2015.

Table 6.20 Comparison between annual agricultural drought sensitivity classification in 2015 and drought effected area on agricultural crops in 2015.

	Annual agricultural drought sensitivity classification in 2015 (% of area)				
	VL	**L**	**M**	**H**	**VH**
Drought affected area	7.42	8.29	16.68	31.83	35.78

Summary

According to annual agricultural drought sensitivity classification, the most dominant class in 2012 and 2014 at province level is combination of high and very high and covers area of 41.89%, and 45.29%, respectively. Meanwhile, combination of very low and low annual agricultural drought sensitivity is dominant in 2015 and covers area of 41.79% (Figure 6.28).

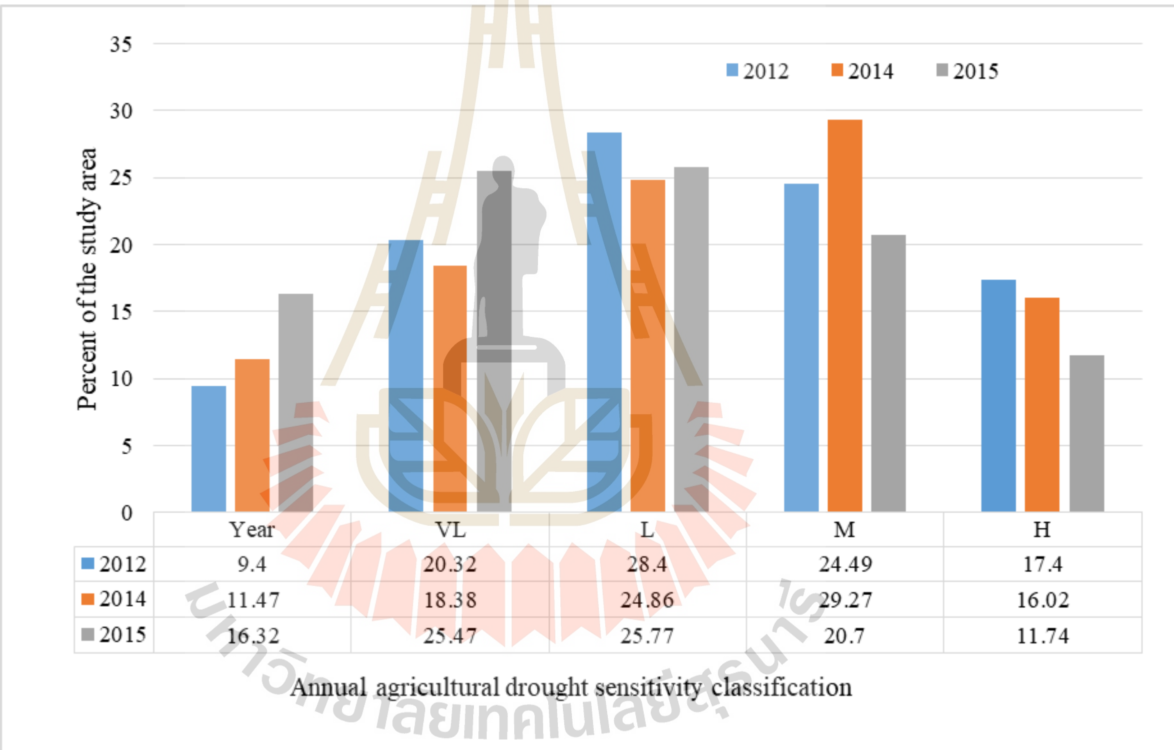


Figure 6.28 Percentage of annual agricultural drought sensitivity classification in 2012, 2014, and 2015.

At district level, there are 14 districts including Bua Lai, Bua Yai, Chakkarat, Dan Khun Thot, Kaeng Sanam Nang, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, and Sida incur high and very high annual agricultural drought sensitivity in every year. Likewise, there are only 4 districts including Khon Buri, Pak Chong, Sikhio, and Wang Nam Khiao incur very low and low annual agricultural drought sensitivity in every year. Meanwhile, there are 14 districts including Ban Lueam, Chaloem Phrakiat, Chok Chai, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khom Thale So, Lam Thamen Chai, Mueang Nakhon Ratchasima, Pak Thong Chai, Phimai, Soeng Sang, Sung Noen, and Tepharak have different annual agricultural drought sensitivity levels among 3 years.

According to consistency test and ROC for best fitness of the model between annual agricultural drought sensitivity classification from 3 years with annual drought effected area on agricultural crops in corresponding year for validation, annual agricultural drought sensitivity classification are acceptable as comparative summary in Table 6.21. It was found that combination of high and very high annual agricultural drought sensitivity in 2012, 2014, and 2015 are consistent with drought effected area on agricultural crops in corresponding year about 56.07%, 78.67%, and 67.61%, respectively. Meanwhile, ROC values of annual agricultural drought sensitivity classification in 2012, 2014, and 2015 are 0.851, 0.898, and 0.887, respectively. Thus, the validate result of annual agricultural drought sensitivity in 2014 can be acceptable.

Table 6.21 Comparison of consistency test and ROC measurement for annual agricultural drought sensitivity classification in 3 years.

Drought effected area in year	Annual agricultural drought sensitivity (% of area)					ROC
	VL	L	M	H	VH	
2012	2.98	11.33	29.63	33.17	22.90	0.851
2014	0.50	4.14	16.69	43.70	34.97	0.898
2015	7.42	8.29	16.68	31.83	35.78	0.887

As results, it can be suggested that the optimum derived multiple linear equation for annual agricultural drought sensitivity classification is Eq. 6.3 since it provides the highest consistency percentage and ROC value.

Discussions

Agricultural drought sensitivity assessment is here considered into 2 patterns: (1) overall agricultural drought sensitivity assessment and (2) annual agricultural drought sensitivity assessment that derive to identify different characteristics of agricultural drought sensitivity of time period. The first pattern is applied to describe drought characteristics of specific area while the second pattern is applied to characterize the effected agricultural drought in each year.

In this study, four conditions with various factors on overall agricultural drought sensitivity consist of vegetation, climate, physical and socioeconomic condition. For vegetation condition, the time period of agricultural phenology is derived from the start and end of crop season that effectively indicate abundance or dwarf of vegetation in each year. Especially, time series of NDVI and VCI in start to end of crop season is very important for assessing healthy agricultural crop. While, the climate condition use SPI and SPEI that are the most popular meteorological drought index for identify wet or dry situation. Meanwhile, the physical condition selects the significant factors that relevant agricultural condition which consists of land use, soil drainage, agricultural irrigation area, slope, elevation, distance to river and drainage density. Lastly, the socioeconomic condition consists of agricultural occupation, agricultural production and population density that are important factors since they make indeed understand to sense of relevant human factors from impact of agricultural drought.

On contrary, most of existing drought studies in Thailand applied only few conditions. Wattanakij (2006); Jamphon (2004); Homdee et al. (2016); Wichitarapongsakun et al. (2016) applied only climate condition. Mongkolsawat et al., (2000); Prathumchai et al. (2001); Suwanwerakamtorn et al. (2005); Udomchoke and Chuchip (2005); Kaewpruksapimon, (2006); Punprasit (2006); Department of Disaster Prevention and Mitigation, (2007); Srisurat (2010); Chanchaeng (2012); Ano et al. (2013) applied climate and physical conditions. Mongkolsawat et al. (2009) used vegetation and climate conditions. Baimoung et al., (2005) applied three conditions: vegetation, climate and physical conditions for drought assessment. Therefore, the integration of significant conditions (vegetation, climate, physical and socioeconomic) can be considered as a prototype of agricultural drought sensitivity assessment in Thailand.

The unique characteristics of overall agricultural drought sensitivity, which were derived based on the average value of influential factors, indicates severity of drought in each specific area at district and province levels. Moreover, inter-crop season (early and late of crop season: 3 months) and crop season (6 months) illustrate the dominant of time period that significant identify to agricultural drought sensitivity.

The results of the study disclosed that overall agricultural drought sensitivity can be indicated the effected agricultural drought area of the inter-crop season and crop season. The current study is expected to serve as a guideline for preparedness, mitigation, and early warning system to government agencies who respond agricultural drought.

CHAPTER VII

ADAPTIVE CAPACITY ASSESSMENT

This chapter presents results of the first objectives focusing on adaptive capacity assessment as component of agricultural drought vulnerability analysis. Main results consist of (1) characteristics of adaptive capacity factor and (2) adaptive capacity assessment. Details of each component is separately described and discussed in this chapter.

7.1 Characteristics of adaptive capacity factor

Adaptive capacity factors are the degree ability of people to adjust to impact of drought. In this study, the selected factors consist of (1) proportion of people below poverty line, (2) illiteracy rate, (3) income from agricultural sector, (4) farm holding size, (5) income from non-agricultural sector and (6) information accessibility. Brief descriptions of each are as follow:

(1) Proportion of people below poverty line: Proportion of people below poverty line at district level is here extracted from socio-economic report at household level of National Statistical Office (2016). Basically, poverty line varies from place to place. Figure 7.1 displays variation of poverty line from three levels (province, region and country) between 2000 and 2016.

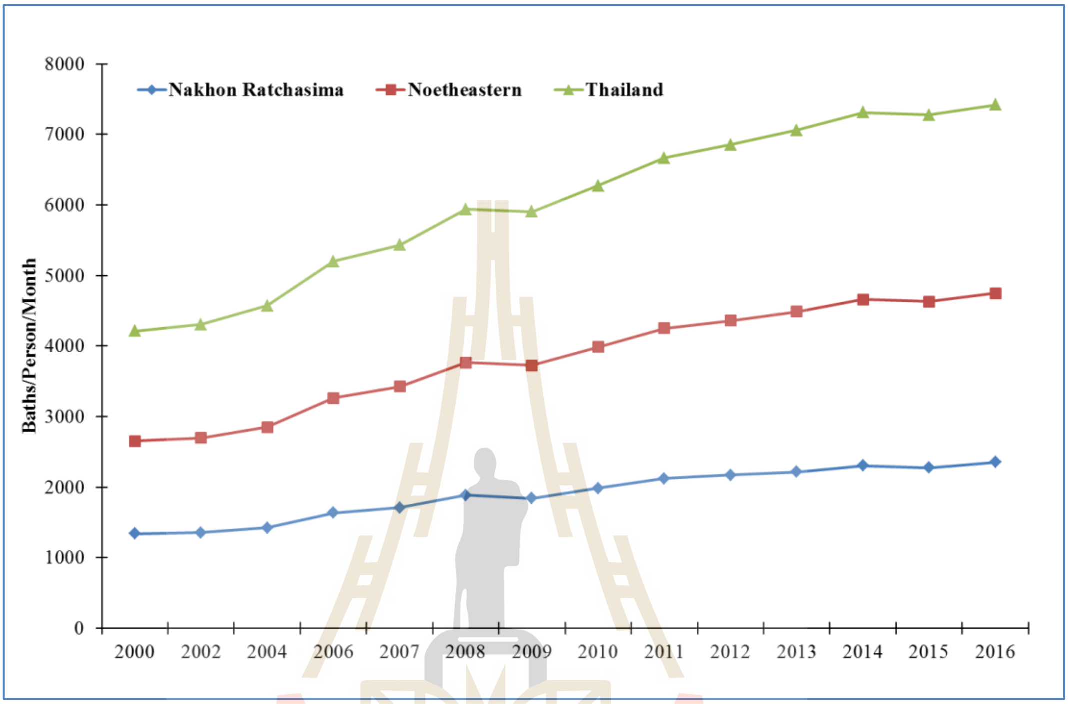


Figure 7.1 Variation of poverty line of Thailand by province, region and country during 2000 to 2016.

(2) Illiteracy: It represents human capital to reduce effect of drought. Illiteracy was extracted from Village Basic Information (NRD 2C) data which comprises 7 groups of 33 indicators (Table 7.1). The information of illiteracy rate is retrieved from Educational Level of People indicator under Knowledge and Education group.

(3) Income from agricultural sector: Basically, areas with higher farm income are able to prepare and respond to effect of drought. This factor is combined income from 2 indicators: Rice Productivity and Other Crop Productivity under Economy group of Village Basic Information (NRD 2C) data.

(4) Farm holding size: In general, areas with higher farm holding size are able to prepare and respond to impact of drought. This factor is combined agricultural areas from 2 indicators: Rice Productivity and Other Crop Productivity under Economy group of Village Basic Information (NRD 2C) data.

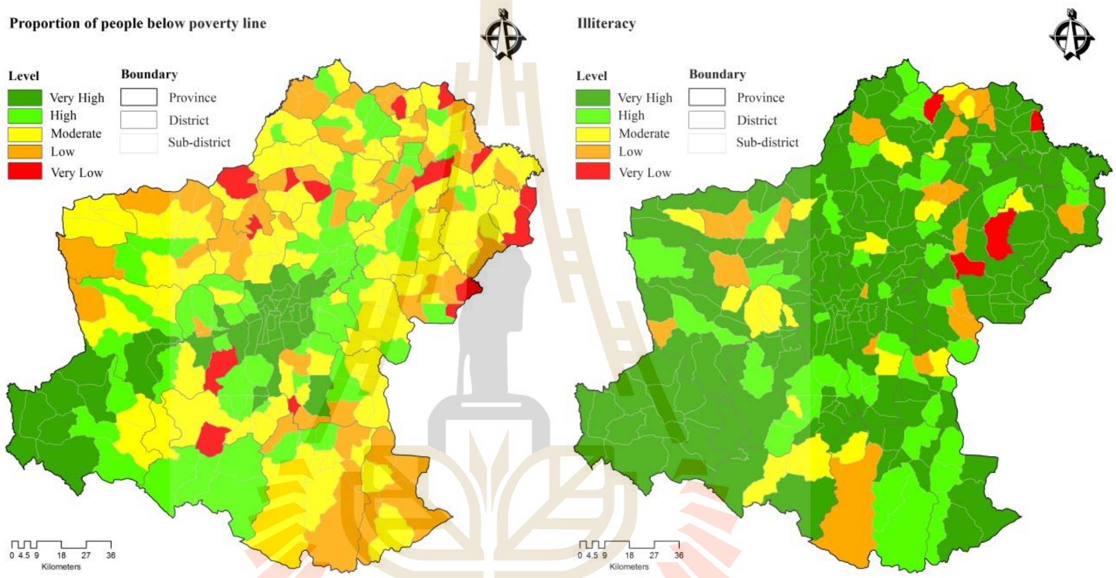
(5) Income from non-agricultural sector: Basically, areas with a higher dependence on agricultural are assumed to be a less economically diversified and more susceptible to drought. This factor is extracted from Employment indicator under Economy group of Village Basic Information (NRD 2C) data.

(6) Information accessibility: The quality of infrastructure is an important measure of the relative adaptive capacity of areas. This factor is extracted from Communication indicator under Infrastructure group of Village Basic Information (NRD 2C) data.

Table 7.1 Structure of Village Basic Information (NRD 2C) data: Group and indicators.

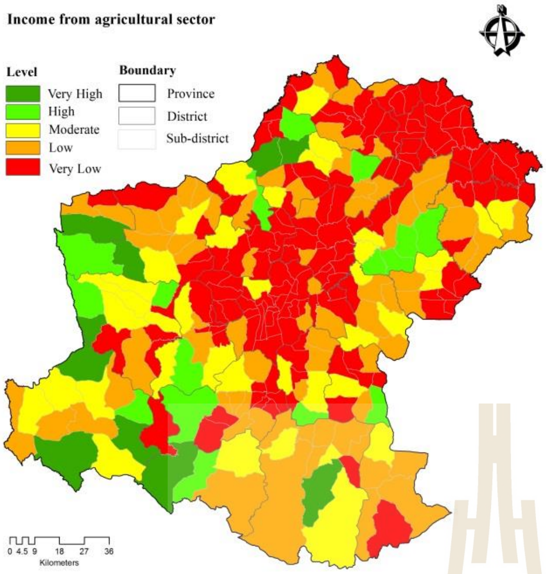
Group	**Indicators**
Infrastructure (7 indicators)	Road
	Clean drinking water
	Water for domestic uses
	Water for agriculture
	Electricity accessibility
	Farmland ownership
	Communication
Economy (7 indicators)	Employment
	Employment within community
	Rice Productivity
	Other Crop Productivity
	Other Agricultural Productivity
	Household Industry
	Benefits from Tourism
Health and Sanitation (3 indicators)	Work safety
	Contagious Disease Prevention
	Sport Activities
Knowledge and Education (3 indicators)	Educational Level of People
	Study Continuation Rate (High School)
	Present Educational Enrollment
Participation and Community Strength (5 indicators)	Community Participation
	People Grouping
	Access to Community Fund
	Community Learning
	Social Security
Natural resources and Environment (5 indicators)	Soil Quality
	Water Quality
	Forest Recovery/Tree Planting
	Land Utilizations
	Environmental Management
Community Risk and Disaster (3 indicators)	Safety from Drug
	Safety from Disaster
	Safety from Risk within Community

In practice, adaptive capacity factors to drought effect are classified into 5 levels (VL, L, M, H, and VH) using natural break method and then combined to generate adaptive capacity index using Eq. 3.4. Map of adaptive capacity factors is illustrated in Figure 7.2 while adaptive capacity classification and rating of each factor is reported in Tables 7.2 to 7.7.

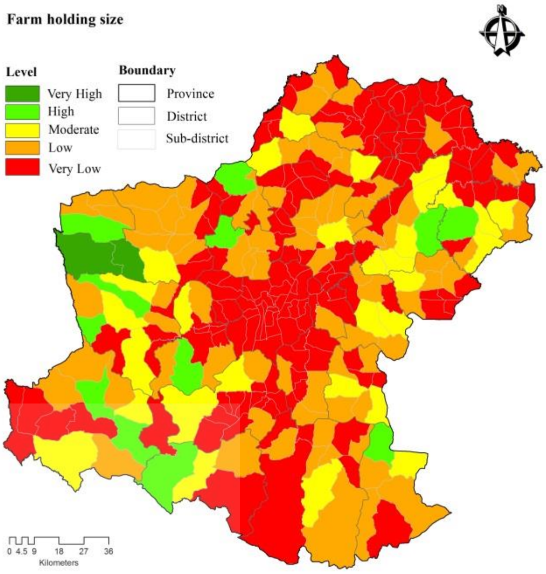


Proportion of people below poverty line Illiteracy

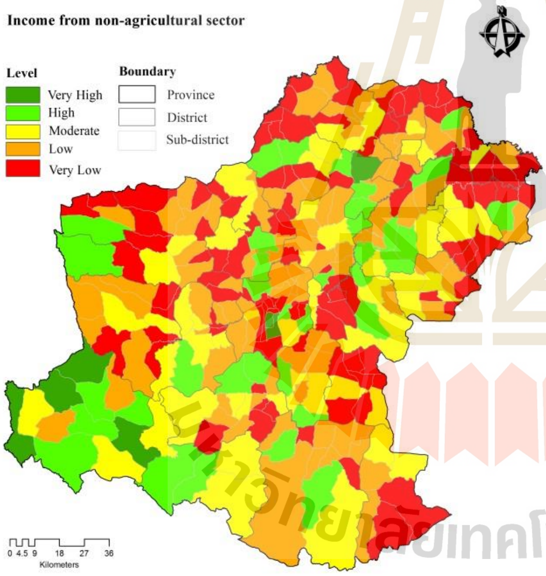
Figure 7.2 Distribution of adaptive capacity factors.



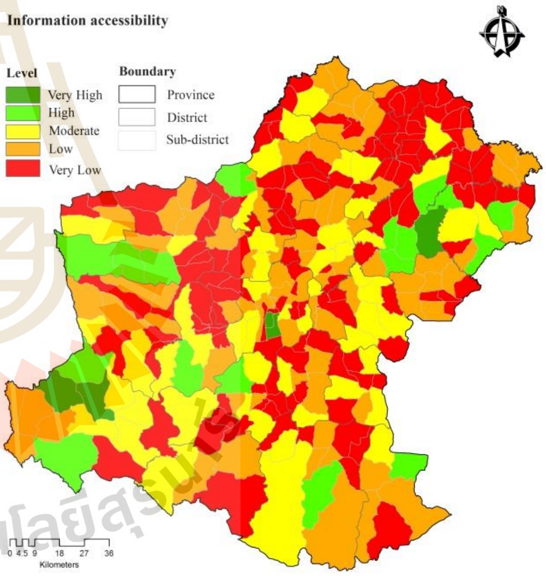
Income from agricultural sector



Farm holding size



Income from non-agricultural sector



Information accessibility

Figure 7.2 (Continued).

Table 7.2 Classification of adaptive capacity by proportion of people below poverty line.

Level of adaptive capacity	Proportion of people below poverty line (%)	Rating
Very low	>20.09	1
Low	15.72-20.09	2
Moderate	12.83-15.72	3
High	9.86-12.83	4
Very high	<9.86	5

Table 7.3 Classification of adaptive capacity by illiteracy.

Level of adaptive capacity	Illiteracy (person)	Rating
Very low	>1,051	1
Low	393-1,051	2
Moderate	222-393	3
High	85-222	4
Very high	< 85	5

Table 7.4 Classification of adaptive capacity by income from agricultural sector.

Level of adaptive capacity	Income from agricultural sector (Baht/Y)	Rating
Very low	< 7,373,656	1
Low	7,373,656-15,042,259	2
Moderate	15,042,259-24,480,539	3
High	24,480,539-43,946,992	4
Very high	>43,946,992	5

Table 7.5 Classification of adaptive capacity by farm holding size.

Level of adaptive capacity	Farm holding size (Rai)	Rating
Very low	<103,083	1
Low	103,083-194,397	2
Moderate	194,397-297,270	3
High	297,270-469,913	4
Very high	>469,913	5

Table 7.6 Classification of adaptive capacity by income from non-agricultural sector.

Level of adaptive capacity	Income from non-agricultural sector (Baht/Y)	Rating
Very low	< 1,346,577	1
Low	1,346,5777-2,433,789	2
Moderate	2,433,789-3,996,790	3
High	3,996,790-6,710,143	4
Very high	>6,710,143	5

Table 7.7 Classification of adaptive capacity by information accessibility.

Level of adaptive capacity	Information accessibility (Household)	Rating
Very low	<5,612	1
Low	5,612-9,696	2
Moderate	9,696-15,667	3
High	15,667-30,660	4
Very high	>30,660	5

7.2 Adaptive capacity assessment

Distribution of adaptive capacity classification is displayed in Figure 7.3. Meanwhile, percentage of adaptive capacity classification at provincial and district levels are presented in Table 7.8 and Table 7.9, respectively. Comparison of adaptive capacity classification at district level is displayed in Figure 7.4.

Table 7.8 Percentage of adaptive capacity classification at provincial level.

Adaptive capacity index	Percentage of areas (%)				
	Very low	Low	Moderate	High	Very high
	7.53	31.2	23.45	24.91	12.9

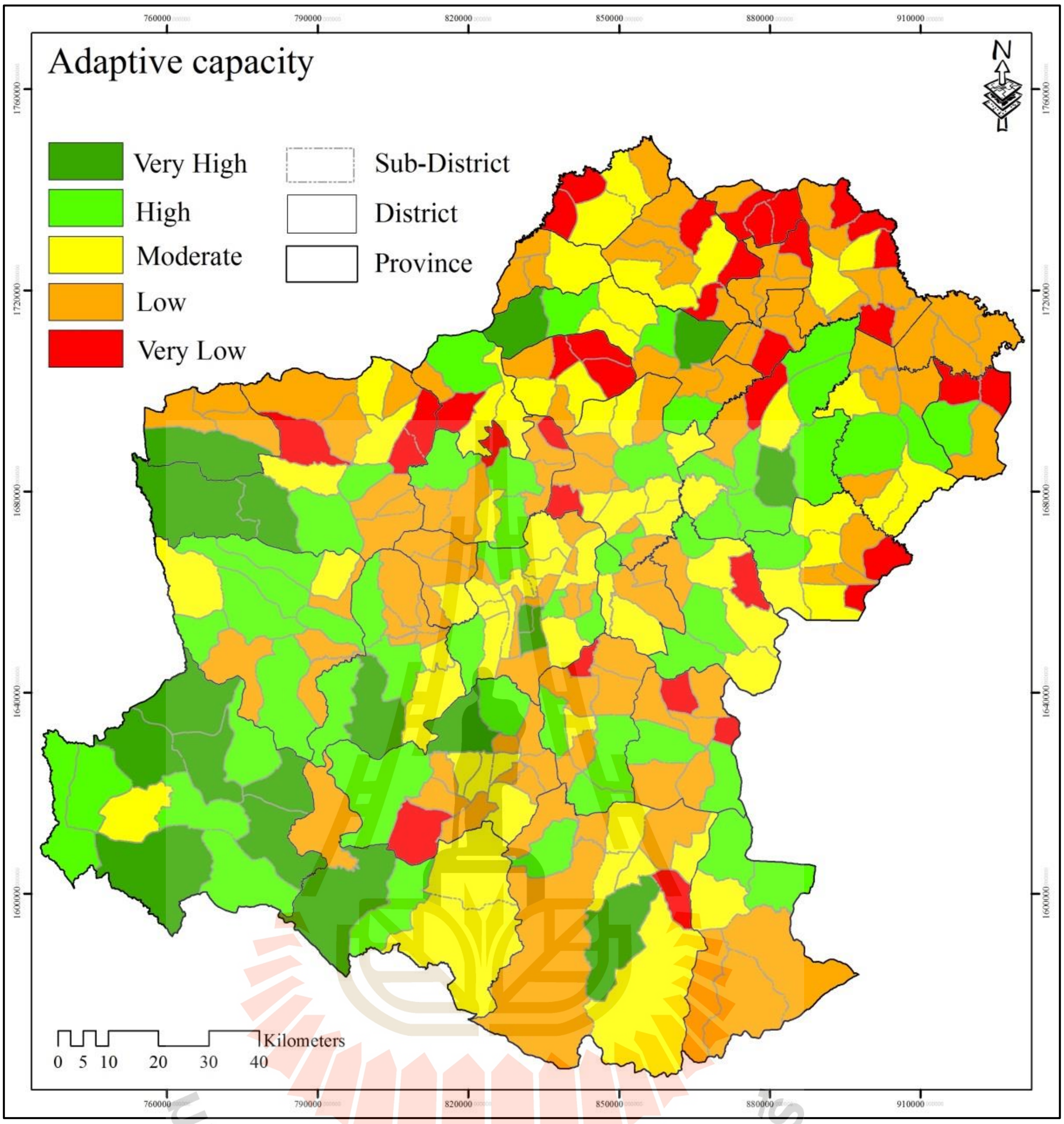


Figure 7.3 Distribution of adaptive capacity classification.

Table 7.9 Percentage of adaptive capacity classification at district level.

Districts	Percentage of adaptive capacity classification				
	Very low	Low	Moderate	High	Very high
Ban Lueam	0.05	48.94	50.71	0.19	0.11
Bua Lai	76.27	23.64	0.08	0	0
Bua Yai	23.15	44.48	32.27	0.03	0.07
Chakkarat	9.53	10.07	41.22	39.18	0
Chaloem Phrakiat	0	45.05	43.95	11	0
Chok Chai	4.33	48.06	5.06	42.55	0
Chum Phuang	0.04	34.21	31.94	33.81	0
Dan Khun Thot	13.1	30.44	15.68	13.49	27.29
Huai Thalaeng	14.56	20.49	49.78	15.15	0.02
Kaeng Sanam Nang	27.77	19.81	52.42	0	0
Kham Sakae Saeng	40.57	26.79	32.56	0.04	0.04
Khom Thale So	0	76.35	23.55	0.1	0
Khon Buri	2.89	45.74	35.93	4.77	10.68
Khong	0.12	22.2	19.94	28.98	28.76
Lam Thamen Chai	34.36	34.9	0.02	30.72	0
Mueang Nakhon Ratchasima	0.04	25.33	45.51	23.39	5.73
Mueang Yang	0.38	99.62	0	0	0
Non Daeng	27	72.8	0	0.17	0.03
Non Sung	5.14	33.91	44.07	16.88	0
Non Thai	9.31	40.8	7.35	42.54	0
Nong Bunnak	12.74	54.97	0.03	32.27	0
Pak Chong	0	0.07	6.21	39.32	54.4
Pak Thong Chai	10.25	26.06	16.51	35.87	11.31
Phimai	6.27	8.6	13.44	62.2	9.5
Phra Thong Kham	14	9.5	39.9	36.56	0.05
Prathai	27.55	49.92	22.38	0.15	0
Sida	21.94	77.95	0.11	0	0
Sikhio	0	23.56	17.48	58.87	0.1
Soeng Sang	0.03	64.24	11.6	24.13	0
Sung Noen	0	21.57	19.68	38.05	20.7
Tepharak	0.07	51.51	0.1	0	48.31
Wang Nam Khiao	0.03	14.51	48.43	12.61	24.42

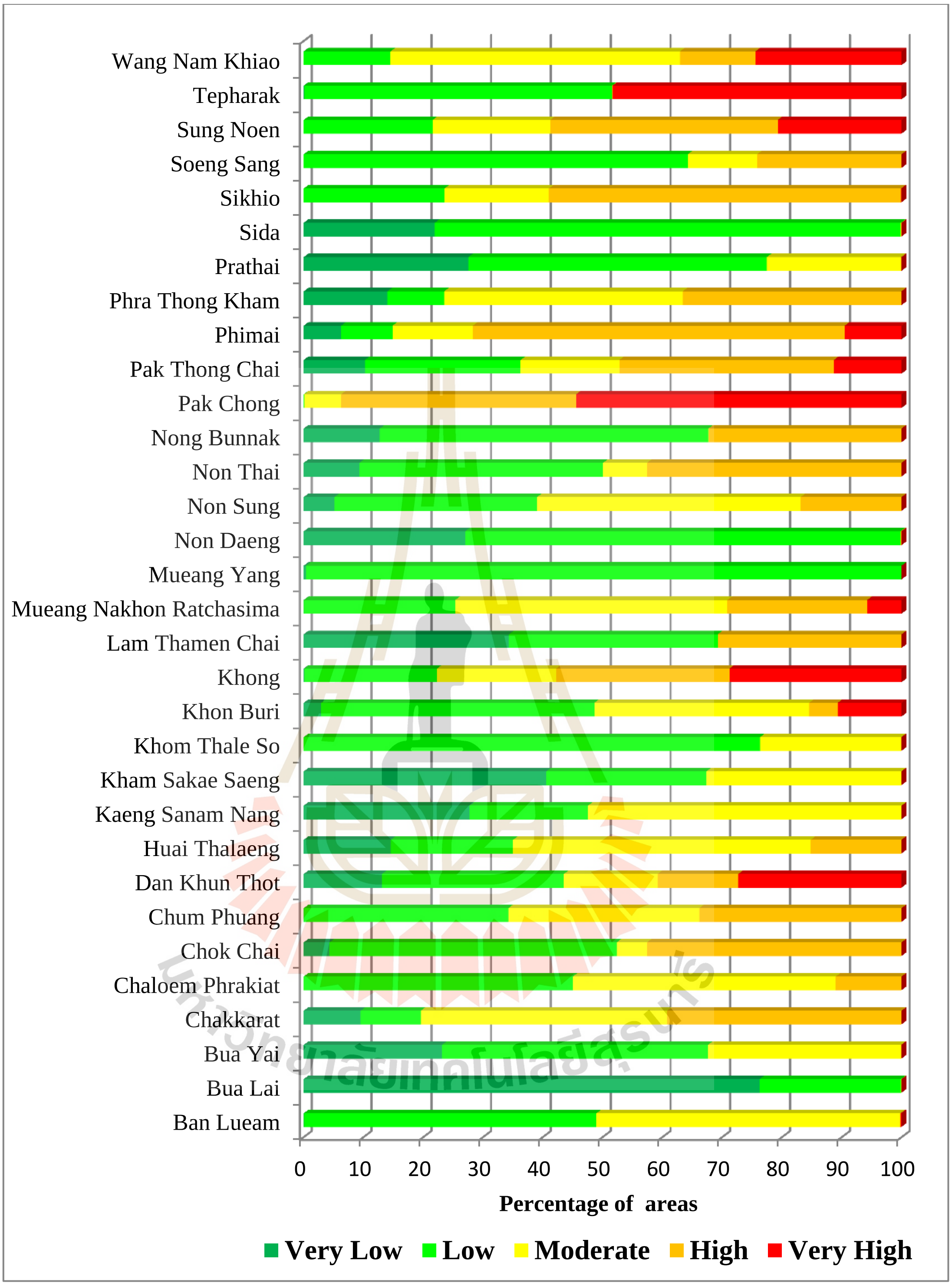


Figure 7.4 Comparison of adaptive capacity classification to drought effect at district level.

Summary

According to adaptive capacity classification, the most dominant class of adaptive capacity to agricultural drought effect at provincial level is very low and low adaptive capacity and covers area of 38.73%, while moderate, and high and very high adaptive capacity to agricultural drought effect cover area of 23.45% and 37.81%, respectively.

At district level, very low and low adaptive capacity to drought effect are dominant in 18 districts including Bua Lai, Bua Yai, Chaloem Phrakiat, Chok Chai, Chum Phuang, Dan Khun Thot, Kham Sakae Saeng, Khom Thale So, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, Non Thai, Nong Bunnak, Prathai, Sida, Soeng Sang, and Tepharak. On contrary, high and very high adaptive capacity to drought effect are dominant in 6 districts including Khong, Pak Chong, Pak Thong Chai, Phimai, Sikhio, and Sung Noen. Meanwhile, moderate adaptive capacity to drought effect is found in 8 districts including Ban Lueam, Chakkarat, Huai Thalaeng, Kaeng Sanam Nang, Mueang Nakhon Ratchasima, Non Sung, Phra Thong Kham, and Wang Nam Khiao.

In summary, the adaptive capacity plays important role to mitigate the agricultural drought effect in each district. It is significant indicator of drought that relevant to human. In the other words, it shows how well people can mitigate drought effect from high to low severity level. In this study, the derived adaptive capacity is integrated with drought exposure and overall agricultural drought to assess agricultural drought vulnerability as a prototype in Thailand.

CHAPTER VIII

AGRICULTURAL DROUGHT VULNERABILITY ASSESSMENT

This chapter presents results of the second objective focusing on agricultural drought vulnerability analysis by integration of exposure hazard, agricultural drought sensitivity and adaptive capacity (see Figure 3.8). Main results consists of (1) component of agricultural drought vulnerability analysis and (2) agricultural drought vulnerability assessment. Details of each component is separately described and discussed in this chapter.

8.1 Component of agricultural drought vulnerability analysis

Three components of agricultural drought vulnerability analysis consists of (1) drought exposure hazard classification (SPI-3m7, SPI-3m10, and SPI-6m10), (2) overall agricultural drought sensitivity classification (3m7, 3m10, and 6m10) and (3) adaptive capacity classification. The relationship structure of each component for agricultural drought vulnerability analysis is simplify displayed as flowchart diagram with input, process, and output in Figure 8.1.

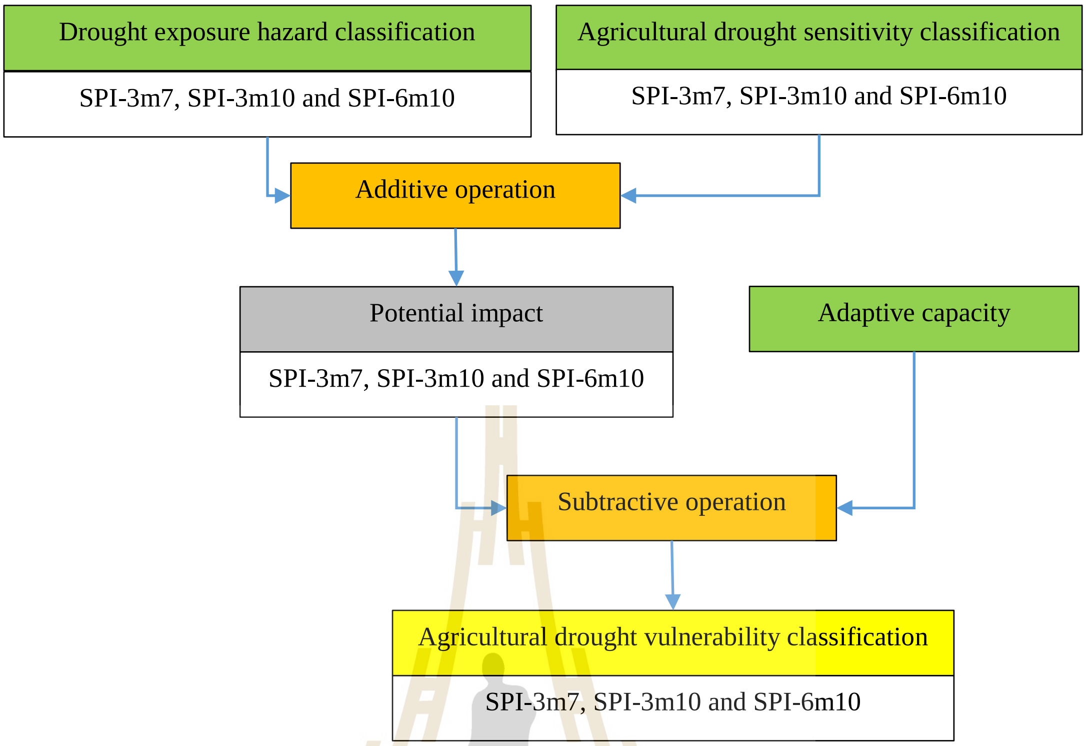
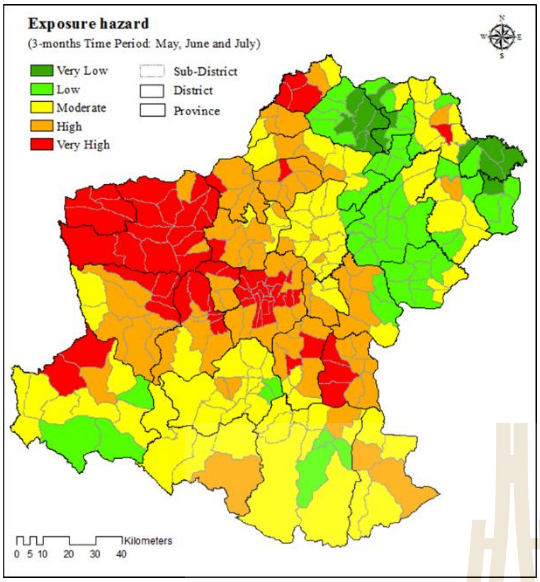


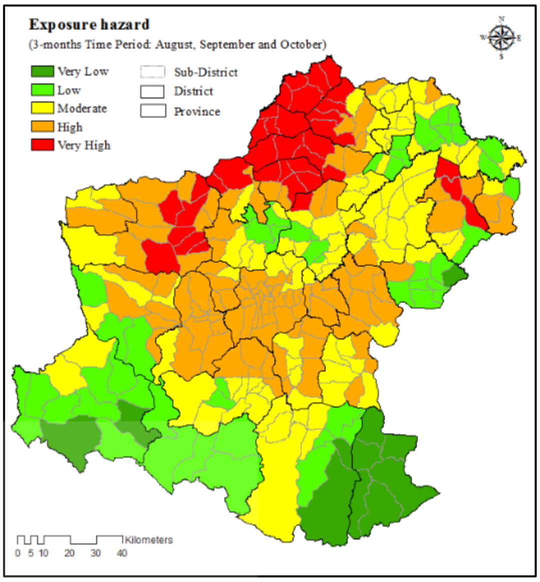
Figure 8.1 Structure of component for agricultural drought vulnerability analysis.

Maps of each component include drought exposure hazard classification (SPI-3m7, SPI-3m10 and SPI-6m10), overall agricultural drought sensitivity classification (3m7, 3m10, and 6m10) and adaptive capacity classification are displayed again in Figure 8.2, 8.3 and 8.4, respectively and basic statistics of each classification is presented in Table 8.1, 8.2 and 8.3, respectively.



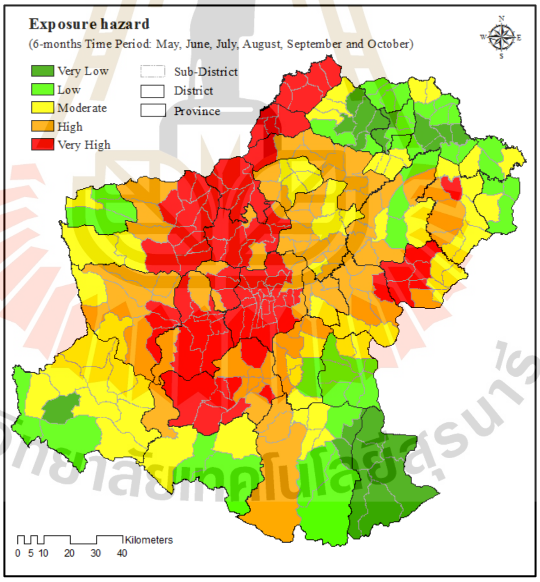
Drought exposure hazard classification

SPI-3m7



Drought exposure hazard classification

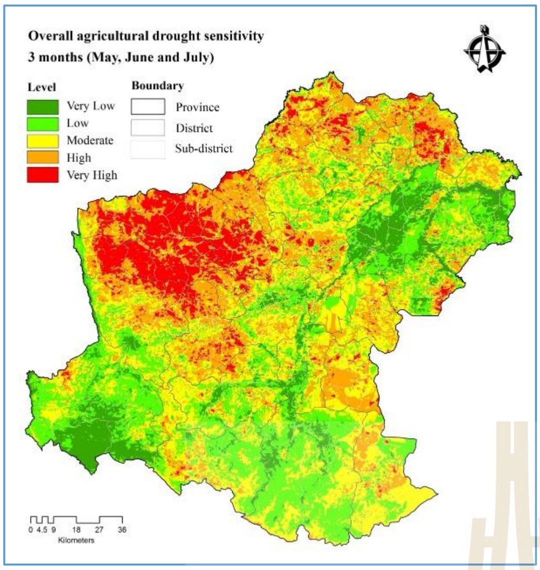
SPI-3m10



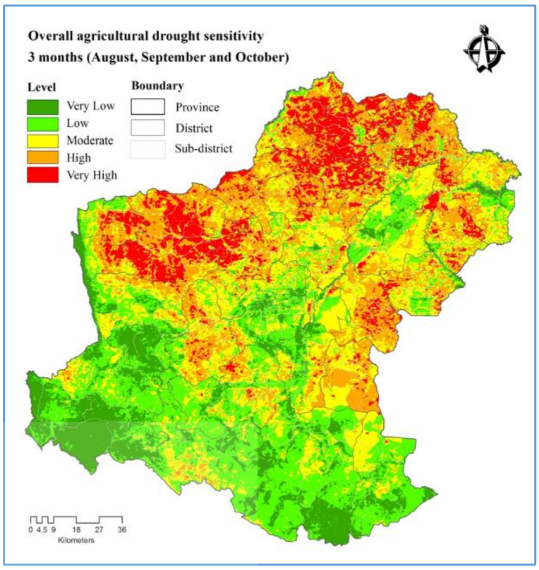
Drought exposure hazard classification

SPI-6m10

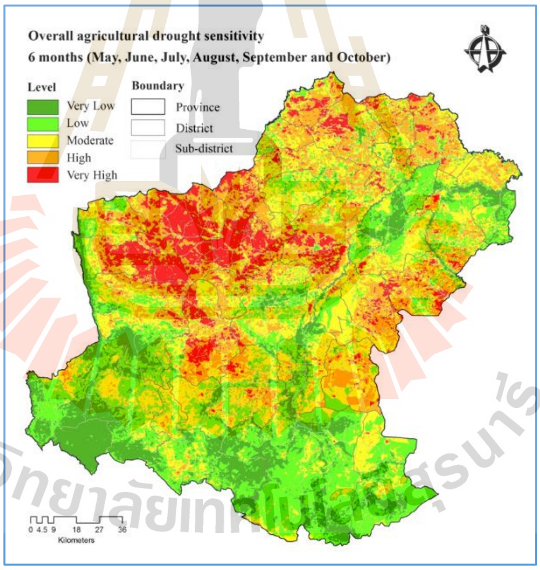
Figure 8.2 Distribution of drought exposure hazard of 3 periods (SPI-3m7, SPI-3m10, and SPI-6m10).



Overall agricultural drought sensitivity classification of 3m7



Overall agricultural drought sensitivity classification of 3m10



Overall agricultural drought sensitivity classification of 6m10

Figure 8.3 Distribution of overall agricultural drought sensitivity classification of 3 periods (3m7, 3m10, and SPI-6m10).

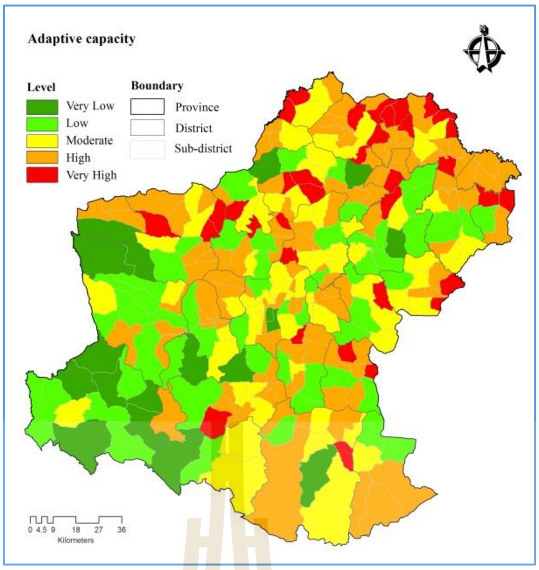


Figure 8.4 Distribution of adaptive capacity classification.

Table 8.1 Percentage of drought exposure hazard classification of 3 SPI periods.

SPI period	**Drought exposure hazard classification (%)**				
	Very low	**Low**	**Moderate**	**High**	**Very high**
3M7	3.2	17.2	36	26.1	17.5
3M10	9.4	21.6	29.8	28.3	10.9
6M10	7.8	18.6	24	27	22.5

Table 8.2 Percentage of agricultural drought sensitivity classification of 3 periods.

Period	**Agricultural drought sensitivity classification (%)**				
	Very low	**Low**	**Moderate**	**High**	**Very high**
3M7	10.10	26.45	30.20	23.30	9.96
3M10	13.62	26.81	25.41	22.83	11.33
6M10	13.70	26.92	26.77	22.64	9.97

Table 8.3 Percentage of adaptive capacity classification.

Adaptive capacity classification (%)				
Very low	**Low**	**Moderate**	**High**	**Very high**
7.53	31.2	23.45	24.91	12.9

8.2 Agricultural drought vulnerability assessment

In practice, the derived exposure hazard classification of 3 SPI periods and overall agricultural drought sensitivity classification of 3 periods is separately combined using additive operation and the derived result as potential impacts is then combined with adaptive capacity classification using subtractive operation for final agricultural drought vulnerability classification of 3 periods. (See Figure 8.1)

The result of agricultural drought vulnerability assessment include (1) agricultural drought vulnerability classification of 3m7 period, (2) agricultural drought vulnerability classification of 3m10 period, and (3) agricultural drought vulnerability classification of 6m10 period. Details of agricultural drought vulnerability classification of 3 periods are separately described and discussed in the following section.

8.2.1 Agricultural drought vulnerability assessment of 3m7 period.

Distribution of agricultural drought vulnerability classification of 3m7 period (May, June, and July) is displayed in Figure 8.5. Meanwhile, percentage of agricultural drought vulnerability classification at provincial and district levels are reported in Table 8.4 and Table 8.5, respectively. Comparison of agricultural drought vulnerability classification at district level is displayed in Figure 8.6.

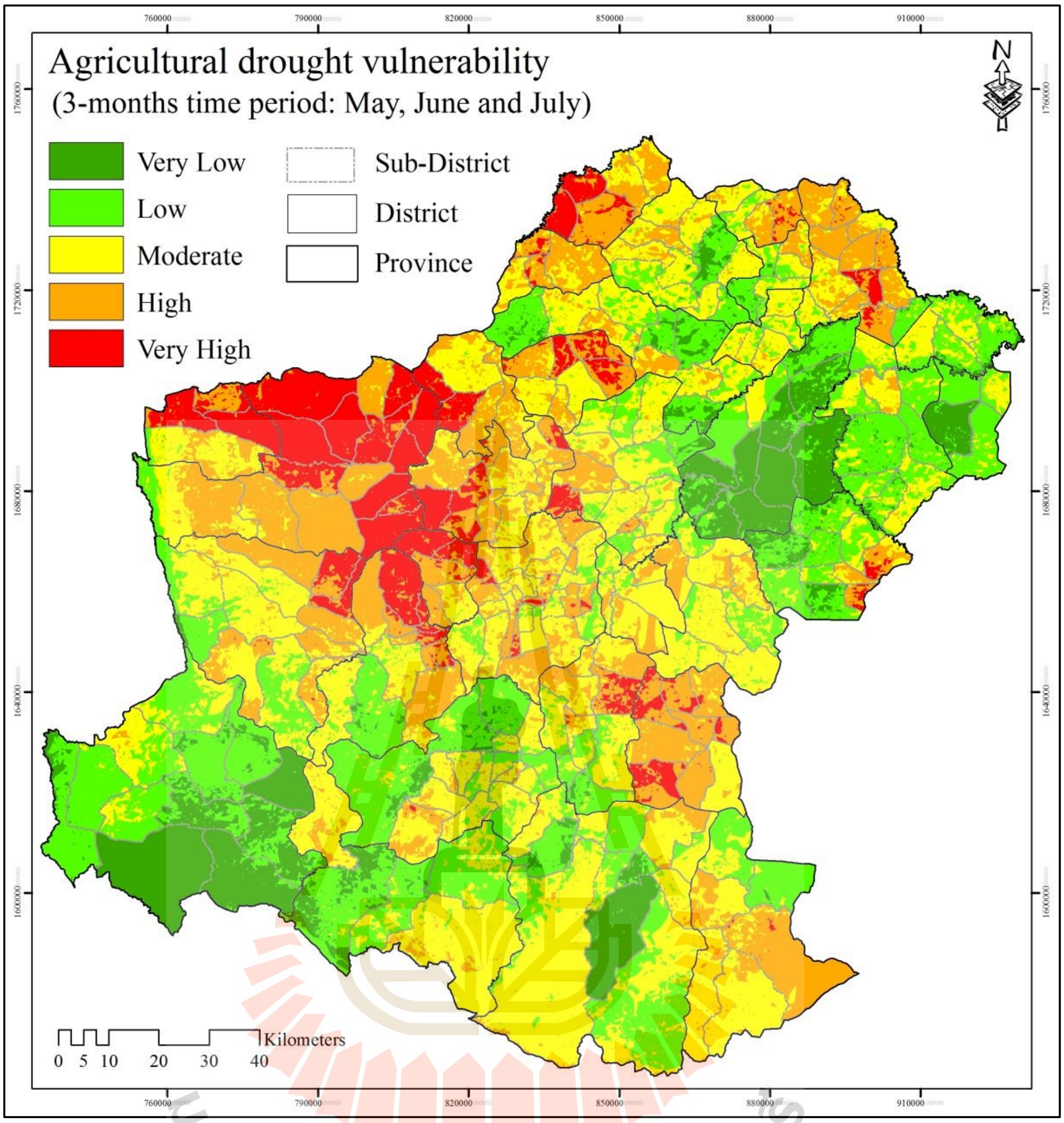


Figure 8.5 Distribution of agricultural drought vulnerability classification of 3m7 period.

Table 8.4 Percentage of agricultural drought vulnerability classification of 3m7 period at provincial level.

Agricultural drought vulnerability classification of 3m10 period (%)				
Very low	**Low**	**Moderate**	**High**	**Very high**
10.38	25.45	35.40	20.36	8.42

Table 8.5 Percentage of agricultural drought vulnerability classification of 3m7 period at district level.

Districts	Agricultural drought vulnerability classification (%)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.03	0.21	32.43	62.31	5.02
Bua Lai	0.04	10.41	41.95	43.09	4.52
Bua Yai	5.74	26.83	57.73	9.68	0.02
Chakkarat	0.06	16.16	68.72	15.03	0.03
Chaloem Phrakiat	0.00	9.06	71.24	19.70	0.00
Chok Chai	1.24	23.64	45.49	23.47	6.16
Chum Phuang	4.04	60.58	32.53	2.86	0.00
Dan Khun Thot	0.00	2.55	9.26	37.41	50.78
Huai Thalaeng	14.55	53.86	17.81	10.60	3.19
Kaeng Sanam Nang	0.00	0.11	17.22	52.46	30.21
Kham Sakae Saeng	0.01	0.46	36.70	43.28	19.56
Khom Thale So	0.00	0.36	18.81	43.58	37.25
Khon Buri	12.81	28.35	55.91	2.94	0.00
Khong	9.57	44.30	36.25	9.82	0.05
Lam Thamen Chai	28.86	57.24	13.84	0.06	0.00
Mueang Nakhon Ratchasima	0.02	7.84	53.70	35.11	3.33
Mueang Yang	7.82	51.02	41.03	0.13	0.00
Non Daeng	0.09	18.10	76.51	5.30	0.00
Non Sung	1.58	26.56	52.22	15.70	3.94
Non Thai	0.00	0.32	31.12	48.93	19.62
Nong Bunnak	0.00	0.13	17.93	65.53	16.41
Pak Chong	43.07	46.53	10.11	0.29	0.00
Pak Thong Chai	4.67	50.56	37.51	7.12	0.14
Phimai	67.40	28.19	4.39	0.02	0.00
Phra Thong Kham	0.00	0.21	38.63	39.96	21.19
Prathai	0.38	8.29	26.66	58.15	6.51
Sida	3.57	43.43	38.99	14.01	0.00
Sikhio	0.62	19.02	45.70	28.23	6.43
Soeng Sang	0.19	18.92	46.89	33.77	0.24
Sung Noen	1.43	21.60	28.91	31.80	16.27
Tepharak	0.00	2.86	31.13	25.29	40.72
Wang Nam Khiao	9.00	38.21	48.70	4.09	0.00

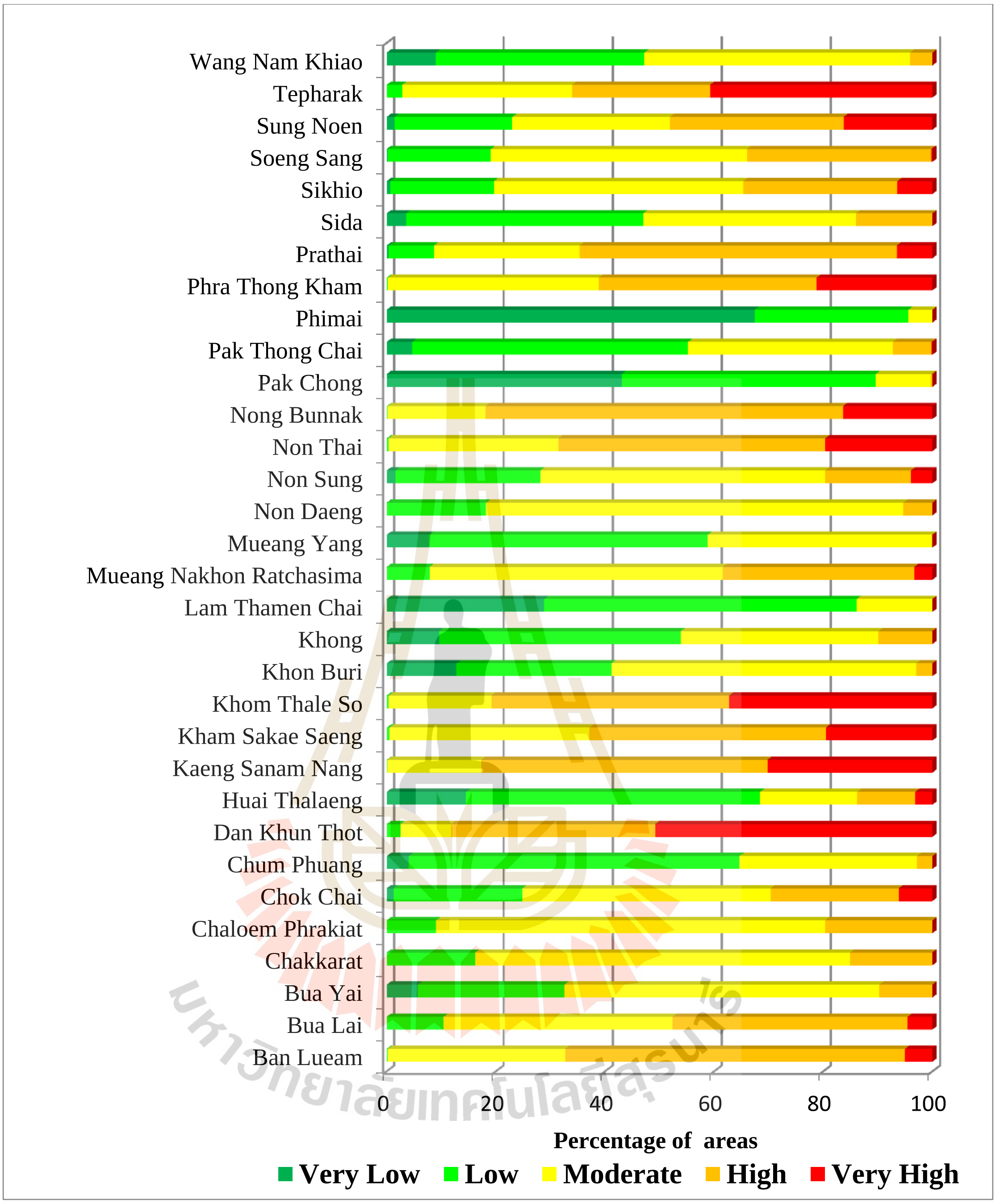


Figure 8.6 Comparison of agricultural drought vulnerability classification of 3m7 period at district level.

As results, at provincial level, it is found that about 35.83% of the total area are very low and low agricultural drought vulnerability and area of high and very high agricultural drought vulnerability is about 28.78% of the total area, while moderate agricultural drought vulnerability class covers area of 35.40% of the total area.

At district level, combination of very low and low agricultural drought vulnerability is dominant in 9 districts including Chum Phuang, Huai Thalaeng, Khong, Lam Thamen Chai, Mueang Yang, Pak Chong, Pak Thong Chai, Phimai, and Sida. On contrary, combination of high and very high agricultural drought vulnerability is dominant in 12 districts including Ban Lueam, Bua Lai, Dan Khun Thot, Kaeng Sanam Nang, Kham Sakae Saeng, Khom Thale So, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, Sung Noen, and Tepharak. Meanwhile, moderate agricultural drought vulnerability is mostly found in 11 districts including Bua Yai, Chakkarat, Chaloem Phrakiat, Chok Chai, Khon Buri, Mueang Nakhon Ratchasima, Non Daeng, Non Sung, Sikhio, Soeng Sang, and Wang Nam Khiao.

8.2.2 Agricultural drought vulnerability assessment of 3m10 period

Distribution of agricultural drought vulnerability classification of 3m10 period is displayed in Figure 8.7. Meanwhile, percentage of agricultural drought vulnerability classification at provincial and district levels are reported in Table 8.6 and Table 8.7, respectively. Comparison of agricultural drought vulnerability classification at district level is displayed in Figure 8.8.

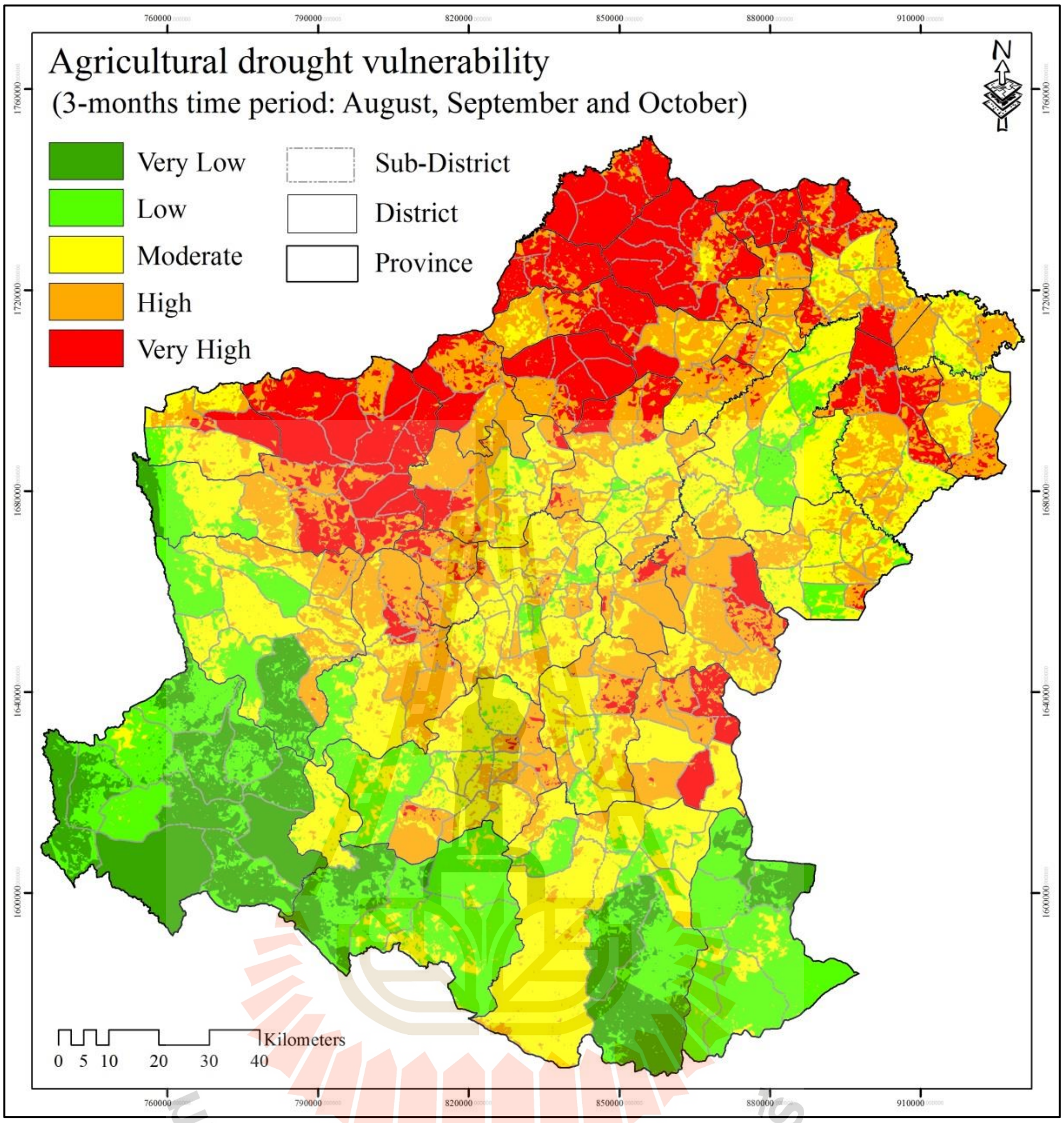


Figure 8.7 Distribution of agricultural drought vulnerability classification of 3m10 period.

Table 8.6 Percentage of agricultural drought vulnerability classification of 3m10 period at provincial level.

Agricultural drought vulnerability classification of 3m10 period (%)				
Very low	**Low**	**Moderate**	**High**	**Very high**
10.14	18.28	29.22	25.34	17.01

Table 8.7 Percentage of agricultural drought vulnerability classification of 3m10 period at district level.

Districts	Agricultural drought vulnerability classification (%)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	0.08	16.92	83.00
Bua Lai	0.00	0.00	0.02	11.11	88.86
Bua Yai	0.00	0.00	2.35	15.78	81.87
Chakkarat	0.00	0.01	18.81	64.72	16.46
Chaloem Phrakiat	0.00	3.43	23.25	68.01	5.32
Chok Chai	0.00	4.36	54.19	37.71	3.73
Chum Phuang	0.00	1.70	28.63	36.85	32.82
Dan Khun Thot	2.68	7.41	10.99	23.19	55.72
Huai Thalaeng	0.00	13.17	56.33	29.60	0.90
Kaeng Sanam Nang	0.00	0.00	0.00	6.73	93.27
Kham Sakae Saeng	0.00	0.00	0.38	23.06	76.56
Khom Thale So	0.00	0.00	17.33	64.13	18.54
Khon Buri	22.45	21.20	52.67	3.67	0.00
Khong	0.00	0.19	18.48	49.45	31.88
Lam Thamen Chai	0.00	0.15	39.72	55.26	4.87
Mueang Nakhon Ratchasima	0.00	7.32	62.51	29.49	0.68
Mueang Yang	0.00	2.87	44.61	51.99	0.53
Non Daeng	0.00	0.15	22.44	71.64	5.77
Non Sung	0.00	4.50	43.75	37.64	14.12
Non Thai	0.00	3.41	35.74	48.38	12.46
Nong Bunnak	0.00	0.03	33.22	40.10	26.65
Pak Chong	63.17	35.63	1.19	0.00	0.00
Pak Thong Chai	0.04	23.38	48.19	27.24	1.15
Phimai	0.14	25.58	61.46	12.52	0.30
Phra Thong Kham	0.00	0.01	2.62	59.74	37.64
Prathai	0.00	0.90	23.88	43.09	32.13
Sida	0.00	0.00	5.72	70.00	24.28
Sikhio	12.85	29.30	36.85	20.37	0.63
Soeng Sang	13.17	79.09	7.73	0.01	0.00
Sung Noen	0.02	12.40	31.82	50.35	5.41
Tepharak	0.05	9.31	48.48	20.57	21.59
Wang Nam Khiao	15.83	62.51	21.42	0.24	0.00

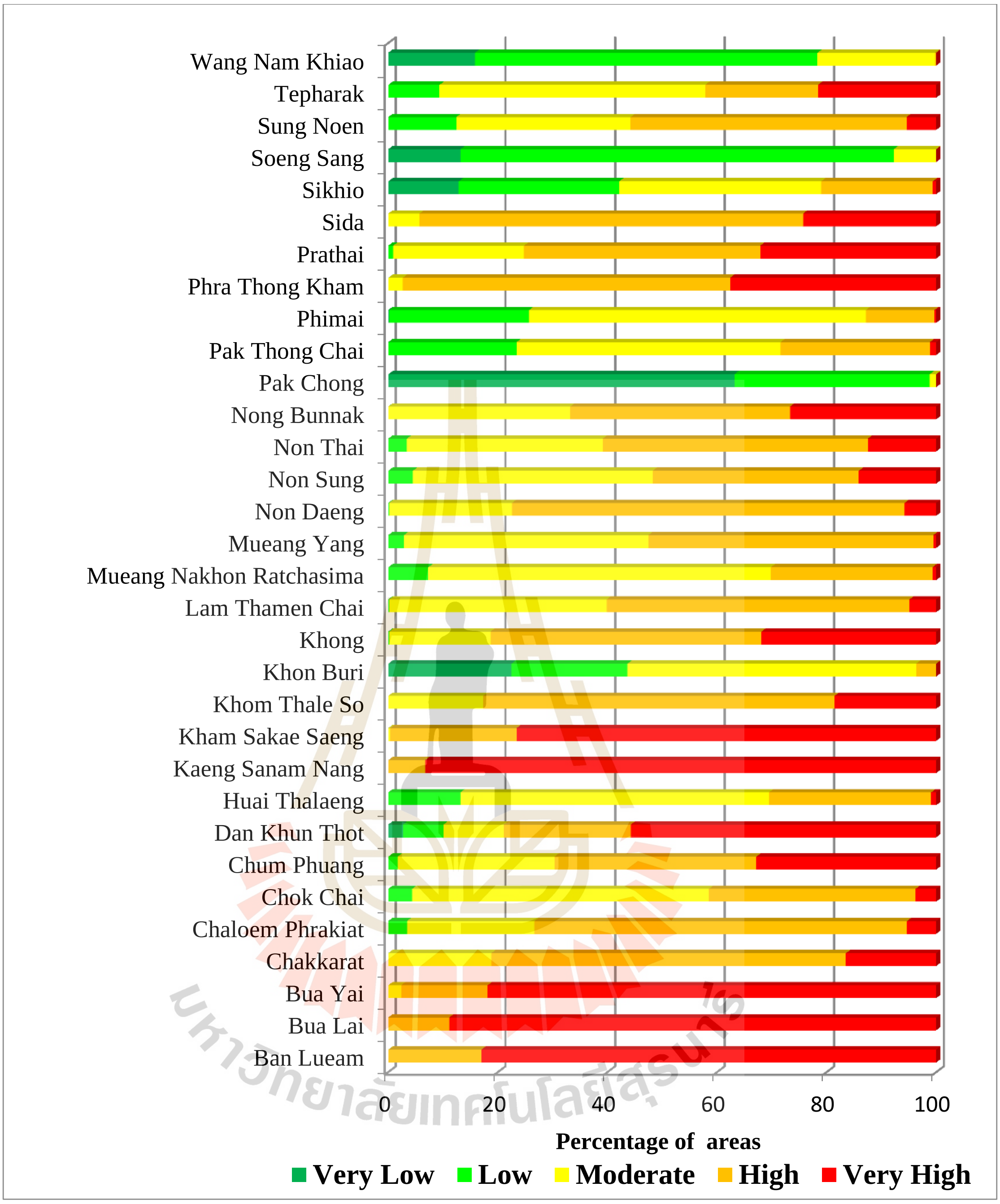


Figure 8.8 Comparison of agricultural drought vulnerability classification of 3m10 period at district level.

As results, at provincial level, it is found that about 28.42% of the total area are very low and low agricultural drought vulnerability and area of high and very high agricultural drought vulnerability is about 42.35% of the total area, while moderate agricultural drought vulnerability class covers area of 29.22% of the total area.

At district level, combination of very low and low agricultural drought vulnerability is dominant in 4 districts including Pak Chong, Sikhio, Soeng Sang, and Wang Nam Khiao. On contrary, combination of high and very high agricultural drought vulnerability is dominant in 21 districts including Ban Lueam, Bua Lai, Bua Yai, Chakkarat, Chaloem Phrakiat, Chum Phuang, Dan Khun Thot, Kaeng Sanam Nang, Kham Sakae Saeng, Khom Thale So, Khong, Lam Thamen Chai, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, Sida, and Sung Noen. Meanwhile, moderate agricultural drought vulnerability is mostly found in 7 districts including Chok Chai, Huai Thalaeng, Khon Buri, Mueang Nakhon Ratchasima, Pak Thong Chai, Phimai, and Tepharak.

8.2.3 Agricultural drought vulnerability assessment of 6m10 period.

Distribution of agricultural drought vulnerability classification of 6m10 period is displayed in Figure 8.9. Meanwhile, percentage of agricultural drought vulnerability classification at provincial and district levels are reported in Table 8.8 and Table 8.9, respectively. Comparison of agricultural drought vulnerability classification at district level is displayed in Figure 8.10.

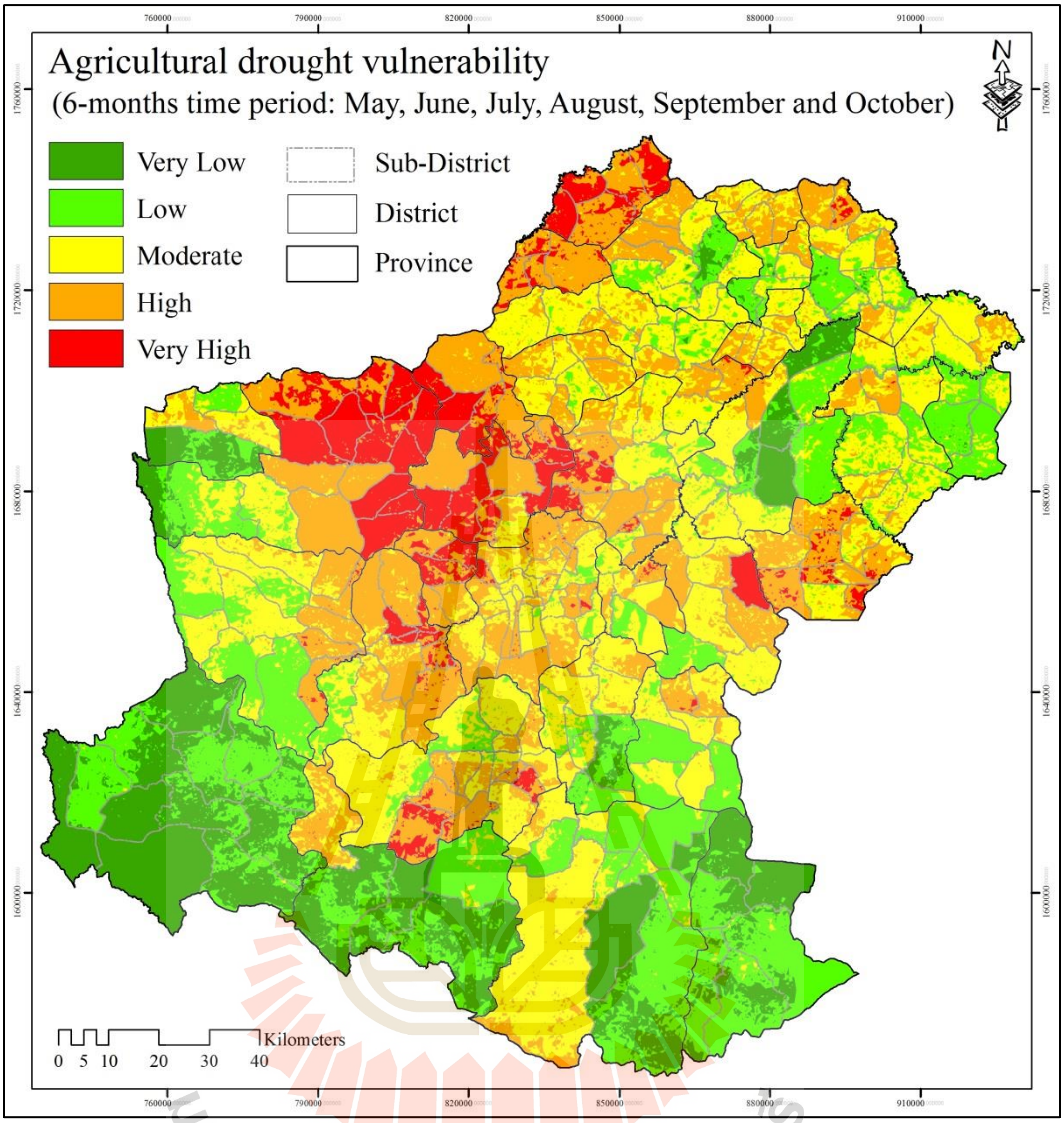


Figure 8.9 Distribution of agricultural drought vulnerability classification of 6m10 period.

Table 8.8 Percentage of agricultural drought vulnerability classification of 6m10 period at provincial level.

Agricultural drought vulnerability classification of 6m10 period (%)				
Very low	**Low**	**Moderate**	**High**	**Very high**
14.95	22.96	30.44	24.02	7.62

Table 8.9 Percentage of agricultural drought vulnerability classification of 6m10 period at district level.

Districts	Agricultural drought vulnerability classification (%)				
	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.01	1.93	80.43	17.63
Bua Lai	0.02	0.80	45.13	54.05	0.00
Bua Yai	4.70	22.20	45.90	27.14	0.06
Chakkarat	0.01	13.24	47.54	29.65	9.56
Chaloem Phrakiat	0.00	15.73	54.32	28.93	1.02
Chok Chai	9.61	29.47	50.92	10.01	0.00
Chum Phuang	0.08	24.91	59.09	15.83	0.09
Dan Khun Thot	4.65	11.92	11.41	29.47	42.55
Huai Thalaeng	0.02	1.62	27.35	62.46	8.54
Kaeng Sanam Nang	0.00	0.00	1.39	50.85	47.75
Kham Sakae Saeng	0.00	3.31	51.74	44.72	0.23
Khom Thale So	0.00	0.00	7.48	61.44	31.08
Khon Buri	20.95	36.26	38.11	4.67	0.01
Khong	0.24	7.60	66.19	25.35	0.63
Lam Thamen Chai	0.90	79.37	19.66	0.08	0.00
Mueang Nakhon Ratchasima	0.00	3.68	43.04	51.18	2.11
Mueang Yang	0.00	12.07	72.75	15.18	0.00
Non Daeng	0.13	2.09	58.65	39.05	0.08
Non Sung	0.01	5.65	39.14	45.97	9.23
Non Thai	0.00	0.15	7.12	47.88	44.84
Nong Bunnak	0.05	41.24	45.17	13.08	0.45
Pak Chong	67.55	32.26	0.17	0.03	0.00
Pak Thong Chai	0.09	7.73	54.33	30.64	7.21
Phimai	27.43	33.25	33.55	5.74	0.01
Phra Thong Kham	0.00	0.00	1.12	61.20	37.68
Prathai	1.55	24.81	45.10	27.13	1.42
Sida	2.91	42.36	40.24	14.48	0.00
Sikhio	0.05	36.29	41.33	21.79	0.54
Soeng Sang	40.66	58.50	0.83	0.00	0.00
Sung Noen	0.00	7.49	26.80	57.44	8.28
Tepharak	33.63	24.57	28.48	13.25	0.07
Wang Nam Khiao	45.07	38.69	6.88	9.31	0.04

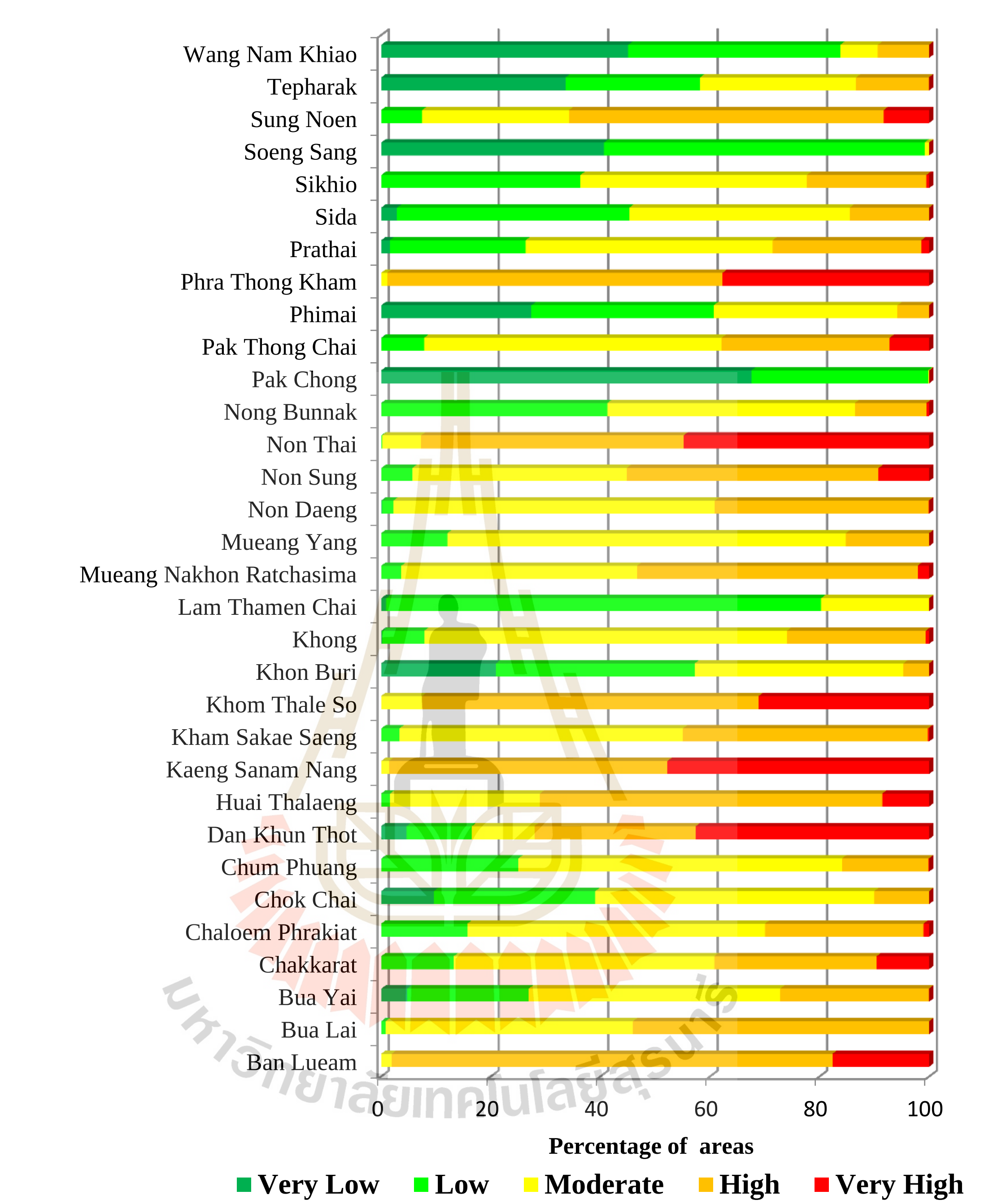


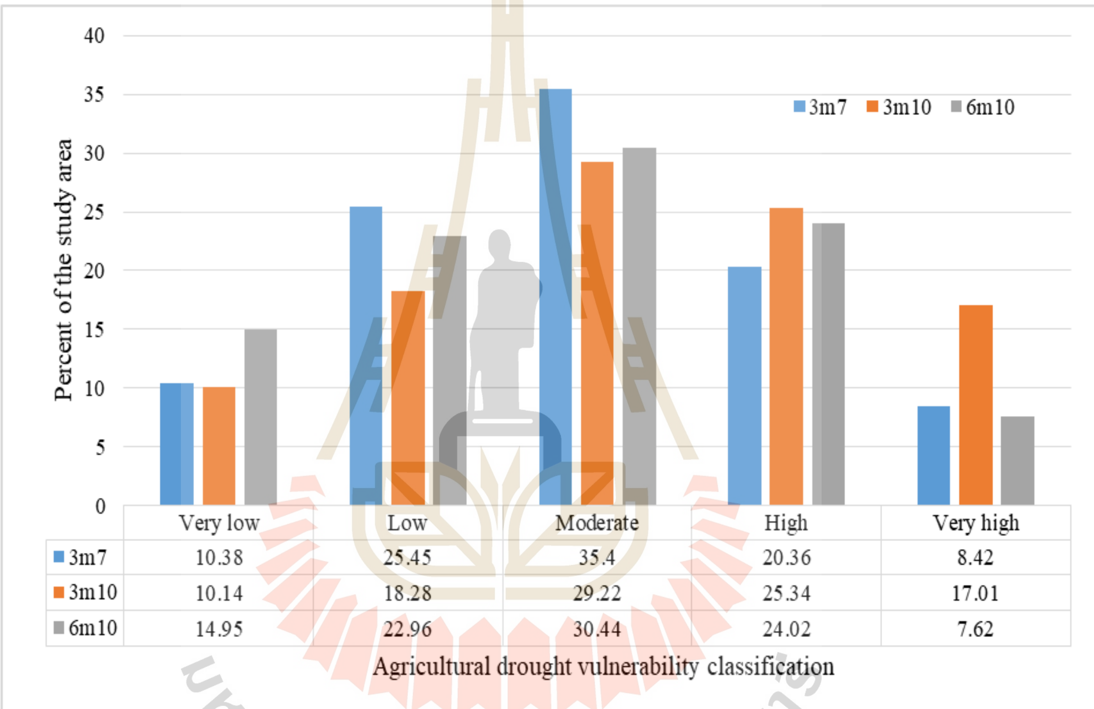
Figure 8.10 Comparison of agricultural drought vulnerability classification of 3m10 period at district level.

As results, at provincial level, it is found that about 37.91% of the total area are very low and low agricultural drought vulnerability and area of high and very high agricultural drought vulnerability are about 31.64% of the total area while moderate agricultural drought vulnerability class covers area of 30.44% of the total area.

At district level, combination of very low and low agricultural drought vulnerability is dominant at 8 districts including Khon Buri, Lam Thamen Chai, Pak Chong, Phimai, Sida, Soeng Sang, Tepharak, and Wang Nam Khiao. On contrary, combination of high and very agricultural drought vulnerability is dominant at 11 districts including Ban Lueam, Bua Lai, Dan Khun Thot, Huai Thalaeng, Kaeng Sanam Nang, Khom Thale So, Mueang Nakhon Ratchasima, Non Sung, Non Thai, Phra Thong Kham, and Sung Noen. Meanwhile, moderate agricultural drought vulnerability is mostly found at 13 districts including Bua Yai, Chakkarat, Chaloem Phrakiat, Chok Chai, Chum Phuang, Kham Sakae Saeng, Khong, Mueang Yang, Non Daeng, Nong Bunnak, Pak Thong Chai, Prathai, and Sikhio.

Summary

According to agricultural drought vulnerability classification of 3 periods (3m7, 3m10, and 6m10) at province level, the most dominant class of 3m7 period is very low and low agricultural drought vulnerability and covers area of 35.83%, while moderate, and high and very high agricultural drought vulnerability in this period cover area of 35.40% and 28.78%, respectively. Likewise, the most dominant class of 6m10 period is very low and low agricultural drought vulnerability and covers area of 37.91%, while moderate, and high and very high agricultural drought vulnerability in this period cover area of 30.44% and 31.64%, respectively. In contrast, the most dominant class of 3m10 period is high and very high agricultural drought vulnerability and covers area of 42.35%, while very low and low, and moderate agricultural drought vulnerability in this period cover area of 28.42% and 29.22%, respectively (Figure 8.11).



	Very low	Low	Moderate	High	Very high
3m7	10.38	25.45	35.4	20.36	8.42
3m10	10.14	18.28	29.22	25.34	17.01
6m10	14.95	22.96	30.44	24.02	7.62

Figure 8.11 Percentage of agricultural drought vulnerability classification of 3 periods.

In addition, results of agricultural drought vulnerability classification of 3 periods at district level showed that there are few districts which commonly have the same levels of agricultural drought vulnerability among 3 periods. Herewith, there are 8 districts including Ban Lueam, Bua Lai, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Non Thai, Phra Thong Kham and Sung Noen have high and very high agricultural drought vulnerability in every period (3m7, 3m10, and 6m10). Likewise, there is only 1 district, Pak Chong has very low and low agricultural drought vulnerability in every period. Meanwhile, moderate agricultural drought vulnerability is found in Chok Chai district. On contrary, there are 22 districts including Bua Yai, Chakkarat, Chaloem Phrakiat, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khon Buri, Khong, Lam Thamen Chai, Mueang Nakhon Ratchasima, Mueang Yang, Non Daeng, Non Sung, Nong Bunnak, Pak Thong Chai, Phimai, Prathai, Sida, Sikhio, Soeng Sang, Tepharak, and Wang Nam Khiao have different agricultural drought vulnerability levels among 3 periods. These findings show influence of adaptive capacity on agricultural drought vulnerability in 3 periods.

In this study, agricultural drought vulnerability assessment is considered to explore the significant time periods (3m, 3m10, and 6m10) that affected from agricultural drought vulnerability in Nakhon Ratchasima province. The main components of agricultural drought vulnerability consist of drought exposure hazard, agricultural drought sensitivity and adaptive capacity that derive to insight the vulnerability of agricultural drought at each time periods. Therefore, the integration of significant components is a prototype of agricultural drought vulnerability study at local scale (Nakhon Ratchasima province).

CHAPTER IX

CONCLUSION AND RECOMMENDATION

Under this chapter, five main results which were reported accordingly to objective in the study including (1) drought exposure hazard assessment (Chapter V), (2) overall agricultural drought sensitivity assessment (Chapter VI), (3) annual agricultural drought sensitivity assessment (Chapter VI), (4) adaptive capacity assessment (Chapter VII) and (5) agricultural drought vulnerability assessment (Chapter VIII) were here separately concluded, discussed and recommended for future research and development.

9.1 Conclusion

9.1.1 Drought exposure hazard assessment

In this study, drought exposure hazard was here assessed based on the additive operation between meteorological drought frequency and intensity of 3 SPI periods, namely SPI-3m7 (May, June, and July), SPI-3m10 (August, September and October), and SPI-6m10 (May to October) in Nakhon Ratchasima Province at local scale like Shahid and Behrawan (2008); Murthy et al. (2014); Murthy et al. (2015b) and Sehgal and Dhakar (2016). In contrast, most of the drought studies as mentioned in literature reviews assessed drought exposure hazard at national or regional scales (Xiaoqian et al., 2013; Murthy et al., 2015b; Pei et al., 2016). In addition, it used different time periods which can be explain drought exposure in more detail for specific periods (3m7, 3m10, and 6m10) that effected to drought condition and impacted to agricultural crop in study area.

According to drought exposure hazard classification, the most dominant class of all 3 periods (SPI-3m7, SPI-3m10, and SPI-6m10) at province level was high and very high drought exposure hazard and covered area of 43.60%, 39.20%, and 49.50%, respectively. Meanwhile very low and low drought exposure hazard of 3 periods covered area of 20.40%, 31.00%, and 26.40% and moderate drought exposure hazard of 3 periods covered area of 36.00%, 29.80%, and 24.00%, respectively.

At district level, there were 9 districts including Chakkarat, Chaloem Phrakiat, Chok Chai, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Mueang Nakhon Ratchasima, Phra Thong Kham, and Sung Noen incurred combined high and very high drought exposure hazard class in every period. Meanwhile, none of districts had the same combined very low and low drought exposure hazard class in every period. The pattern of very low and low drought exposure hazard among 3 periods randomly distributed in 16 districts including Bua Lai, Bua Yai, Huai Thalaeng, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, Nong Bunnak, Pak Chong, Phimai, Prathai, Sida, Sikhio, Soeng Sang, Tepharak and Wang Nam Khiao. Likewise, none of districts always incurred moderate drought exposure hazard in every period. The pattern of moderate drought exposure hazard class among 3 periods randomly occurred in 16 districts including Bua Lai, Chum Phuang, Kham Sakae Saeng, Khon Buri, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Pak Chong, Pak Thong Chai, Prathai, Sida, Soeng Sang and Wang Nam Khiao.

In addition, it was found that combination of high and very high exposure drought hazard of 3 periods were consistent with combination of high and very high economic crop yield variation which represents drought effected area on crop yield about 62.10%, 65.54%, and 62.04%, respectively. Therefore, the classification of exposure drought hazard of 3 periods were acceptable.

9.1.2 Overall agricultural drought sensitivity assessment

Overall agricultural drought sensitivity was assessed using weighting linear combination (SAW) of vegetation, climate, physical and socio-economic factors on agricultural drought including agricultural drought frequency, agricultural drought intensity, SPI, SPEI, land use, soil drainages, agricultural irrigation area, slope, elevation, distance to river, drainage density, agricultural occupation, economic crop production, and population density. Herein, overall agricultural drought sensitivity classification with 3 periods (3m7, 3m10, and 6m10) was implemented according to dynamic data of climate factors (SPI and SPEI).

According to overall agricultural drought sensitivity classification, the most dominant class of 3 periods (3m7, 3m10, and 6m10) at province level was very low and low and covered area of 36.55%, 40.43%, and 40.62%, respectively. Meanwhile, high and very high overall agricultural drought sensitivity of 3 periods covered area of 33.26%, 34.16%, and 32.61% and moderate overall agricultural drought sensitivity of 3 periods covered area of 30.20%, 25.41%, and 26.77%, respectively.

At district level, there were 11 districts including Ban Lueam, Bua Lai, Bua Yai, Dan Khun Thot, Kaeng Sanam Nang, Non Daeng, Non Thai, Phra Thong Kham, Prathai, Sung Noen, and Tepharak always incurred at high and very high overall agricultural drought sensitivity in every period. At the same time, there were 5 districts including Chok Chai, Khon Buri, Lam Thamen Chai, Pak Chong, and Wang Nam Khiao always incurred at very low and low overall agricultural drought sensitivity in every period. Meanwhile, there were 2 districts including Chaloem Phrakiat and Mueang Yang always incurred at moderate overall agricultural drought sensitivity in every period. On contrary, there were 14 districts including Chakkarat, Chok Chai, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khom Thale So, Khong, Lam Thamen Chai, Mueang Nakhon Ratchasima, Non Daeng, Non Sung, Pak Thong Chai, Sida, Sikhio, Soeng Sang, and Sung Noen had different overall agricultural drought sensitivity levels among 3 periods.

In addition, it was found that combination of high and very high overall agricultural drought sensitivity classification of 3 periods (3m7, 3m10, and 6m10) were consistent with an accumulate drought effected area on agricultural crops during 2012 to 2015 about 47.03%, 54.93%, and 47.30%, respectively. Likewise, ROC values for best fit test of overall agricultural drought sensitivity classification of 3 periods were 0.891, 0.923, and 0.912, respectively. Thus, the classifications of overall agricultural drought sensitivity of 3 periods were acceptable.

9.1.3 Annual agricultural drought sensitivity assessment

Annual agricultural drought sensitivity was here assessed using multiple linear regression equation, which were derived from linear relationship between overall agricultural drought sensitivity index of 6m10 period as independent variable and vegetation, climate, physical and socio-economic factors (in 2012, 2014, and 2015) on agricultural drought as independent variables using CART of Cubist software.

The derived multiple linear regression equation in 2012, 2014, and 2015 (Eq. 6.3, 6.4, and 6.5) provided different significant factors to classify annual agricultural drought sensitivity. In the current study, the significant factors for annual agricultural drought sensitivity classification in 2012 were drainage density, land use in 2012, population density in 2011, SPEI in 2012, distance to river, and soil drainage. Meanwhile, most of the pre-selected influential factors on overall agricultural drought sensitivity in 2014 were included except slope, PASG in 2014, and SOSA in 2014. In the meantime, the significant factors for annual agricultural drought sensitivity in 2015 were distance to river, land use in 2015, population density in 2015, drainage density, economic crop production in 2015, SPI in 2015, soil, elevation, and SOSA in 2015.

According to annual agricultural drought sensitivity classification, the most dominant class in 2012 and 2014 at province level was combination of high and very high and covered area of 41.89%, and 45.29%, respectively. Meanwhile, combination of very low and low annual agricultural drought sensitivity was dominant in 2015 and covered area of 41.79%.

At district level, there were 14 districts including Bua Lai, Bua Yai, Chakkarat, Dan Khun Thot, Kaeng Sanam Nang, Khong, Mueang Yang, Non Daeng, Non Sung, Non Thai, Nong Bunnak, Phra Thong Kham, Prathai, and Sida incurred high and very high annual agricultural drought sensitivity in every year. Likewise, there were only 4 districts including Khon Buri, Pak Chong, Sikhio, and Wang Nam Khiao incurred very low and low annual agricultural drought sensitivity in every year.

Meanwhile, there were 14 districts including Ban Lueam, Chaloem Phrakiat, Chok Chai, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khom Thale So, Lam Thamen Chai, Mueang Nakhon Ratchasima, Pak Thong Chai, Phimai, Soeng Sang, Sung Noen, and Tepharak had different annual agricultural drought sensitivity levels among 3 years.

Furthermore, it was found that combination of high and very high annual agricultural drought sensitivity in 2012, 2014, and 2015 were consistent with drought effected area on agricultural crops in corresponding year about 56.07%, 78.67%, and 67.61%, respectively. Meanwhile, ROC values of annual agricultural drought sensitivity classification in 2012, 2014, and 2015 were 0.851, 0.898, and 0.887, respectively. Therefore, the validation of annual agricultural drought sensitivity in 2015 can be acceptable.

9.1.4 Adaptive capacity assessment

Adaptive capacity was here assessed the degree ability of people to adjust to impact of drought using adaptive capacity index (Eq. 3.4) based on socio-economic factors including (1) proportion of people below poverty line, (2) illiteracy rate, (3) income from agricultural sector, (4) farm holding size, (5) income from non-agricultural sector and (6) information accessibility.

According to adaptive capacity classification, the most dominant class of adaptive capacity to agricultural drought effect at provincial level was very low and low adaptive capacity and covered area of 38.73%, while moderate, and high and very high adaptive capacity to agricultural drought effect covered area of 23.45% and 37.81%, respectively.

At district level, combination of very low and low adaptive capacity to agricultural drought effect were dominant in 18 districts including Bua Lai, Bua Yai, Chaloem Phrakiat, Chok Chai, Chum Phuang, Dan Khun Thot, Kham Sakae Saeng, Khom Thale So, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, Non Thai, Nong Bunnak, Prathai, Sida, Soeng Sang, and Tepharak and covered area of 38.73% of the study area. Meanwhile, combination of high and very high adaptive capacity to agricultural drought effect were dominant in 6 districts including Khong, Pak Chong, Pak Thong Chai, Phimai, Sikhio, and Sung Noen and covered area of 37.81%. At the same time, area of moderate adaptive capacity to agricultural drought effect that was dominant in 8 district including Ban Lueam, Chakkarat, Huai Thalaeng, Kaeng Sanam Nang, Mueang Nakhon Ratchasima, Non Sung, Phra Thong Kham, and Wang Nam Khiao was 23.45%.

9.1.5 Agricultural drought vulnerability assessment

Agricultural drought vulnerability was here assessed by integration of three derived components including drought exposure hazard classification (SPI-3m7, SPI-3m10 and SPI-6m10), agricultural drought sensitivity classification (3m7, 3m10 and 6m10) and adaptive capacity classification.

According to agricultural drought vulnerability classification of 3 periods (3m7, 3m10, and 6m10) at province level, the most dominant class of 3m7 period was very low and low agricultural drought vulnerability and covered area of 35.83%, while moderate, and high and very high agricultural drought vulnerability in this period covered area of 35.40% and 28.78%, respectively. Likewise, the most dominant class of 6m10 period was very low and low agricultural drought vulnerability and covered area of 37.91%, while moderate, and high and very high agricultural drought vulnerability in this period covered area of 30.44% and 31.64%, respectively. In contrast, the most dominant class of 3m10 period was high and very high agricultural drought vulnerability and covered area of 42.35%, while very low and low, and moderate agricultural drought vulnerability in this period covered area of 28.42% and 29.22%, respectively.

At district level, agricultural drought vulnerability classification of 3 periods showed that there were few districts which commonly had the same levels of agricultural drought vulnerability among 3 periods. Herewith, there were 8 districts including Ban Lueam, Bua Lai, Dan Khun Thot, Kaeng Sanam Nang, Khom Thale So, Non Thai, Phra Thong Kham, and Sung Noen had high and very high agricultural drought vulnerability in every period (3m7, 3m10, and 6m10). Likewise, there was only 1 district, Pak Chong had very low and low agricultural drought vulnerability in every period. Meanwhile, moderate agricultural drought vulnerability was found in Chok Chai district. On contrary, there were 22 districts including Bua Yai, Chakkarat, Chaloem Phrakiat, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khon Buri, Khong, Lam Thamen Chai, Mueang Nakhon Ratchasima, Mueang Yang, Non Daeng, Non Sung, Nong Bunnak, Pak Thong Chai, Phimai, Prathai, Sida, Sikhio, Soeng Sang, Tepharak, and Wang Nam Khiao had different agricultural drought vulnerability levels among 3 periods. These finding showed influence of adaptive capacity on agricultural drought vulnerability in 3 periods.

In conclusion, it appears that geospatial modeling can be efficiently used as tools to assess drought exposure hazard, agricultural drought sensitivity and adaptive capacity for agricultural drought vulnerability assessment.

9.2 Recommendation

Many objectives were here investigated and implemented, the possibly expected recommendations could be made for further studies as following.

(1) For exposure drought hazard study, it should be considered length time of drought event or continuous of drought events in order to analyze accumulative intensity of continuously drought condition.

(2) For overall agricultural drought sensitivity study, it should be considered more significant factors at local scale such as ground water, soil moisture, water requirement of each crop.

(3) In order to more understanding of drought on agricultural crop, study of drought on specify crop such as rice, maize, sugarcane, or cassava should be examined with appropriate significant factors on selected crops.

(4) For adaptive capacity study, it should be considered more significant factors at local scale such as policy on mitigation and prevention drought, community of farmer and agricultural cooperative.

(5) For agricultural drought vulnerability analysis, the result should be validated using interviews and questionnaires.

(6) In this study, monthly temperature is extracted from MODIS product (MOD11C3) in order to create SPEI that used corporate with monthly temperature from stationary. The spatial resolution of LST of MOD11C3 product is rather low (5600 m). In order to improve quality of LST, thermal sensors data from existing satellites with moderate spatial resolution are recommended for calculation SPEI.

REFERENCES

REFERENCES

Abramowitz, M., and Stegun, I.A. (1965). **Handbook of Mathematical Functions: With Formulas, Graphs, and Mathematical Tables; Dover Publications: Mineola**. Ner York: USA. (Quoted by Tan et al., 2015).

Ano, T., Hormwichian, R., Jitrapinate, N., Compliew, S., and Kangrang, A. (2013). The Estimation of Drought Risk Area using Potential Surface Analysis Technique. **Academic journal Ubon Ratchathani University**. 6(2): 13-21.

Antwi-Agyei, P., Fraser, E.D.G., Dougill, A.J., Stringer, L.C., and Simelton, E. (2012). Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socioeconomic data. **Applied Geography**. 32: 324-334.

Assimacopoulos, D., Kampregou, E., Andreu, J., Bifulco, C., Carli, A.D., Stefano, L.D., Dias, S., Gudmundsson, L., Haro-Monteagudo, D., Musolino, D., Paredes-Arquiola, J., Rego, F., Seidl, I., Solera, A., Urquijo, J., Lanen, H.V., and Wolters, W. (2014). **Future drought impact and vulnerability-case study scale**. Technical report No. 20. Drought-R&SPI.

Baimoung, S., Waranuchit, W., Prakanrat, S., Amatayakul, P., Sukhanthamat, A., Yuttaphan, A., Pyomjamsri, A., and Panprom, M. (2005). **Meteorological drought classification using Normalized Different Vegetation Index**. [On-line]. Available: http://www.arcims.tmd.go.th/Research_files/.

Blaikie P., Cannon T., and Davis I. (1994). **At risk: natural hazards, people's vulnerability and disasters.** London, UK: Routledge;

Brown, J.F., Wardlow, B.D., Tadesse, T., Hayes, M.J., and Reed, B.C. (2008). The vegetation drought response index (VegDRI): A new integrated approach for monitoring drought stress in vegetation. **GIScience and Remote Sensing**. 45: 16-46.

Chanchaeng, P. (2012). **Drought risk assessment in the areas of Kamphaeng Saen District in Nakhon Pathom Province through using Geographic Information System**. M.Sc. Thesis, National Institute of Development Administration (NIDA).

Chopra, P. (2006). **Drought risk assessment using remote sensing and GIS: A case study of Gujarat**. M.Sc. Thesis, ICT, India and IIRS, the Netherlands.

Department of Disaster Prevention and Mitigation. (2007). **Analysis of drought risk area Northeastern. Department of Disaster Prevention and Mitigation (DDPM)**. Department of Disaster Prevention and Mitigation, Ministry of the Interior.

Department of Environmental Quality Promotion (2004). **The spatial database of Natural Resources and Environment Nakhon Ratchasima Province.** Ministry of Natural Resources and Environment.

Eklund, L., and Seaquist, J. (2015). Meteorological, agricultural and socioeconomic drought in the Duhok Governorate, Iraqi Kurdistan. **Nat Hazard**. 76: 421-441.

Eklundh, L., and Jonsson, P. (2015). **TIMESAT 3.2 with parallel processing Software Manaul**. [On-line]. Available: http://www.nateko.lu.se/TIMESAT/.

Fortaine, M.M., and Steinemann, A.C. (2009). Assessing vulnerability to natural hazards: Impact-based method and application to drought in Washington State. **Nat. Hazards Rev**. 10: 11-18.

Garen, D.C. (1993). Revised surface-water supply index for western United States. **Journal of Water Resources Planning and Management**. 119(4): 437-454.

Gbetibouo, G.A., and Ringler, C. (2009). **Mapping South African farming sector vulnerability to climate change and variability**. Environment and Production Technology Division. IFPRI Discussion Paper 00885.

Gibbs, W.J., and Maher, J.V. (1967). **Rainfall Deciles as Drought Indicators. Australian Bureau of Meteorology**, Bull. 48, 37 pp. (Quoted by Keyantash J., and Dracup J.A., 2002).

Guttman, N.B. (1999). Accepting the standardized precipitation index: a calculation algorithm. **Journal of the American water resources association**. 35(2): 311-322.

Hayes, M.J., Svoboda, M., Wardlow, B.D., Anderson, M.C., and Kogan, F. (2012). **Drought monitoring: Historical and current perspectives**. Remote sensing of drought: Innovative monitoring approaches. CRC Press.

Homdee, T., Pongput, K., and Kanae, S. (2016). A comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand. **Agricultural and natural resource**. 50: 211-219.

Jain, V.K., Pandey, R.P., and Jain, M.K. (2015). Spatial-temporal assessment of vulnerability to drought. **Nat Hazards**. 76: 443-469.

Jamphon, C. (2004). **Intensity of drought in Thailand**. Climatological Group. Meteorological Development Bureau. (in Thai).

Kaewpruksapimon, C. (2006). **Fuzzy logic technique for drought risk identification of Burirum province**. M.Sc. Thesis, Faculty of Graduate Studies, Mahidol University.

Keim, A., Johnson, F., Westra, S., Dijk, A.V., Evans, J.P., Donnell, A.O., Rouillard, A., Barr, C., Tyler, J., Thyer, M., Jakob, D., Woldemeskel, F., Sivakumar, B., and Mehrotra, R. (2016). **Natural hazards in Australia: droughts**. Climate Change.

Kim, H., Park, J., Yoo, J., and Kim, T.W. (2015). Assessment of drought hazard, vulnerability, and risk: A case study for administrative districts in South Korea. **Journal of Hydrological environment research**. 9: 28-35.

Knutson, C., Hayes, M.J., and Phillips, T. (1998). **How to Reduce Drought Risk**. Western Drought Coordination Council report.

Kogan, F.N. (1995). Application of vegetation index and brightness temperature for drought detection. **Advances Space Res**. 15(11): 91-100.

Kogan, F.N. (1997). Global drought watch from space. **Bulletin of the American Meteorological Society**. 78(4): 621-636.

Lawrimore, J., Richard, R., Heim, J.R., Svoboda, M., Swail, V., and Englehart, P.J. (2002). Beginning a new era of drought monitoring across North America. **Bulletin of the American Meteorological Society**. 83: 1191-1192.

Leichenko R.M., and O’Brien K.L. (2002). **The dynamics of rural vulnerability to global change: the case of southern Africa.** Mitigation andAdaptation Strategies for Global Change 7, 1–18

Liang, L., Shu-he, Z., Zhi-hao, Q., Ke-xun, H., Chong, C., Yun-xiao, L., and Xing-dong, Z. (2014). Drought change trend using MODIS TVDI and its relationship with climate factors in China from 2001 to 2010. **Journal of Integrative Agriculture**. 13(7): 1501-1508

Maria, R., Vivas, E., Serralheiro, R., and Carvalho, M.D. (2015). Socioeconomic evaluation of drought effect. Main principles and application to Guadiana and Algarve case studies. **Water Resour Manage**. 29: 575-588.

McCarthy, J., Canziani, O., Leary, N., Dokken, D., and White, K. (2001). **In Climate Change 2001: Impacts, Adaptation, and Vulnerability. IPCC (Inter-governmental Panel on Climate Change) (2001)**. Cambridge University Press. Cambridge.

McKee, T.B., Doesken, N.J., and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In Proceedings of **the 8th Conference of Applied Climatology**. (pp 179-184). Anaheim, California: American Meteorological Society.

McKee, T.B., Doesken, N.J., and Kleist, J. (1995). Drought Monitoring with Multiple Time Scales. Proceeding of **the Ninth Conference on Applied Climatology**. American Meteorological Society: Boston.

Mishra, A.K., and Singh, V.P. (2010). A review of drought concepts. **Journal of Hydrology**. 391: 2002-2016.

Mishra, A.K., Singh, V.P., and Desai, V.R. (2009). Drought characterization: a probabilistic approach. **Stochast Environ Res Risk Assess.** 23: 41-55.

Mongkolsawat, C., Thirangoon, P., Suwanweramtorn, R., Karladee, N., Paiboonsank, S., and Champathet, P. (2000). An evaluation of drought risk area in Northeast Thainald using Remotely Sensed data and GIS. In Proceeding of **the 21st Asian Conference on Remote Sensing.** Taipei, Taiwan.

Mongkolsawat, C., Wattanakij, N., Kamchai, T., Mongkolsawat, K., and Chuyakhai, D. (2009). Exploration of spatio-temporal drought pattern using satellite-derived indices for crop management in Northeastern Thailand. In Proceeding of the **30th Asian Conference on Remote Sensing.** Beijing, China.

Murthy, C.S., Laxman, B., and Sesha Sai, M.V.R. (2015a). Geospatial analysis of agricultural drought vulnerability using a composite index based on exposure, sensitivity and adaptive capacity. **International Journal of Disaster Risk Reduction**. 12: 163-171.

Murthy, C.S., Laxman, B., Sesha Sai, M.V.R., and Diwakar, P.G. (2014). **Analysis agricultural drought vulnerability at sub-district level through exposure, sensitivity, and adaptive capacity based composite index**. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8.

Murthy, C.S., Yahav, M., Mohammed Ahamed, J., Laxman, B., Prawasi, R., Sesha Sai, M.V.R., and Hooda, R.S. (2015b). A study on agricultural drought vulnerability at disaggregated level in a highly irrigated and intensity cropped state of India. **Environ Monit Assess**. 187-140.

Nalbantis, I. (2008). Evaluation of a hydrological drought index. **European Water**. 23(24): 67-77.

Nalbantis, I., and Tsakiris, G. (2009). Assessment of hydrological drought revisited. Water Resour Manage. 23: 881-897.

National Drought Mitigation Center (2016). [On-line]. Available: http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx.

Nelson, S.A. (2014). **Natural Hazards and Natural Disasters**. [On-line]. Available: http://www.tulane.edu/~sanelson/Natural_Disasters/introduction.htm.

Nithiyanan S. (2003). **An analysis of drought and drought risk area in Changwat Nakhon Ratchasima.** M.Sc. Thesis, Faculty of Graduate Studies, Ramkhamhaeng University.

Office of agricultural economics (2010). **Geospatial Data of Agricultural Land Use Based on Color Orthophotography 1:4000, Nakhon Ratchasima Province.** Office of agricultural economics.

Palmer, W.C. (1965). **Meteorological drought (Research Paper No. 45)**. Department of Commerce Weather Bureau: Washington, D.C.

Pandey, S., Pandey, A.C., Galkate, R.V., Byun, H-R., and Mal, B.C. (2010). Integrating Hydro-Meteorological and Physiographic factors for assessment of vulnerability to drought. **Water Resour Manage**. 24: 4199-4217.

Park, S.P., Im, J., Jang, E., and Rhee, J. (2016). Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. **Agricultural and Forest Meteorological**. 216: 157-169.

Pei, W., Fu, Q., Liu, D., Li, T., and Cheng, K. (2016). Assessing agricultural drought vulnerability in the Sanjiang Plain based on an improved projection pursuit model. **Nat Hazards**. 82: 683-701.

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

Prathumchai, K., Honda, K., and Nualchawee, K. (2001). Drought risk evaluation using remote sensing and GIS: A case study in Lop Buri Province. In Proceedings of **the 22nd Asian Conference on Remote Sensing, 5-9, Singapore**. National University of Singapore, Singapore Institute of Surveyors and Valuers: Asian Association on Remote Sensing.

Punprasit, J. (2006). **Geographic information system for drought risk area assessment by regression analysis in Lop Buri province**. M.Sc. Thesis, Faculty of Graduate Studies, Mahidol University.

Quiring, S.M., and Ganesh, S. (2010). Evaluating the utility of the vegetation condition index (VCI) for monitoring meteorological drought in Texas. **Agricultural and Forest Meteorological**. 150: 330-339.

Rahmat, S.N., Jayasuriya, N., and Bhuiyan, M. (2015). Assessing droughts using meteorological drought indices in Victoria, Australia. **Hydrology research**. 43(6): 463-476.

Sayari, N., Bannayan, M., Alizadeh, A., and Farid, A. (2013). Using drought indices to assess climate change impacts on drought conditions in the northeast of Iran (case study: Kasharood basin). **Meteorological applications**. 20: 115-127.

Sehgal, V.K., and Dhakar, R. (2016). Geospatial approach for assessment of biophysical vulnerability to agricultural drought and its intra-seasonal variations. **Environ Monit Assess.** 188: 197.

Shafer, B.A., and Dezman, L.E. (1982). Development of a surface water supply index to assess the severity of drought condition in snow pact runoff area. In Proceedings of **the 50th Annual Meeting, Western Snow Conference**. (pp 164-175).

Shahid, S., and Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. **Nat Hazards**. 46: 391-413.

Singh, V.P., Guo, H., and Yu, F.X. (1993). Parameter estimation for 3-parameter log-logistic distribution (LLD3) by Pome. Stoch. **Hydrol. Hydraul**. 7: 163-177. (Quoted by Tan et al., 2015).

Son, N.T., Chen, C.F., Chen, C.R., Chang, L.Y., and Minh, V.Q. (2012). Monitoring agricultural drought in the Lower Mekong Basin using MODIS NDVI and land surface temperature data. **International Journal of Applied Earth Observation and Geoinformation**. 18: 417-427.

Sonmez, F.K., Komuscu, A.U., Erkan, A., and Turgu, E. (2005). An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. **Natural Hazards**. 35: 243-264.

Srisurat S. (2010). **Drought risk area analysis in Nakhonnayok Province.** The report of research by Srinakharinwirot University.

Stagge, J.H., Kohn, I., Tallaksen, L.M., and Stahl, K. (2015). Modeling drought impact occurrence based on meteorological drought indices in Europe. **Journal of Hydrology**. 530: 37-50.

Steinemann, A.C., Hayes, M.J., and Cavalcanti, L.F.N. (2005). Drought indicators and triggers. Drought and water crises: science technology, and management issues. **Taylor & Francis Group**. 71-92.

Subrahmanyam, V.P. (1967). **Incidence and Spread of Continental Drought**. WMO/IHD Report No.2. WMO, Geneva.

Sudaryatno (2016). Drought vulnerability mapping with Geomorphological approach in Yogyakarta Special Region (DIY) and Central Java. In Proceedings of **the**

2nd International Conference of Indonesian Society for Remote Sensing (ICOIRS)**. (pp 1755-1315).

Suwanwerakamtorn, R., Mongkolsawat, C., Srisul, K., and Ratanasermpong, S. (2005). Drought assessment using GIS technology in the Nam Choen watershed, Northeast part of Thailand. In Proceedings of **Asian Conference on Remote Sensing (ACRS)**.

Svoboda, M. (2012). **Drought risk management. Caribbean Drought Training Workshop**, Kingston, Jamaica.

Svoboda, M., LeComte, D., Heyes, M., Heim, R., Gleason, K., Angel, J., Rippey, B., Tinker, R., Palecki, M., Stooksbury, D., Miskus, D., and Stephens, S. (2002). The Drought Monitor. Bulletin of the American Meteorological Society. **American meteorological society.** 83: 1181-1190.

Tadesse, T., Wardlow, B., Svoboda, M., and Brown, J. (2010). The Vegetation Outlook (VegOut): A New Method for prediction vegetation seasonal greenness. **GIScience & Remote Sensing**. 1: 25-52.

Tan, C., Yang, J., and Li, M. (2015). Temporal-Spatial variation of drought indicated by SPI and SPEI in Ningxia Hui autonomous region, China. **Atmosphere**. 6: 1399-1421.

Thai Meteorological Department. (2003). **Thailand's climate statistics in the 30-year period (1971-2000)**. Meteorological Information Report No. 551.5-03-2003.

Tomas, T., Jaiswal, R.K., Galkate, R., Nayak, P.C., and Ghosh N.C. (2016). Drought indicators-based integrated assessment of drought vulnerability- a case study of Bundelkhand droughts in central India. **Nat Hazards**. 81: 1627-1652.

Tsangaratos, P., Pizpikis, T., Vasileiou, E., Pliakas, F., Schuth, C., and Kallioras, A. (2013). Development of multi-criteria decision support system (dss) coupled with gis for identifying optimal locations for soil aquifer treatment (sat) facilities. **The Geological Society of Greece**, vol. XLVII 2013 Proceedings of the 13th International Congress, Chania.

Udomchoke, V., and Chuchip, P. (2005). **Drought classification in Eastern of Thailand.** Proceedings of 43rd Kasetsart University Annual Conference : Fisheries, Natural Resources and Environmental Economics

Van Loon, A.F. (2015). Hydrological drought explained. **WIREs Water**. 2: 359-392.

Vicenta-Serrano, S.M., Begueria, S., and Lopez-Moreno, J.I. (2010). A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. **Journal of Climate**. Vol. 23 1696- 1718.

Vicenta-Serrano, S.M., Begueria, S., Gimeno, L, Eklundh, L., Giuliani, G., Weston, D., Kenawy, A.E., Lopez-Moreno, J.I., Nieto, R., Ayenew, T., Konte, D., Ardo, J., and Pegram, G.GS. (2012). Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. **Applied Geography**. 34: 471-486.

Wang, Z., Jiang, J., Liao, Y., and Deng, L. (2015). Risk assessment of maize drought hazard in the middle region of farming-pastoral ecotone in Northern China. **Nat Hazards**. 75: 1515-1534.

Wardlow, B.D. (2010). **Vegetation Drought Response Index (VegDRI) A new tool for monitoring vegetation drought stress at local to national scales**. National Drought Mitigation Center (NDMC) University of Nebraska-Lincoln.

Wardlow, B.D., Tadesse, T., Brown, J.F., Callahan, K., Swain, S., and Hunt, E. (2012). **The Vegetation Drought Response Index (VegDRI): An Integration of Satellite, Climate, and Biophysical Data**. Research Gate.

Wattanakij, N., Thavorntam, W., and Mongkolsawat, C. (2006). **Analyzing spatial pattern of drought in the Mortheast of Thailand using Multi-Temporal Standardized Precipitation Index (SPI).** ResearchGat.

Wichitarapongsakun, P., Sarin, C., Klomjet, P., and Chuenchooklin, S. (2016). Meterological drought in the Sakea River basin using Standardized Precipitation Index (SPI) and the Meterological Drought Index (D). **Naresuan University Journal: Science and Technology.** 24(3): 123-135.

Whitmore, J.S. (2000). Drought Management on farmland. **Water Science and Technology Library.** Published by Kluwer Academic Publishers.

Wilhite, D.A. (1992). **Chapter eighteen Drought: Its physical and social dimension**. Drought Mitigation Center Faculty Publications.

Wilhite, D.A. (2000). **Chapter1 Drought as a natural hazard: Concepts and definitions**. Drought Mitigation Center Faculty Publications.

Wilhite, D.A., and Buchanan-Smith, M. (2005). Drought as Hazard: Understanding the natural and social context. Drought and water crises: science technology, and management issues. **Taylor & Francis Group**. 3-29.

Wilhite, D.A., and Glantz, M.H. (1985). **Understanding the Drought Phenomenon: The Role of Definitions**. Drought Mitigation Center Faculty Publications.

Wisner, B., Blaikie, P., Cannon, T., and Davis, I. (2003). **At Risk: natural hazards, people's vulnerability and disasters**.

Wu, H., Hayes, M.J., Weiss, A., and Hu, Q. (2001). An evaluation of the standardized precipitation index, the China-Z index and the statistical Z-score. International **Journal of Climatology**. 21: 745-758.

Xiaoqian, L., Yanglin, W., Jian, P., Braimoh, A.K., and He, Y. (2013). Assessing Vulnerability to Drought Based on Exposure, Sensitivity and Adaptive Capacity: A Case Study in Middle Inner Mongolia of China. Chin. **Geogra**. 23: 13-25.

Yusuf, A.A., and Francisco, H.A. (2009). **Climate change vulnerability mapping for Southeast Asia**. Economic and Environment Program for Southeast Asia (EEPSEA).

Zhang, A., and Jia, G. (2013). Monitoring meteorological drought in semiarid regions using multi-sensor microwave remote sensing data. **Remote Sensing of Environment**. 134: 12-23.

APPENDIX

APPENDIX

THE PERCENTAGE OF AREAS

Table A-1 The percentage of areas (Sq.km.) agricultural frequency drought of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	47.97	27.81	11.89	7.19	5.15
Bua Lai	17.21	15.15	14.60	22.06	30.98
Bua Yai	18.99	12.49	13.01	26.77	28.74
Chakkarat	68.87	17.54	8.69	3.86	1.03
Chaloem Phrakiat	68.59	10.92	9.88	8.41	2.20
Chok Chai	61.17	21.28	12.06	4.37	1.12
Chum Phuang	44.65	18.30	16.80	15.02	5.23
Dan Khun Thot	38.99	31.95	15.31	7.99	5.75
Huai Thalaeng	47.55	17.82	13.95	12.79	7.88
Kaeng Sanam Nang	43.79	22.19	12.13	16.37	5.52
Kham Sakae Saeng	41.78	35.73	15.12	6.39	0.98
Khom Thale So	51.46	32.47	10.98	3.42	1.67
Khon Buri	83.87	11.95	2.74	0.93	0.50
Khong	22.71	23.00	23.87	21.88	8.53
Lam Thamen Chai	59.83	20.04	14.17	5.42	0.54
Mueang Nakhon Ratchasima	60.28	23.79	10.23	3.84	1.86
Mueang Yang	11.21	9.94	39.75	37.20	1.90
Non Daeng	14.57	17.55	28.56	19.99	19.33
Non Sung	22.62	18.93	33.30	22.19	2.96
Non Thai	31.79	27.46	20.36	13.85	6.55
Nong Bunnak	85.03	8.05	5.30	1.49	0.13
Pak Chong	90.45	7.58	1.20	0.43	0.34
Pak Thong Chai	60.61	24.04	8.48	4.74	2.12
Phimai	42.43	23.83	26.11	7.11	0.52
Phra Thong Kham	66.17	18.76	10.50	4.12	0.45
Prathai	9.42	8.96	22.77	35.76	23.08
Sida	6.23	8.11	11.59	31.94	42.13

Table A-1 (Continued).

Districts Name	Very Low	Low	Moderate	High	Very High
Sikhio	66.65	24.24	7.23	1.72	0.16
Soeng Sang	86.40	10.02	2.71	0.80	0.06
Sung Noen	56.66	29.50	10.74	2.86	0.24
Tepharak	42.30	28.07	20.99	7.66	0.98
Wang Nam Khiao	78.17	14.79	5.08	1.75	0.21

Table A-2 The percentage of areas (Sq.km.) agricultural intensity drought of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	11.21	19.55	29.21	35.85	4.18
Bua Lai	36.86	36.14	15.98	8.38	2.64
Bua Yai	38.84	34.11	14.46	10.62	1.99
Chakkarat	1.95	12.20	21.51	44.15	20.20
Chaloem Phrakiat	3.81	20.82	13.37	19.37	42.63
Chok Chai	2.69	24.37	24.36	29.86	18.72
Chum Phuang	11.95	31.49	28.14	24.83	3.59
Dan Khun Thot	10.51	27.44	35.08	23.69	3.28
Huai Thalaeng	13.87	26.99	21.34	27.76	10.03
Kaeng Sanam Nang	9.33	27.27	26.22	33.27	3.91
Kham Sakae Saeng	2.85	18.96	35.04	39.84	3.31
Khom Thale So	8.12	22.33	26.25	39.84	3.46
Khon Buri	1.26	4.95	8.00	29.56	56.24
Khong	13.65	40.09	27.25	17.29	1.73
Lam Thamen Chai	2.61	24.38	33.98	34.08	4.94
Mueang Nakhon Ratchasima	7.67	20.71	23.36	35.41	12.85
Mueang Yang	20.73	43.16	29.74	5.61	0.76
Non Daeng	31.43	32.39	25.78	9.64	0.76
Non Sung	10.86	42.28	29.28	14.56	3.02
Non Thai	18.23	31.77	27.20	21.01	1.80
Nong Bunnak	0.43	6.77	11.00	25.47	56.32
Pak Chong	0.95	5.58	21.85	36.31	35.32
Pak Thong Chai	5.33	24.83	26.16	21.57	22.11
Phimai	3.39	20.69	33.59	35.34	6.99
Phra Thong Kham	2.34	14.75	24.19	51.13	7.60
Prathai	33.73	43.77	17.13	4.38	0.99
Sida	55.96	32.39	8.50	2.94	0.21
Sikhio	2.08	21.57	34.84	29.74	11.77
Soeng Sang	0.63	4.68	9.85	31.65	53.20
Sung Noen	3.23	30.71	38.45	22.67	4.94
Tepharak	3.66	33.01	36.56	20.56	6.21
Wang Nam Khiao	1.57	12.32	22.16	27.79	36.15

Table A-3 Percentage of drought exposure hazard classification of SPI-3m7 period (May, June and July) at district level.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	22.4	77.6	0
Bua Lai	25.0	44.7	30.3	0	0
Bua Yai	51.8	48.3	0	0	0
Chakkarat	0	24.6	13.0	62.4	0
Chaloem Phrakiat	0	0	45.2	54.8	0
Chok Chai	0	0	20.8	61.6	17.6
Chum Phuang	0	33.6	58.0	8.4	0
Dan Khun Thot	0	0	0	5.9	94.1
Huai Thalaeng	0	81.4	18.6	0	0
Kaeng Sanam Nang	0	0	19.7	20.8	59.5
Kham Sakae Saeng	0	0	0	91.2	8.8
Khom Thale So	0	0	0	61.7	38.4
Khon Buri	0	15.4	78.9	5.7	0
Khong	0	19.1	55.0	26.0	0
Lam Thamen Chai	18.4	81.6	0	0	0
Mueang Nakhon Ratchasima	0	0	0	56.9	43.1
Mueang Yang	74.8	25.2	0	0	0
Non Daeng	0	100	0	0	0
Non Sung	0	6.2	86.4	7.4	0
Non Thai	0	0	21.5	70.2	8.3
Nong Bunnak	0	0	0	56.2	43.8
Pak Chong	0	31.2	44.1	7.0	17.8
Pak Thong Chai	0	6.1	87.6	6.3	0
Phimai	0	79.2	20.8	0	0
Phra Thong Kham	0	0	0	90.5	9.5
Prathai	6.6	12.9	66.1	8.0	6.4
Sida	39.6	60.4	0	0	0
Sikhio	0	0	18.0	59.3	22.6
Soeng Sang	0	0	60.4	39.6	0
Sung Noen	0	0	20.7	46.7	32.6
Tepharak	0	0	0	0	100
Wang Nam Khiao	0	0	69.0	31.0	0

Table A-4 Percentage of drought exposure hazard classification of SPI-3m10 period (August, September and October) at district level.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	0	100
Bua Lai	0	0	76.6	23.5	0
Bua Yai	0	0	24.2	27.5	48.2
Chakkarat	0	0	13.0	87.0	0
Chaloem Phrakiat	0	0	10.8	89.2	0
Chok Chai	0	0	34.6	65.4	0
Chum Phuang	0	15.0	14.4	43.1	27.6
Dan Khun Thot	0	0	18.6	48.2	33.3
Huai Thalaeng	10.3	59.2	15.5	15.1	0
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	0	25.1	75.0
Khom Thale So	0	0	15.8	84.2	0
Khon Buri	27.9	20.9	51.2	0	0
Khong	0	0	25.5	20.2	54.3
Lam Thamen Chai	0	16.3	18.4	65.3	0
Mueang Nakhon Ratchasima	0	0	19.3	80.7	0
Mueang Yang	0	49.7	50.3	0	0
Non Daeng	0	84.7	15.3	0	0
Non Sung	0	19.8	54.4	19.3	6.5
Non Thai	0	34.4	38.6	27.0	0
Nong Bunnak	0	0	73.2	26.8	0
Pak Chong	24.4	57.8	17.8	0	0
Pak Thong Chai	0	7.6	62.4	29.9	0
Phimai	0	0	88.7	11.4	0
Phra Thong Kham	0	0	18.4	35.6	46.0
Prathai	0	47.1	45.6	7.3	0
Sida	0	0	100	0	0
Sikhio	0	40.1	20.1	39.8	0
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	15.0	85.0	0
Tepharak	0	0	31.8	68.2	0
Wang Nam Khiao	0	100	0	0	0

Table A-5 Percentage of drought exposure hazard classification of SPI-6m10 period (May to October) at district level.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0	0	0	0	100
Bua Lai	0	100	0	0	0
Bua Yai	45.2	24.3	30.5	0	0
Chakkarat	0	0	27.9	62.6	9.5
Chaloem Phrakiat	0	0	33.4	66.6	0
Chok Chai	0	20.8	34.5	44.7	0
Chum Phuang	0	0	51.9	39.7	8.4
Dan Khun Thot	0	0	27.4	23.5	49.2
Huai Thalaeng	0	0	30.5	12.0	57.5
Kaeng Sanam Nang	0	0	0	0	100
Kham Sakae Saeng	0	0	57.6	42.4	0
Khom Thale So	0	0	0	35.6	64.4
Khon Buri	5.6	41.5	10	43.0	0
Khong	0	0	0	84.0	16.0
Lam Thamen Chai	0	69.3	30.7	0	0
Mueang Nakhon Ratchasima	0	0	0	16.0	84.0
Mueang Yang	0	49.7	50.3	0	0
Non Daeng	0	21.2	78.8	0	0
Non Sung	0	0	34.3	65.8	0
Non Thai	0	0	0	20.5	79.5
Nong Bunnak	0	80.1	19.9	0	0
Pak Chong	6.2	24.5	69.3	0	0
Pak Thong Chai	0	0	0	35.1	64.9
Phimai	0	27.2	22.1	50.7	0
Phra Thong Kham	0	0	0	0	100
Prathai	33.4	49.0	17.6	0	0
Sida	39.6	60.5	0	0	0
Sikhio	0	0	23.3	62.3	14.4
Soeng Sang	100	0	0	0	0
Sung Noen	0	0	0	28.1	71.9
Tepharak	0	81.9	18.1	0	0
Wang Nam Khiao	0	43.5	42.0	14.5	0

Table A-6 The percentage of areas (Sq.km.) SPEI of each district and categories at 3 months of time periods (May, June and July).

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	4.14	58.83	37.03
Bua Lai	0.00	0.00	86.53	13.47	0.00
Bua Yai	1.57	21.79	48.54	28.10	0.00
Chakkarat	0.00	0.00	7.78	92.22	0.00
Chaloem Phrakiat	0.00	0.00	0.00	100.00	0.00
Chok Chai	0.00	0.00	0.00	93.74	6.26
Chum Phuang	3.08	77.89	19.03	0.00	0.00
Dan Khun Thot	0.00	0.00	0.00	41.22	58.78
Huai Thalaeng	0.00	3.90	34.14	50.27	11.68
Kaeng Sanam Nang	0.00	0.00	21.61	43.75	34.64
Kham Sakae Saeng	1.81	51.96	35.07	11.16	0.00
Khom Thale So	0.00	0.00	0.00	0.00	100.00
Khon Buri	0.00	0.00	8.95	86.12	4.93
Khong	34.80	34.57	12.23	18.40	0.00
Lam Thamen Chai	0.00	87.43	12.57	0.00	0.00
Mueang Nakhon Ratchasima	0.00	0.46	2.15	40.47	56.92
Mueang Yang	0.00	46.01	53.99	0.00	0.00
Non Daeng	0.00	100.00	0.00	0.00	0.00
Non Sung	3.22	18.84	19.88	47.34	10.72
Non Thai	0.00	0.00	0.48	54.00	45.52
Nong Bunnak	0.00	0.00	0.00	100.00	0.00
Pak Chong	15.66	42.99	41.36	0.00	0.00
Pak Thong Chai	0.00	0.00	58.26	38.29	3.45
Phimai	25.13	58.11	16.36	0.40	0.00
Phra Thong Kham	0.00	0.00	0.94	96.86	2.20
Prathai	0.00	19.13	79.51	1.36	0.00
Sida	0.00	51.05	48.95	0.00	0.00
Sikhio	0.00	2.67	23.50	41.77	32.07
Soeng Sang	0.00	0.00	0.00	31.09	68.91
Sung Noen	0.00	0.00	3.87	27.43	68.71
Tepharak	0.00	0.00	0.00	99.12	0.88
Wang Nam Khiao	0.00	5.76	94.15	0.09	0.00

Table A-7 The percentage of areas (Sq.km.) SPEI of each district and categories at 3 months of time periods (August, September and October).

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.06	19.03	74.73	6.17
Bua Lai	0.00	0.00	0.00	57.65	42.35
Bua Yai	0.00	0.00	23.90	64.29	11.82
Chakkarat	0.00	0.00	0.85	20.21	78.95
Chaloem Phrakiat	0.00	0.00	50.63	49.37	0.01
Chok Chai	0.00	1.21	25.18	57.93	15.68
Chum Phuang	0.00	0.57	9.55	58.11	31.77
Dan Khun Thot	0.00	0.00	15.45	68.11	16.44
Huai Thalaeng	0.00	0.00	6.66	53.98	39.36
Kaeng Sanam Nang	0.00	0.99	7.65	43.62	47.74
Kham Sakae Saeng	0.00	0.00	0.00	31.08	68.92
Khom Thale So	0.00	13.00	77.38	9.62	0.00
Khon Buri	0.00	5.71	30.51	54.08	9.70
Khong	0.00	0.00	12.99	41.48	45.53
Lam Thamen Chai	0.00	8.57	62.65	28.78	0.00
Mueang Nakhon Ratchasima	16.32	46.97	36.04	0.67	0.00
Mueang Yang	21.46	63.31	10.88	3.86	0.49
Non Daeng	0.00	0.00	18.33	81.67	0.00
Non Sung	8.27	32.02	41.07	13.93	4.71
Non Thai	0.00	0.00	25.08	69.75	5.17
Nong Bunnak	0.00	0.00	0.00	1.24	98.76
Pak Chong	43.75	48.47	7.47	0.30	0.00
Pak Thong Chai	0.00	7.86	84.24	7.90	0.00
Phimai	0.00	18.87	52.26	28.05	0.82
Phra Thong Kham	0.00	0.00	0.00	95.66	4.34
Prathai	0.00	1.72	55.35	38.48	4.44
Sida	0.00	0.00	2.65	97.35	0.00
Sikhio	11.36	63.56	23.64	1.44	0.00
Soeng Sang	0.00	0.00	8.64	38.81	52.54
Sung Noen	0.00	9.73	48.99	30.85	10.43
Tepharak	2.08	6.17	17.12	33.44	41.18
Wang Nam Khiao	0.00	13.90	60.84	25.26	0.00

Table A-8 The percentage of areas (Sq.km.) SPEI of each district and categories at 6 months of time periods (May to October).

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	99.65	0.35	0.00
Bua Lai	0.00	0.00	95.18	4.82	0.00
Bua Yai	2.48	37.25	60.26	0.00	0.00
Chakkarat	0.00	0.00	4.53	95.47	0.00
Chaloem Phrakiat	0.00	0.00	60.31	39.69	0.00
Chok Chai	0.00	0.00	51.16	45.28	3.55
Chum Phuang	36.35	54.49	9.17	0.00	0.00
Dan Khun Thot	0.00	0.00	2.45	50.38	47.17
Huai Thalaeng	0.00	6.23	38.74	47.30	7.74
Kaeng Sanam Nang	0.00	0.00	87.73	12.27	0.00
Kham Sakae Saeng	0.63	47.45	47.79	4.13	0.00
Khom Thale So	0.00	0.00	34.45	65.55	0.00
Khon Buri	0.00	5.93	69.24	24.14	0.69
Khong	48.12	25.79	26.09	0.00	0.00
Lam Thamen Chai	0.21	99.79	0.00	0.00	0.00
Mueang Nakhon Ratchasima	5.37	33.24	57.92	3.47	0.00
Mueang Yang	2.91	97.09	0.00	0.00	0.00
Non Daeng	3.61	96.39	0.00	0.00	0.00
Non Sung	3.49	14.12	27.63	40.30	14.45
Non Thai	0.00	0.02	11.29	60.72	27.97
Nong Bunnak	0.00	0.00	0.00	32.53	67.47
Pak Chong	50.48	43.16	6.36	0.00	0.00
Pak Thong Chai	0.00	65.36	34.64	0.00	0.00
Phimai	31.32	56.03	12.52	0.13	0.00
Phra Thong Kham	0.00	0.00	8.28	81.41	10.32
Prathai	0.00	23.22	73.51	3.27	0.00
Sida	0.00	63.74	36.26	0.00	0.00
Sikhio	15.35	24.93	42.33	16.42	0.98
Soeng Sang	0.00	0.00	0.81	48.31	50.88
Sung Noen	0.00	9.10	21.97	40.37	28.56
Tepharak	0.00	0.00	0.00	100.00	0.00
Wang Nam Khiao	1.21	94.54	4.25	0.00	0.00

Table A-9 The percentage of areas (Sq.km.) land use of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	1.08	6.06	4.22	30.26	58.38
Bua Lai	0.07	6.31	6.42	13.65	73.55
Bua Yai	0.48	7.18	5.04	13.54	73.76
Chakkarat	0.10	11.61	5.80	36.91	45.57
Chaloem Phrakiat	1.08	42.74	6.62	18.31	31.26
Chok Chai	0.25	9.67	7.29	37.58	45.21
Chum Phuang	2.02	10.28	7.46	20.55	59.69
Dan Khun Thot	1.12	8.47	4.58	46.68	39.15
Huai Thalaeng	0.32	5.55	6.72	15.72	71.69
Kaeng Sanam Nang	2.78	7.47	3.23	22.30	64.23
Kham Sakae Saeng	0.25	4.35	4.47	11.44	79.50
Khom Thale So	2.41	8.62	6.56	42.84	39.58
Khon Buri	1.07	55.59	4.79	29.88	8.66
Khong	0.62	6.09	5.00	12.92	75.37
Lam Thamen Chai	0.81	7.27	10.73	34.56	46.63
Mueang Nakhon Ratchasima	0.91	29.03	12.95	24.54	32.57
Mueang Yang	2.08	5.62	5.00	3.48	83.81
Non Daeng	1.26	8.65	7.83	3.91	78.35
Non Sung	0.78	9.57	6.18	1.77	81.69
Non Thai	1.05	6.82	4.29	12.33	75.51
Nong Bunnak	0.16	3.76	4.31	59.51	32.26
Pak Chong	1.20	40.60	15.95	41.26	0.99
Pak Thong Chai	1.05	30.38	8.37	24.39	35.81
Phimai	0.82	7.32	4.16	23.35	64.34
Phra Thong Kham	0.40	5.52	5.84	33.08	55.15
Prathai	1.74	8.55	5.17	2.16	82.39
Sida	0.19	5.75	4.75	3.67	85.64
Sikhio	0.39	18.63	10.89	51.47	18.62
Soeng Sang	0.74	41.56	3.45	44.59	9.66
Sung Noen	0.43	10.32	9.22	47.94	32.09
Tepharak	0.24	10.97	8.74	58.62	21.44
Wang Nam Khiao	0.45	52.15	8.73	36.33	2.35

Table A-10 The percentage of areas (Sq.km.) soil drainage of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	33.25	2.25	0.10	41.81	22.59
Bua Lai	61.27	0.00	1.88	8.29	28.56
Bua Yai	59.66	2.52	9.68	3.21	24.93
Chakkarat	28.20	3.29	0.52	50.92	17.07
Chaloem Phrakiat	32.30	2.78	3.24	4.86	56.82
Chok Chai	12.89	23.63	1.01	41.36	21.10
Chum Phuang	53.06	0.70	1.25	19.28	25.71
Dan Khun Thot	14.67	4.90	5.17	49.78	25.48
Huai Thalaeng	46.59	3.50	2.87	44.59	2.44
Kaeng Sanam Nang	43.11	0.41	1.42	24.04	31.02
Kham Sakae Saeng	29.46	12.87	0.43	45.02	12.23
Khom Thale So	18.57	0.00	0.19	50.80	30.44
Khon Buri	3.74	6.40	0.93	29.87	59.07
Khong	49.62	4.83	4.56	22.88	18.12
Lam Thamen Chai	32.18	0.05	0.05	8.53	59.19
Mueang Nakhon Ratchasima	34.70	10.62	1.47	23.67	29.54
Mueang Yang	96.60	0.38	0.00	0.00	3.03
Non Daeng	69.55	0.00	1.95	0.90	27.61
Non Sung	79.62	5.26	0.66	8.40	6.07
Non Thai	50.09	8.04	0.50	29.54	11.84
Nong Bunnak	9.98	22.84	0.04	60.94	6.19
Pak Chong	11.20	11.72	8.20	43.07	25.81
Pak Thong Chai	13.54	14.26	2.81	28.76	40.63
Phimai	65.15	3.82	0.71	8.45	21.87
Phra Thong Kham	24.64	2.98	0.24	56.58	15.55
Prathai	81.34	0.30	3.16	2.29	12.90
Sida	78.75	0.00	11.66	2.08	7.51
Sikhio	5.38	4.41	3.87	43.87	42.46
Soeng Sang	15.65	6.67	0.11	17.44	60.14
Sung Noen	24.93	3.84	4.98	43.25	23.00
Tepharak	3.94	13.24	17.94	20.86	44.02
Wang Nam Khiao	4.39	7.63	1.36	23.10	63.52

Table A-11 The percentage of areas (Sq.km.) irrigation areas of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	0.00	0.00	100.00
Bua Lai	0.00	0.00	0.00	0.00	100.00
Bua Yai	0.00	0.00	0.00	0.00	100.00
Chakkarat	0.00	0.00	0.00	0.00	100.00
Chaloem Phrakiat	8.74	0.00	0.00	0.00	91.26
Chok Chai	36.09	0.00	0.00	0.00	63.91
Chum Phuang	1.98	0.00	0.00	0.00	98.02
Dan Khun Thot	0.00	0.00	0.00	0.00	100.00
Huai Thalaeng	0.00	0.00	0.00	0.00	100.00
Kaeng Sanam Nang	0.00	0.00	0.00	0.00	100.00
Kham Sakae Saeng	0.00	0.00	0.00	0.00	100.00
Khom Thale So	4.87	0.00	0.00	0.00	95.13
Khon Buri	7.19	0.00	0.00	0.00	92.81
Khong	0.00	0.00	0.00	0.00	100.00
Lam Thamen Chai	0.00	0.00	0.00	0.00	100.00
Mueang Nakhon Ratchasima	19.27	0.00	0.00	0.00	80.73
Mueang Yang	0.00	0.00	0.00	0.00	100.00
Non Daeng	0.38	0.00	0.00	0.00	99.62
Non Sung	2.06	0.00	0.00	0.00	97.94
Non Thai	0.00	0.00	0.00	0.00	100.00
Nong Bunnak	0.00	0.00	0.00	0.00	100.00
Pak Chong	0.00	0.00	0.00	0.00	100.00
Pak Thong Chai	11.89	0.00	0.00	0.00	88.11
Phimai	27.96	0.00	0.00	0.00	72.04
Phra Thong Kham	0.00	0.00	0.00	0.00	100.00
Prathai	0.25	0.00	0.00	0.00	99.75
Sida	0.00	0.00	0.00	0.00	100.00
Sikhio	1.12	0.00	0.00	0.00	98.88
Soeng Sang	0.00	0.00	0.00	0.00	100.00
Sung Noen	2.49	0.00	0.00	0.00	97.51
Tepharak	0.00	0.00	0.00	0.00	100.00
Wang Nam Khiao	0.00	0.00	0.00	0.00	100.00

Table A-12 The percentage of areas (Sq.km.) slope of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	43.82	56.18	0.00	0.00	0.00
Bua Lai	56.11	43.89	0.00	0.00	0.00
Bua Yai	67.56	32.44	0.00	0.00	0.00
Chakkarat	44.73	55.27	0.00	0.00	0.00
Chaloem Phrakiat	45.99	53.91	0.09	0.00	0.00
Chok Chai	52.27	44.56	3.02	0.15	0.00
Chum Phuang	65.55	34.45	0.00	0.00	0.00
Dan Khun Thot	26.20	68.33	3.57	1.02	0.88
Huai Thalaeng	70.18	29.82	0.00	0.00	0.00
Kaeng Sanam Nang	37.37	62.63	0.00	0.00	0.00
Kham Sakae Saeng	45.60	54.40	0.00	0.00	0.00
Khom Thale So	30.49	69.51	0.00	0.00	0.00
Khon Buri	11.75	36.33	12.35	10.88	28.69
Khong	61.91	38.09	0.00	0.00	0.00
Lam Thamen Chai	46.01	53.99	0.00	0.00	0.00
Mueang Nakhon Ratchasima	49.21	50.79	0.00	0.00	0.00
Mueang Yang	98.28	1.72	0.00	0.00	0.00
Non Daeng	71.60	28.40	0.00	0.00	0.00
Non Sung	84.60	15.40	0.00	0.00	0.00
Non Thai	60.20	39.80	0.00	0.00	0.00
Nong Bunnak	34.19	65.16	0.65	0.00	0.00
Pak Chong	6.18	31.70	26.30	8.24	27.58
Pak Thong Chai	33.96	41.08	8.20	5.45	11.32
Phimai	75.55	24.45	0.00	0.00	0.00
Phra Thong Kham	35.93	64.07	0.00	0.00	0.00
Prathai	88.57	11.43	0.00	0.00	0.00
Sida	93.12	6.88	0.00	0.00	0.00
Sikhio	14.30	58.00	13.63	5.87	8.21
Soeng Sang	12.81	62.33	12.04	5.43	7.39
Sung Noen	24.41	65.48	7.22	1.48	1.40
Tepharak	11.00	69.52	10.82	7.42	1.23
Wang Nam Khiao	3.56	20.48	27.60	21.76	26.59

Table A-13 The percentage of areas (Sq.km.) elevation of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	52.87	46.76	0.36	0.00	0.00
Bua Lai	80.63	19.37	0.00	0.00	0.00
Bua Yai	79.63	20.15	0.22	0.00	0.00
Chakkarat	62.50	36.57	0.93	0.00	0.00
Chaloem Phrakiat	62.01	27.20	10.79	0.00	0.00
Chok Chai	52.27	36.16	11.57	0.00	0.00
Chum Phuang	93.87	6.13	0.00	0.00	0.00
Dan Khun Thot	5.65	53.39	38.44	2.52	0.00
Huai Thalaeng	88.22	11.55	0.23	0.00	0.00
Kaeng Sanam Nang	76.78	23.22	0.00	0.00	0.00
Kham Sakae Saeng	73.59	26.41	0.00	0.00	0.00
Khom Thale So	46.71	52.58	0.70	0.00	0.00
Khon Buri	0.59	18.89	31.30	44.93	4.28
Khong	68.68	31.11	0.21	0.00	0.00
Lam Thamen Chai	93.18	6.82	0.00	0.00	0.00
Mueang Nakhon Ratchasima	67.20	23.99	8.82	0.00	0.00
Mueang Yang	100.00	0.00	0.00	0.00	0.00
Non Daeng	100.00	0.00	0.00	0.00	0.00
Non Sung	100.00	0.00	0.00	0.00	0.00
Non Thai	90.77	9.23	0.00	0.00	0.00
Nong Bunnak	12.10	43.23	44.67	0.00	0.00
Pak Chong	1.21	1.19	25.57	65.35	6.68
Pak Thong Chai	0.32	47.37	32.54	19.62	0.15
Phimai	93.66	5.97	0.37	0.00	0.00
Phra Thong Kham	31.37	58.83	9.81	0.00	0.00
Prathai	100.00	0.00	0.00	0.00	0.00
Sida	100.00	0.00	0.00	0.00	0.00
Sikhio	0.81	15.55	53.70	29.90	0.04
Soeng Sang	0.00	15.26	64.47	20.28	0.00
Sung Noen	3.46	54.53	37.01	5.00	0.00
Tepharak	12.05	3.77	82.30	1.88	0.00
Wang Nam Khiao	0.12	2.10	16.17	80.03	1.58

Table A-14 The percentage of areas (Sq.km.) distance to river of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	34.10	41.15	22.21	2.55	0.00
Bua Lai	27.36	51.69	20.92	0.03	0.00
Bua Yai	38.45	43.67	16.86	1.01	0.00
Chakkarat	18.66	29.39	25.68	15.26	11.03
Chaloem Phrakiat	26.39	24.37	21.10	21.59	6.55
Chok Chai	31.48	30.32	19.04	14.23	4.94
Chum Phuang	48.56	34.27	13.18	3.98	0.00
Dan Khun Thot	23.64	34.99	23.16	12.68	5.53
Huai Thalaeng	50.57	34.00	10.72	3.88	0.83
Kaeng Sanam Nang	32.65	46.28	20.00	1.06	0.00
Kham Sakae Saeng	66.16	32.79	1.06	0.00	0.00
Khom Thale So	35.96	50.92	13.02	0.10	0.00
Khon Buri	20.63	33.32	23.74	13.51	8.79
Khong	36.78	43.49	17.59	2.14	0.00
Lam Thamen Chai	41.86	40.00	15.21	2.93	0.00
Mueang Nakhon Ratchasima	30.05	34.15	24.59	10.23	0.98
Mueang Yang	37.21	36.91	23.08	2.80	0.00
Non Daeng	52.71	35.33	11.20	0.76	0.00
Non Sung	47.88	35.44	12.30	4.13	0.26
Non Thai	44.12	44.66	10.21	1.01	0.00
Nong Bunnak	7.63	13.17	11.65	11.77	55.79
Pak Chong	14.48	25.74	20.36	15.72	23.71
Pak Thong Chai	22.49	24.97	23.76	18.19	10.59
Phimai	49.80	39.74	9.70	0.76	0.00
Phra Thong Kham	32.45	49.74	16.72	1.08	0.00
Prathai	45.10	47.40	7.50	0.00	0.00
Sida	53.90	43.39	2.72	0.00	0.00
Sikhio	21.54	32.00	24.25	16.97	5.24
Soeng Sang	7.94	18.46	20.17	16.79	36.63
Sung Noen	14.78	19.04	19.17	19.44	27.58
Tepharak	23.95	38.41	24.89	10.80	1.95
Wang Nam Khiao	17.40	31.11	22.16	11.81	17.52

Table A-15 The percentage of areas (Sq.km.) drainage density of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	91.79	0.00	8.21
Bua Lai	0.00	0.00	13.18	0.00	86.82
Bua Yai	0.00	0.00	9.67	0.00	90.33
Chakkarat	0.00	0.00	4.70	0.00	95.30
Chaloem Phrakiat	0.00	0.00	72.13	0.00	27.87
Chok Chai	0.00	0.00	97.75	0.00	2.25
Chum Phuang	0.00	0.00	97.68	0.00	2.32
Dan Khun Thot	7.13	0.00	4.49	0.00	88.38
Huai Thalaeng	0.00	0.00	70.89	0.00	29.11
Kaeng Sanam Nang	0.00	0.00	99.84	0.00	0.16
Kham Sakae Saeng	0.00	0.00	72.36	0.00	27.64
Khom Thale So	0.00	0.00	86.81	0.00	13.19
Khon Buri	0.00	0.00	98.87	0.00	1.13
Khong	0.00	0.00	24.97	0.00	75.03
Lam Thamen Chai	0.00	0.00	100.00	0.00	0.00
Mueang Nakhon Ratchasima	0.00	0.00	89.41	0.00	10.59
Mueang Yang	0.00	0.00	56.07	0.00	43.93
Non Daeng	0.00	0.00	0.00	0.00	100.00
Non Sung	0.00	0.00	58.66	0.00	41.34
Non Thai	0.00	0.00	8.82	0.00	91.18
Nong Bunnak	0.00	0.00	7.12	0.00	92.88
Pak Chong	3.07	0.00	74.52	0.00	22.41
Pak Thong Chai	0.00	0.00	100.00	0.00	0.00
Phimai	0.00	0.00	69.60	0.00	30.40
Phra Thong Kham	0.00	0.00	9.01	0.00	90.99
Prathai	0.00	0.00	38.49	0.00	61.51
Sida	0.00	0.00	3.62	0.00	96.38
Sikhio	9.50	0.00	76.83	0.00	13.67
Soeng Sang	0.00	0.00	87.19	0.00	12.81
Sung Noen	0.00	0.00	99.83	0.00	0.17
Tepharak	23.96	0.00	19.14	0.00	56.90
Wang Nam Khiao	0.00	0.00	100.00	0.00	0.00

Table A-16 The percentage of areas (Sq.km.) agricultural occupation of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	22.39	0.00	77.61	0.00
Bua Lai	0.00	0.00	0.00	76.55	23.45
Bua Yai	14.47	6.57	15.61	53.94	9.40
Chakkarat	0.00	16.83	73.64	0.00	9.52
Chaloem Phrakiat	0.00	0.00	55.78	44.22	0.00
Chok Chai	17.20	10.55	27.50	33.51	11.24
Chum Phuang	0.00	0.00	8.42	49.59	41.99
Dan Khun Thot	0.00	0.00	40.39	27.22	32.39
Huai Thalaeng	12.03	15.11	11.88	17.65	43.34
Kaeng Sanam Nang	0.00	0.00	20.81	79.19	0.00
Kham Sakae Saeng	0.00	0.00	15.67	26.54	57.79
Khom Thale So	0.00	0.00	61.66	38.34	0.00
Khon Buri	0.00	4.65	68.81	24.68	1.86
Khong	0.00	19.84	13.87	40.25	26.05
Lam Thamen Chai	0.00	0.00	0.00	0.00	100.00
Mueang Nakhon Ratchasima	56.07	34.70	3.39	5.84	0.00
Mueang Yang	0.00	0.00	0.00	0.00	100.00
Non Daeng	0.00	0.00	83.50	16.50	0.00
Non Sung	6.17	10.61	43.54	22.97	16.71
Non Thai	0.00	12.05	8.06	61.20	18.68
Nong Bunnak	0.00	0.00	26.54	23.25	50.21
Pak Chong	6.95	74.62	18.42	0.00	0.00
Pak Thong Chai	0.00	12.04	54.38	20.79	12.80
Phimai	0.00	14.41	45.31	6.25	34.03
Phra Thong Kham	0.00	0.00	0.00	41.69	58.31
Prathai	0.00	0.00	0.00	48.95	51.05
Sida	0.00	0.00	82.70	17.30	0.00
Sikhio	0.00	47.72	20.98	25.79	5.52
Soeng Sang	0.00	0.00	61.68	12.74	25.58
Sung Noen	0.00	69.08	16.76	14.16	0.00
Tepharak	48.40	13.73	0.00	19.77	18.10
Wang Nam Khiao	0.00	43.53	56.47	0.00	0.00

Table A-17 The percentage of areas (Sq.km.) economic crop production of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	0.00	0.00	0.00	100.00	0.00
Bua Lai	0.00	0.00	100.00	0.00	0.00
Bua Yai	0.00	0.00	0.00	0.00	100.00
Chakkarat	0.00	0.00	100.00	0.00	0.00
Chaloem Phrakiat	0.00	0.00	100.00	0.00	0.00
Chok Chai	0.00	100.00	0.00	0.00	0.00
Chum Phuang	0.00	0.00	0.00	100.00	0.00
Dan Khun Thot	0.00	0.00	0.00	100.00	0.00
Huai Thalaeng	0.00	0.00	100.00	0.00	0.00
Kaeng Sanam Nang	0.00	0.00	0.00	100.00	0.00
Kham Sakae Saeng	0.00	0.00	0.00	100.00	0.00
Khom Thale So	0.00	0.00	100.00	0.00	0.00
Khon Buri	100.00	0.00	0.00	0.00	0.00
Khong	0.00	0.00	100.00	0.00	0.00
Lam Thamen Chai	100.00	0.00	0.00	0.00	0.00
Mueang Nakhon Ratchasima	0.00	0.00	100.00	0.00	0.00
Mueang Yang	0.00	0.00	0.00	0.00	100.00
Non Daeng	0.00	0.00	0.00	0.00	100.00
Non Sung	0.00	0.00	0.00	100.00	0.00
Non Thai	0.00	0.00	0.00	0.00	100.00
Nong Bunnak	100.00	0.00	0.00	0.00	0.00
Pak Chong	0.00	100.00	0.00	0.00	0.00
Pak Thong Chai	0.00	100.00	0.00	0.00	0.00
Phimai	0.00	0.00	100.00	0.00	0.00
Phra Thong Kham	0.00	0.00	0.00	0.00	100.00
Prathai	0.00	0.00	0.00	0.00	100.00
Sida	0.00	100.00	0.00	0.00	0.00
Sikhio	0.00	100.00	0.00	0.00	0.00
Soeng Sang	100.00	0.00	0.00	0.00	0.00
Sung Noen	0.00	0.00	100.00	0.00	0.00
Tepharak	0.00	0.00	0.00	100.00	0.00
Wang Nam Khiao	0.00	0.00	100.00	0.00	0.00

Table A-18 The percentage of areas (Sq.km.) population density of each district and categories.

Districts Name	Very Low	Low	Moderate	High	Very High
Ban Lueam	49.29	50.71	0.00	0.00	0.00
Bua Lai	0.00	76.55	23.45	0.00	0.00
Bua Yai	0.00	90.60	9.40	0.00	0.00
Chakkarat	0.00	75.53	17.62	6.85	0.00
Chaloem Phrakiat	68.02	10.59	0.00	21.39	0.00
Chok Chai	25.69	37.84	36.48	0.00	0.00
Chum Phuang	24.19	33.58	22.68	19.55	0.00
Dan Khun Thot	47.81	39.89	12.30	0.00	0.00
Huai Thalaeng	10.25	49.98	39.77	0.00	0.00
Kaeng Sanam Nang	0.00	47.63	52.37	0.00	0.00
Kham Sakae Saeng	58.08	25.04	16.87	0.00	0.00
Khom Thale So	0.00	71.17	28.83	0.00	0.00
Khon Buri	71.92	23.75	2.57	1.75	0.00
Khong	6.52	63.29	30.19	0.00	0.00
Lam Thamen Chai	34.66	34.62	30.72	0.00	0.00
Mueang Nakhon Ratchasima	9.18	12.62	43.50	23.81	10.90
Mueang Yang	25.23	74.77	0.00	0.00	0.00
Non Daeng	27.36	72.64	0.00	0.00	0.00
Non Sung	1.01	29.84	40.67	28.48	0.00
Non Thai	24.41	36.36	39.23	0.00	0.00
Nong Bunnak	15.41	47.41	37.18	0.00	0.00
Pak Chong	48.25	21.74	23.05	6.95	0.00
Pak Thong Chai	41.86	32.41	19.33	6.40	0.00
Phimai	14.76	13.22	20.81	51.21	0.00
Phra Thong Kham	13.81	67.82	18.37	0.00	0.00
Prathai	6.38	73.58	20.04	0.00	0.00
Sida	21.52	78.48	0.00	0.00	0.00
Sikhio	54.83	33.77	5.41	5.99	0.00
Soeng Sang	64.34	24.21	11.45	0.00	0.00
Sung Noen	44.04	4.22	47.68	4.05	0.00
Tepharak	80.23	19.77	0.00	0.00	0.00
Wang Nam Khiao	100.00	0.00	0.00	0.00	0.00

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