

INTEGRATION OF GEOSPATIAL MODELS FOR AGRICULTURAL DROUGHT VULNERABILITY ASSESSMENT, NAKHON RATCHASIMA, THAILAND

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Abstract

Nakhon Ratchasima province is one of the drought prone areas in Thailand. The main objectives of the study were (1) to assess the exposure to drought hazard, (2) to assess the agricultural drought sensitivity, (3) to assess the adaptive capacity on agricultural drought, and (4) to assess and map the agricultural drought vulnerability and its severity. In this study, the exposure to drought hazard based on a combination of the meteorological drought hazard frequency and intensity of 3 periods (3m7, 3m10, and 6m10), the agricultural drought sensitivity based on a combination of the climate, vegetation, and physical and socioeconomic conditions of the 3 periods, and the adaptive capacity based on socioeconomic data were separately analyzed. Then, the 3 derived classifications were combined to classify the agricultural drought vulnerability. The most dominant class of the exposure to drought hazard classification of the 3 periods was high and very high and covered areas of 43.60%, 39.20%, and 49.50%, respectively, but the most dominant class of agricultural drought sensitivity classification was very low and low and covered area of 36.55%, 40.43%, and 40.62%, respectively. In the meantime, the most dominant class of the adaptive capacity classification was very low and low and covered an area of 38.73%. Subsequently, the most dominant class of agricultural drought vulnerability assessment of the 3m7 and 6m10 periods was very low and low and covered areas of 35.83% and 37.91%, respectively. Conversely, the most dominant class of the 3m10 period was high and very high and covered an area of 42.35%. In conclusion, geospatial modeling can be efficiently used as a tool to assess drought exposure hazard, agricultural drought sensitivity, and adaptive capacity for agricultural drought vulnerability assessment.

Keywords: Exposure to drought hazard assessment, agricultural drought sensitivity assessment, adaptive capacity assessment, agricultural drought vulnerability assessment

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Introduction

Drought is a complex phenomenon because of the unpredictable start and end of its period, the length of the event, as well as the non-specific spatial extent or geography and uncertain frequency and intensity. Park *et al.* (2016) mentioned that drought, unlike other natural disasters such as floods and earthquakes, is a slow developing event and it is difficult to define its spatial extent and temporal starting and ending points. Its severity typically depends on duration, intensity, spatial extent, and local socioeconomic conditions (Son *et al.*, 2012). Wilhite and Buchanan-Smith (2005) stated that 3 characteristics that differentiate drought from other natural disasters are intensity, duration, and spatial extent. Likewise, Mishra *et al.* (2009) claimed that the important characteristics of drought consist of frequency, duration, severity, and spatial extent.

Drought definition can depend on the variables used to identify drought and which can be brought to classify the type of drought (Mishra and Singh, 2010). In general, drought can be classified into 4 types comprising meteorological, agricultural, hydrological, and socioeconomic drought (Wilhite and Glantz, 1985; Whitmore, 2000; American Meteorological Society, 2004; Wilhite and Buchanan-Smith, 2005; Mishra and Singh, 2010).

In Thailand, most of the drought studies are focused on drought risk without specified drought types and they rely on meteorological and/or hydrological data by integration with biophysical data such as the normalised vegetation index (NDVI), elevation, slope, land use, and soil. Prathumchai *et al.* (2001) applied remote sensing and GIS to evaluate the drought risk area of Lop Buri province based on modification of the Ministry of Science, Technology and Environment (MOSTE) criteria. Likewise, Suwanwerakamtorn *et al.* (2005) applied GIS to assess the drought risk area of the Nam Choen watershed by integrating relevant meteorological, hydrological, and biophysical factors using the simple additive weighting method. Similarly,

Kaewpruksapimon (2006) applied the fuzzy logic technique for drought risk area identification in Buriram province based on climate, soil, topography, hydrology, and hydrogeology. Also, Chanchaeng (2012) applied the weighted linear combination method and linear regression analysis to evaluate the drought risk area in Nakhon Pathom province.

Consequently, agricultural drought vulnerability assessment which covers exposure, sensitivity, and adaptive capacity (Murthy *et al.*, 2014; 2015a; 2015b; Pei *et al.*, 2016; Antwi-Agyei *et al.*, 2012) is here examined in Nakhon Ratchasima province since agriculture is still largely based on traditional methods in this area. In addition, agricultural productivity, which crucially relies on the amount of rainfall as an effective irrigation system for farms, is still limited (Punprasit, 2006). Moreover, Thailand is characterized by a monsoon tropical climate with distinctive dry and rainy seasons causing droughts and floods to repeat alternatively (Homdee *et al.*, 2016). The impact of climate change, particularly drought occurrence, has been an important issue in the country for a long time (Prathumchai *et al.*, 2001; Jamphon, 2004), particularly in the Northeast region of Thailand. During past decades, this region has experienced several prolonged severe droughts which have had an effect on agricultural products, especially paddy field and field crops (Department of Disaster Prevention and Mitigation, 2007).

Therefore, this study aims to integrate geospatial modeling for an agricultural drought vulnerability assessment with relevant GIS and satellite-based data. The derived output of the agricultural drought vulnerability assessment with its potential impact on farmers and local people is essential for drought mitigation. The specific objectives of this study are (1) to assess exposure to drought hazard, (2) to assess agricultural drought sensitivity, (3) to assess adaptive capacity on agricultural drought, and (4) to assess and map agricultural drought vulnerability and its severity.

Materials and Methods

Study Area

The study area is Nakhon Ratchasima province which is a part of the Northeast region of Thailand and is situated on the Khorat Plateau between longitudes $101^{\circ} 10.8'$ to $103^{\circ} 0.7'$ E and latitudes $14^{\circ} 7.2'$ and $15^{\circ} 48.6'$ N (Office of Agricultural Economics, 2010). It consists of 32 districts and 289 sub-districts with a total area of 20,784.46 km² (Figure 1).

Research Methodology

In principle, drought vulnerability is composed of 3 components, namely exposure, sensitivity, and adaptive capacity. The combination of the 3 components results in a net impact or vulnerability to the drought (Fontaine and Steinemann, 2009). In this study, research methodology with data collection and preparation was conducted to evaluate the agricultural drought vulnerability derived from 3 main components: exposure to hazard drought assessment, agricultural drought sensitivity assessment, and adaptive capability assessment (Figure 2).

Data Collection and Preparation

The required input data from historical and recent records for agricultural drought vulnerability assessment and mapping were collected and prepared as summarized in Table 1. In addition, the significant data preparation consisting of the standardised precipitation index (SPI) and standardised precipitation evapotranspiration index (SPEI) calculations, image filtering by the Savitsky-Golay algorithm, and the vegetation condition index (VCI) calculation is summarized.

Standardized Precipitation Index (SPI)

The 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). Since the original precipitation data are not the completely

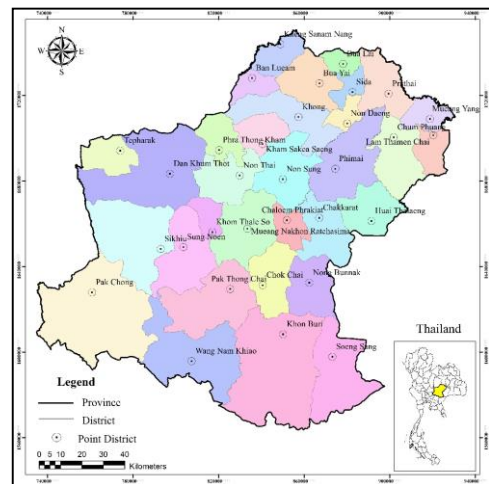


Figure 1. Study area: Location and administrative boundary

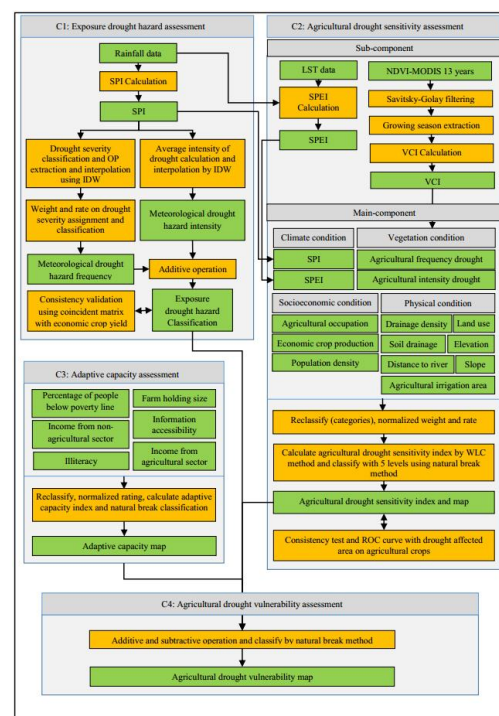


Figure 2. Workflow diagram of the research methodology

Table 1. List of collection and preparation data

Component	Data collection	Data preparation	Output	Scale	Source	Date
Exposure	Rainfall data	SPI calculation and interpolation	SPI, frequency, intensity, and exposure	No scale	TMD	1976-2016
Sensitivity	Rainfall data	SPI calculation and interpolation	SPI, frequency, and intensity	No scale	TMD	1976-2016
	Monthly mean temperature data	SPEI calculation	SPEI	No scale	TMD	2004-2016
	LST-MODIS	SPEI calculation	SPEI	5600 m	NASA	2004-2016
	NDVI-MODIS	VCI calculation for growth period of crop	VCI, Agricultural frequency and intensity drought	250 m	NASA	2000-2016
	Soil series	Reclassification	Soil drainage	1:100,000	LDD, DEQP	
	Slope	Reclassification	Slope	1:50,000	LDD, DEQP	
	Elevation	Reclassification	Elevation	90 meters	DEQP	
	Land use	Reclassification	Land use		LDD	2000-2015
	Stream	Length of stream calculation at sub-watershed level	Drainage density	1:50,000	DEQP	
	Stream	Euclidean distance buffering	Distance to river	1:50,000	DEQP	
Adaptive capacity	Economic crop production	Reclassification with natural break method	Economic crop production	Sub-district	NRD2C	2003-2015
	Population	Population density calculation and reclassification	Population density	Sub-district	NRD2C	2003-2015
	Illiteracy	Reclassification with natural break method	Illiteracy	Sub-district	NRD2C	2003-2015
	Proportion of people below poverty line	Reclassification with natural break method	Proportion of people below poverty line	Sub-district	NSO	2003-2015
	Farm holding size	Reclassification with natural break method	Farm holding size	Sub-district	NRD2C	2003-2015
	Income from agricultural sector	Reclassification with natural break method	Income from agricultural sector	Sub-district	NRD2C	2003-2015
	Income from non-agricultural sector	Reclassification with natural break method	Income from non-agricultural sector	Sub-district	NRD2C	2003-2015
	Information accessibility	Reclassification with natural break method	Information accessibility	Sub-district	NRD2C	2003-2015
Note:	DEQP LDD NASA NRD2C TMD NSO	Department of Environmental Quality Promotion, Land Development Department, National Aeronautics and Space Administration, National Rural Development Committee, Thai Meteorological Department National Statistical Office				

normal distribution, they require transforming time series precipitation into a standardized normal distribution. In practice, this index is firstly calculated by fitting the gamma probability function to a given frequency of total precipitation (Sayari *et al.*, 2013). Then, the SPI with a different time scale can be further applied to each drought type.

In general, the SPI with a short time scale (weeks and months) is suitable for applying to meteorological or agricultural drought, while the SPI with a long time scale (years) is suitable for applying to hydrological drought (Guttman, 1999; Quiring and Ganesh, 2010). In the current study, 3 time scales of the SPI denoted as SPI-3m7 (May, June, and July), SPI-3m10 (August, September, and October), and SPI-6m10 (May, June, July, August, September, and October) were calculated to classify the exposure to the hazard of agricultural drought.

Standardized Precipitation Evapotranspiration Index (SPEI)

Basically, the SPEI applies a similar method as the SPI, but it includes the additive water balance (Stagge *et al.*, 2015). The variables of the SPEI consist of a time series of monthly precipitation and monthly potential evapotranspiration (PET) (Tan *et al.*, 2015). The popularities of this index are its simple interpretation, response to vegetation by applying the temperature or PET, and its flexibility similar to multi-scale as in the SPI. The multi-scale characteristics of the SPEI for short or long-term 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). In this study, the SPEI was applied as 1 variable of climate condition under the agricultural drought sensitivity assessment.

Savitsky-Golay Algorithm

The Savitsky-Golay algorithm for image filtering was applied to enhance the quality of the NDVI dataset between 2004 and 2016 for identification of the start and end of the crop-growing season. As a result, the optimum start of the growing season of the study area is day

177 of the year whereas the end of the growing season is day 337 of the year.

Vegetation Condition Index (VCI)

The VCI is an efficient index to detect drought and to measure the time of its onset, intensity, duration, dynamics, and impacts on vegetation (Kogan, 1995). It can also provide nearly real-time data over the globe at a relatively high spatial resolution because it is a satellite-based drought product (Quiring and Ganesh, 2010). Moreover, it has a high correlation with agricultural production or yield during the crop growth season in Africa, Asia, Europe, North America, and South America (Kogan, 1997).

The VCI, which is a pixel-wise normalization of the NDVI, is useful for making relative assessments of changes in the NDVI signal by filtering out the contribution of a local geographic effect to the spatial variability of NDVI by using the following Equation:

$$VCI = 100 * \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}} \right) \quad (1)$$

where NDVI is the normalized difference vegetation index, $NDVI_{min}$ is the minimum value of the NDVI data, and $NDVI_{max}$ is the maximum value of the NDVI data.

Component 1 Exposure Drought Hazard Assessment

By definition, exposure is defined as the nature and degree to which a system is exposed to significant climatic variations that have different variables such as temperature, precipitation, and extreme weather events (McCarthy *et al.*, 2001). In this study, the meteorological drought hazard frequency and intensity were firstly separately assessed and the derived results were then combined using an additive operation under the GIS environment for the exposure to drought hazard assessment.

In the detail of the meteorological drought hazard frequency assessment, the derived SPI data was applied to classify the drought severity and weighting (Table 2). Then, the SPI data were again applied to extract the

probability of drought occurrence (OP) for each drought severity class (near normal drought (NND), moderate drought (MD), severe drought (SD), and extreme drought (ED)), and to interpolate the information using the inverse distance weighted (IDW) method in each severity class and to classify it into 4 levels using the equal interval method for rating assignment. After that, the assigned weight from the drought severity classification and rate from the OP classification of each drought severity class were combined using the weighted linear combination (WLC) method (Malczewski, 2000) to calculate the meteorological drought

hazard frequency index (DHFI_{Met}) using Equation 2 and then were reclassified into 5 levels (very low (VL), low (L), moderate (M), high (H) and very high (VH)) of meteorological drought frequency using the natural break method.

$$\text{DHFI}_{\text{Met}} = (\text{NND}_w \times \text{NND}_r) + (\text{MD}_w \times \text{MD}_r) + (\text{SD}_w \times \text{SD}_r) + (\text{ED}_w \times \text{ED}_r) \quad (2)$$

where, NND_w, MD_w, SD_w, and ED_w are the weights of each drought severity class (NND, MD, SD, and ED), respectively, while NND_r, MD_r, SD_r, and ED_r are the rates of OP

Table 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 (S)	-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. Influential factors on agricultural drought sensitivity assessment

Conditions	Factors	Reference
Agricultural	Agricultural frequency drought	Murthy <i>et al.</i> (2014; 2015a); Sehgal and Dhakar (2016)
	Agricultural intensity drought	Sehgal and Dhakar (2016)
Climate	SPI	Wardlow (2010); Wardlow <i>et al.</i> (2012); Vicente-Serrano <i>et al.</i> (2012); Stagge <i>et al.</i> (2015); Tan <i>et al.</i> (2015)
	SPEI	
Physical	Land use	Pandey <i>et al.</i> (2010); Wardlow (2010); Jain <i>et al.</i> (2015); Thomas <i>et al.</i> (2016); Sudaryatno (2016)
	Soil drainage	Pandey <i>et al.</i> (2010); Thomas <i>et al.</i> (2016); Jain <i>et al.</i> (2015)
	Agricultural irrigation area	Kim <i>et al.</i> (2015); Wardlow (2010); Eklund and Seaquist (2015)
	Slope	Jain <i>et al.</i> (2015); Thomas <i>et al.</i> (2016); Prathumchai <i>et al.</i> (2001); Sudaryatno (2016)
	Elevation	Xiaoqian <i>et al.</i> (2013); Wardlow (2010)
	Distance to river	Jain <i>et al.</i> (2015); Thomas <i>et al.</i> (2016)
	Drainage density	Suwanwerakamtorn <i>et al.</i> (2005)
Socioeconomic	Agriculture occupation	Kim <i>et al.</i> (2015); Pei <i>et al.</i> (2016); Shahid and Behrawan (2008)
	Economic crop production	Pei <i>et al.</i> (2016); Shahid and Behrawan (2008)
	Population density	Shahid and Behrawan (2008); Kim <i>et al.</i> (2015); Jain <i>et al.</i> (2015); Gbetibouo and Ringler (2009); Pei <i>et al.</i> (2016)

classification under the drought severity class (NND, MD, SD, and ED), respectively.

Like the meteorological drought hazard frequency assessment, the meteorological drought hazard intensity assessment is here considered as the degree of the precipitation deficiency. In this study, the average SPI values from each station that are equal to -1 or less than -1 were applied to classify the severity of drought in terms of its intensity. In practice, the average SPI value (total SPI/years) from each station was firstly interpolated to create a continuous surface using the IDW method and then classified into 5 levels (VL, L, M, H, and VH) of meteorological drought intensity using the natural break method.

In addition, the derived economic crop yield (paddy field, cassava, and maize) variation based on the coefficient variation (CV) classification from high and very high levels were used to validate the drought exposure hazard classification using the coincident matrix.

Component 2. Agricultural Drought Sensitivity Assessment

By definition, sensitivity is defined as the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (McCarthy *et al.*, 2001). In the case of agricultural drought, sensitivity is the susceptibility of a water user or users to the effects of the drought.

Under this component, multiple influential factors (vegetation, climate, physical, and socioeconomic conditions) on agricultural drought sensitivity (Table 3) were combined using the WLC method (Malczewski, 2000) to calculate the agricultural drought sensitivity index and to reclassify its severity into 5 levels (VL, L, M, H, and VH) using the natural break method. The weights of each factor which were pre-assigned by 15 local experts on agricultural drought from questionnaires was normalized using the standardized rank value method (Tsangaratos *et al.*, 2013) as:

$$v = a + (b - a) * \left[\frac{V - A}{B - A} \right] \quad (3)$$

where,

- v is the new weighting value that is between the a and b values,
- V is the original weighting value that is between the A and B values,
- A is the minimum of the original weighting values,
- B is the maximum of the original weighting values,
- a is the minimum of the standardized weighting values, and
- b is the maximum of the standardized weighting values.

Finally, the derived result of the agricultural drought sensitivity classification was validated with an accumulated drought affected area of agricultural crops from a field survey by the Nakhon Ratchasima Provincial Agricultural Extension Office in 2012, 2014, and 2015. Herein, the consistency test using the coincident matrix and receiver operating characteristic (ROC) value by comparison between the accumulated drought affected area and agricultural drought sensitivity classification was applied to validate the result.

Component 3 Adaptive Capacity Assessment

By definition, the adaptive capacity is defined 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 (McCarthy *et al.*, 2001). In the case of agricultural drought, the adaptive capacity represents the ability of people to adjust to the drought impact.

In this study, the reviewed indicators on adaptive capacity from agricultural drought included: (1) the proportion of people below the poverty line (Gbetibouo and Ringler, 2009), (2) illiteracy (Gbetibouo and Ringler, 2009; Antwi-Agyei *et al.*, 2012), (3) income from the agricultural sector (Gbetibouo and Ringler, 2009; Xiaoqian *et al.*, 2013), (4) farm holding size (Gbetibouo and Ringler, 2009), (5) income from the non-agricultural sector (Gbetibouo and Ringler, 2009), and (6) information accessibility (Assimacopoulos *et al.*, 2014). These were firstly prepared and classified into

5 levels and then combined to calculate the adaptive capacity index (ACI) using Equation 4. The derived ACI was further classified into 5 levels (VL, L, M, H, and VH) of the adaptive capacity.

$$ACI = \sum_{i=1}^N \frac{X_i}{N} \quad (4)$$

where X_i is the rating value of the indicator i and N is the number of indicators.

Component 4 Agriculture Drought Vulnerability Assessment

Under this component, the derived exposure drought hazard and agricultural drought sensitivity classification were firstly combined using the additive operation and the derived output was then combined with the adaptive capacity classification using the subtractive operation for agricultural drought vulnerability assessment.

Results and Discussion

Exposure Drought Hazard Assessment

Drought exposure hazard assessment was derived from the combination of the meteorological drought hazard frequency and intensity classification, as shown in Figures 3 and 4, respectively. The spatial distribution of the drought exposure hazard classification of the 3 periods (3m7, 3m10, and 6m10) is displayed in Figure 5.

According to the drought exposure hazard classification (Figure 5), the distribution pattern of the high and very high drought exposure hazard classes of the 3 periods are similar. However, the percentages of the high and very high drought exposure hazard of the 6m10 period are slightly higher than the other periods. There are 9 districts in Nakhon Ratchasima province which are Chakkarat, Chaloem Phrakiat, Chok Chai, Dan Khun Thot, Kaeng Sanam Nang, Kham Thale So, Mueang Nakhon Ratchasima, Phra Thong Kham, and Sung Noen that display high and

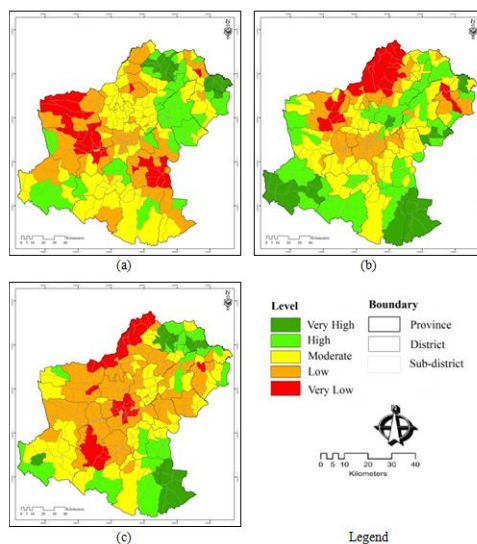


Figure 3. Spatial distribution of meteorological drought hazard frequency classification of 3 periods: (a) 3m7, (b) 3m10, and (c) 6m10

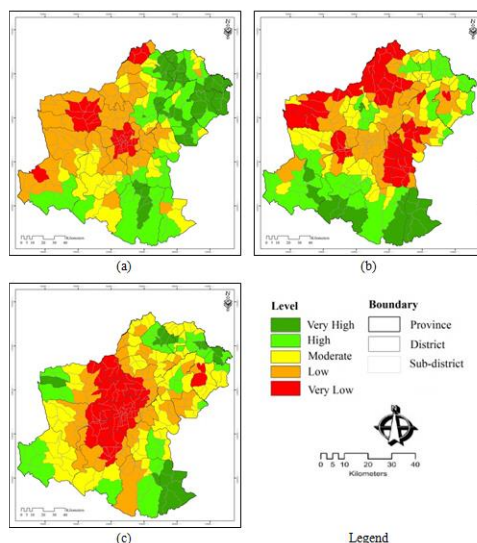


Figure 4. Spatial distribution of meteorological drought hazard intensity classification of 3 periods: (a) 3m7, (b) 3m10, and (c) 6m10

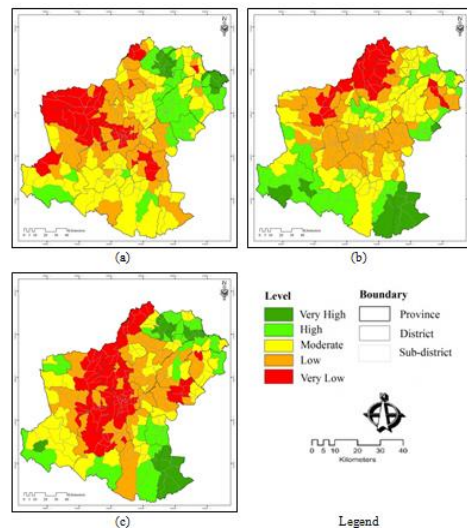
very high drought exposure hazard in the 3 periods.

Conversely, the distribution patterns of the very low and low drought exposure hazard of the 3 periods are dissimilar. None of the districts always shows a very low or low drought exposure hazard in the 3 periods. The patterns of the very low and low drought exposure hazard of the 3 periods are randomly distributed in 16 districts which are 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, the distribution pattern of the moderate drought exposure hazard of the 3 periods is also dissimilar. None of the districts permanently exhibits a moderate drought exposure hazard in the 3 periods. The pattern of the moderate drought exposure hazard class of the 3 periods randomly occurs in 16 districts which are 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, the most dominant classes of the drought exposure hazard in the 3 periods at the provincial level are the high and very high drought exposure hazard and cover areas of 43.60%, 39.20%, and 49.50%, respectively. Meanwhile, the very low and low drought exposure hazard of the 3 periods cover areas of 20.40%, 31.00%, and 26.40%, respectively and the moderate drought exposure hazard of the 3 periods covers areas of 36.00%, 29.80%, and 24.00%, respectively (see details in Figure 5). Thus, at the provincial level, it can be concluded that the drought exposure hazard mostly occurs at the high and very high levels in the 3 periods. Details of the drought exposure hazard classification at the district level in the 3 periods are summarized in Table 4.

For validation of the drought exposure hazard classification, it was found that the high and very high drought exposure hazard classes of the 3 periods are consistent with the high and very high economic crop yield variations in Figure 6 which represents the area of the



Percentage of exposure drought hazard classification at provincial level of 3 periods

Period	Severity of exposure drought hazard classification (% of area)				
	Very low	Low	Moderate	High	Very high
3M7 (May-July)	3.20	17.20	36.00	26.10	17.50
3M10 (August-October)	9.40	21.60	29.80	28.30	10.90
6M10 (May-October)	7.80	18.60	24.20	27.00	22.50

Figure 5. Spatial distribution of exposure drought hazard classification of 3 periods: (a) 3m7, (b) 3m10, and (c) 6m10

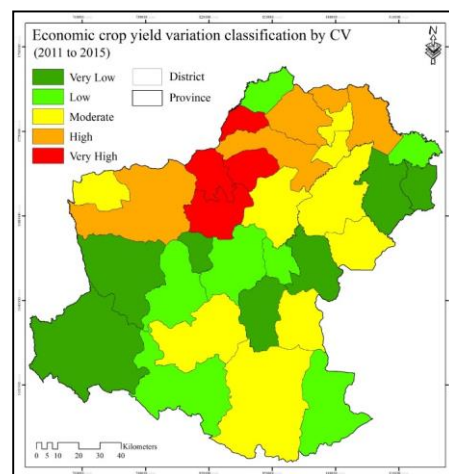


Figure 6. Spatial distribution of economic crop yield variation based on coefficient variation classification of economic crop yield during 2011 to 2015

Table 4. Percentages of drought exposure hazard classification at district level of 3 periods

District	Drought exposure hazard classification (% of area)														
	3M7 period (May-July)					3M10 period (August-October)					6M10 period (May-October)				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
Ban Lueam	0	0	22.4	77.6	0	0	0	0	0	100	0	0	0	0	100
Bua Lai	25	44.7	30.3	0	0	0	0	76.6	23.5	0	0	100	0	0	0
Bua Yai	51.8	48.3	0	0	0	0	0	24.2	27.5	48.2	45.2	24.3	30.5	0	0
Chakkarat	0	24.6	13	62.4	0	0	0	13	87	0	0	0	27.9	62.6	9.5
Chaloem Phrakiat	0	0	45.2	54.8	0	0	0	10.8	89.2	0	0	0	33.4	66.6	0
Chok Chai	0	0	20.8	61.6	17.6	0	0	34.6	65.4	0	0	20.8	34.5	44.7	0
Chum Phuang	0	33.6	58	8.4	0	0	15	14.4	43.1	27.6	0	0	51.9	39.7	8.4
Dan Khun Thot	0	0	0	5.9	94.1	0	0	18.6	48.2	33.3	0	0	27.4	23.5	49.2
Huai Thalaeng	0	81.4	18.6	0	0	10.3	59.2	15.5	15.1	0	0	0	30.5	12	57.5
Kaeng Sanam Nang	0	0	19.7	20.8	59.5	0	0	0	0	100	0	0	0	0	100
Kham Sakae Saeng	0	0	0	91.2	8.8	0	0	0	25.1	75	0	0	57.6	42.4	0
Kham Thale So	0	0	0	61.7	38.4	0	0	15.8	84.2	0	0	0	0	35.6	64.4
Khon Buri	0	15.4	78.9	5.7	0	27.9	20.9	51.2	0	0	5.6	41.5	10	43	0
Khong	0	19.1	55	26	0	0	0	25.5	20.2	54.3	0	0	0	84	16
Lam Thamen Chai	18.4	81.6	0	0	0	0	16.3	18.4	65.3	0	0	69.3	30.7	0	0
Mueang Nakhon Ratchasima	0	0	0	56.9	43.1	0	0	19.3	80.7	0	0	0	0	16	84
Mueang Yang	74.8	25.2	0	0	0	0	49.7	50.3	0	0	0	49.7	50.3	0	0
Non Daeng	0	100	0	0	0	0	84.7	15.3	0	0	0	21.2	78.8	0	0
Non Sung	0	6.2	86.4	7.4	0	0	19.8	54.4	19.3	6.5	0	0	34.3	65.8	0
Non Thai	0	0	21.5	70.2	8.3	0	34.4	38.6	27	0	0	0	0	20.5	79.5
Nong Bunnak	0	0	0	56.2	43.8	0	0	73.2	26.8	0	0	80.1	19.9	0	0
Pak Chong	0	31.2	44.1	7	17.8	24.4	57.8	17.8	0	0	6.2	24.5	69.3	0	0
Pak Thong Chai	0	6.1	87.6	6.3	0	0	7.6	62.4	29.9	0	0	0	0	35.1	64.9
Phimai	0	79.2	20.8	0	0	0	0	88.7	11.4	0	0	27.2	22.1	50.7	0
Phra Thong Kham	0	0	0	90.5	9.5	0	0	18.4	35.6	46	0	0	0	0	100
Prathai	6.6	12.9	66.1	8	6.4	0	47.1	45.6	7.3	0	33.4	49	17.6	0	0
Sida	39.6	60.4	0	0	0	0	0	100	0	0	39.6	60.5	0	0	0
Sikhio	0	0	18	59.3	22.6	0	40.1	20.1	39.8	0	0	0	23.3	62.3	14.4
Soeng Sang	0	0	60.4	39.6	0	100	0	0	0	0	100	0	0	0	0
Sung Noen	0	0	20.7	46.7	32.6	0	0	15	85	0	0	0	0	28.1	71.9
Tepharak	0	0	0	0	100	0	0	31.8	68.2	0	0	81.9	18.1	0	0
Wang Nam Khiao	0	0	69	31	0	0	100	0	0	0	0	43.5	42	14.5	0

Table 5. Comparison between drought exposure hazard classification of 3 periods and high and very high economic crop yield during 2011 to 2015

Economic crop yield variation (high and very high)	Period	Drought exposure hazard classification (% of area)				
		VL	L	M	H	VH
	3M7 (May to July)	7.34	11.03	19.53	30.73	31.37
	3M10 (August to October)	0.00	9.10	25.36	29.48	36.06
	6M10 (May to October)	8.72	11.64	17.60	24.12	37.92

drought effect on crop yield at about 62.10%, 65.54%, and 62.04%, respectively (Table 5). These percentages are greater than the combined percentages of the very low, low, and moderate drought exposure hazard classes. Thus, the classifications of the drought exposure hazard of the 3 periods are acceptable.

In addition, it can be observed that the drought exposure hazard classification of the 3m7 and 3m10 periods highly relates to the meteorological drought hazard frequency in the same periods (Figure 3 and Figure 5,

respectively) and most of the extreme drought occurs in the starting period (May to July) and in ending period (August to October) of the rainy season. In the meantime, the drought exposure hazard classification of the 6m10 period highly relates with the combination of the meteorological drought hazard frequency and the intensity of the 6m10 period, and the drought exposure hazard of this period mostly occurs all the time throughout the crop season. These findings imply that the suitable period for meteorological drought detection should be May to July or August to October, whereas

Table 6. Normalized rating value of influential factors for agricultural drought sensitivity assessment

Factors	Severity levels of agricultural drought sensitivity				
	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 7. Average and normalized weighting values of influential factors for agricultural drought sensitivity assessment

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

May to October is the suitable period for agricultural drought detection.

The results indicate that the drought exposure hazard is of a non-specific spatial extent or location and temporal starting and ending points, as mentioned by many researchers (Rouault and Richard, 2005; Wilhite and Buchanan-Smith, 2005; Mishra and Singh, 2010; Son *et al.*, 2012; Park *et al.*, 2016). For instance, Rouault and Richard (2005) illustrated that drought frequently occurs in Southern Africa in all climatic areas at all times of the year with a different intensity, spatial extent, and duration.

Agricultural Drought Sensitivity Assessment

The agricultural drought sensitivity assessment of the 3 periods was here derived from integration of influential factors (vegetation, climate, physical and socioeconomic conditions) using the WLC method to calculate the agricultural drought sensitivity index and to classify its severity using the natural break method. Tables 6 and 7 summarize the normalized rating and weighting values of the influential factors on agricultural drought sensitivity (Figure 7). Meanwhile, the equation for generating the agricultural drought sensitivity index of the 3 periods using the Map

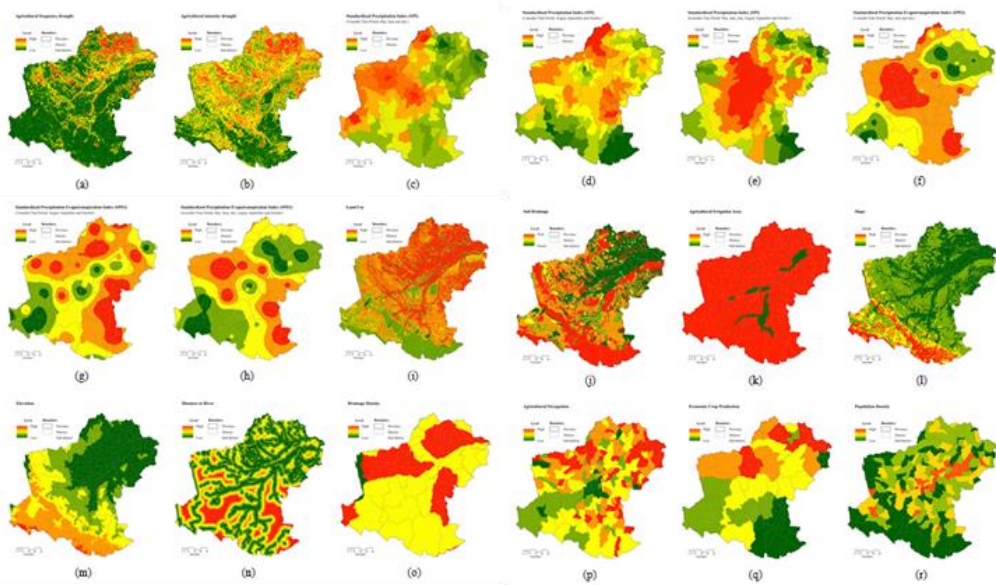


Figure 7. Factor maps for agricultural drought sensitivity assessment: (a) Agricultural frequency drought, (b) Agricultural intensity drought, (c) SPI 3m7 period, (d) SPI 3m10 period, (e) SPI 6m10 period, (f) SPEI 3m7 period, (g) SPEI 3m10 period, (h) SPEI 6m10 period, (i) Land use, (j) Soil drainage, (k) Agricultural irrigation area, (l) Slope, (m) Elevation, (n) Distance to river, (o) Drainage density, (p) Agricultural occupation, (q) Economic crop production, and (r) Population density

Algebra function under Spatial Analyst Tools of ESRI ArcMap software is presented in Equation 5 and the spatial distribution of the agricultural drought sensitivity classification of the 3 periods is displayed in Figure 8.

$$Y = 0.904 \times X1 + 0.870 \times X2 + 0.711 \times X3 + 1.000 \times X4 + 0.581 \times X5 + 0.552 \times X6 + 0.615 \times X7 + 0.485 \times X8 + 0.230 \times X9 + 0.581 \times X10 + 0.519 \times X11 + 0.422 \times X12 + 0.485 \times X13 + 0.100 \times X14 \quad (5)$$

where,

- Y is the agricultural drought sensitivity,
- X1 is the agricultural drought frequency,
- X2 is the agricultural drought intensity,
- X3 is the SPI of the 3m7, 3m10, and 6m10 periods,
- X4 is the average SPEI of the 3m7, 3m10, and 6m10 periods,
- X5 is the land use,
- X6 is the soil drainage,
- X7 is the agricultural irrigation area,
- X8 is the slope,

X9 is the elevation,

X10 is the distance to river,

X11 is the drainage density,

X12 is the agricultural occupation at the sub-district,

X13 is the economic crop production, and

X14 is the population density at the sub-district.

From reference to Table 7, it can be observed that the top 3 most important factors for agricultural drought sensitivity assessment from the experts' opinions are the SPEI (climate condition), agricultural drought frequency, and intensity (vegetation condition). These factors play an important role in agricultural drought sensitivity assessment. In contrast, the top 3 least important factors are population density (socioeconomic condition), elevation (physical condition), and agricultural occupation (socioeconomic condition).

According to the agricultural drought sensitivity classification (Figure 8), the severity of the agricultural drought sensitivity in the 3

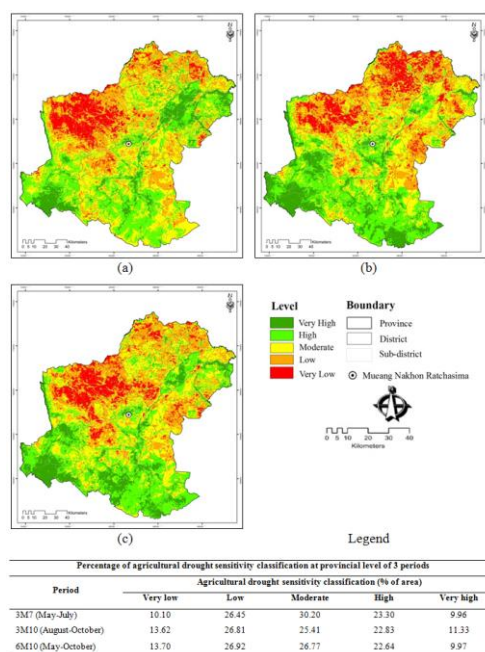


Figure 8. Spatial distribution of agricultural drought sensitivity classification of 3 periods: (a) 3m7, (b) 3m10, and (c) 6m10

periods with high and very high levels is always present in 9 districts which are Ban Lueam, Bua Lai, Bua Yai, Dan Khun Thot, Kaeng Sanam Nang, Non Daeng, Non Thai, Phra Thong Kham, Prathai, Sung Noen, and Tepharak districts. In contrast, 5 districts, Chok Chai, Khon Buri, Lam Thamen Chai, Pak Chong, and Wang Nam Khiao, show a very low or low agricultural drought sensitivity in every period. Meanwhile, there are 2 districts, Chaloem Phrakiat and Mueang Yang, which display moderate agricultural drought sensitivity in every period. Furthermore, there are 14 districts which are Chakkarat, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Kham Thale So, Khong, Mueang Nakhon Ratchasima, Non Sung, Nong Bunnak, Pak Thong Chai, Phimai, Sida, Sikhio, and Soeng Sang which display different levels of agricultural drought sensitivity during the 3 periods.

In addition, the most dominant class of the agricultural drought sensitivity

classification in the 3 periods at the provincial level is very low and low covering areas of 36.55%, 40.43%, and 40.62%, respectively. Meanwhile, the high and very high agricultural drought sensitivity of the 3 periods covers areas of 33.26%, 34.16%, and 32.61%, respectively and the moderate agricultural drought sensitivity of the 3 periods covers areas of 30.20%, 25.41%, and 26.77%, respectively (Figure 8). Details of the agricultural drought sensitivity classification of the 3 periods at the district level are summarized in Table 8. For validation of the agricultural drought sensitivity classification using the coincident matrix and ROC value, the combination of high and very high agricultural drought sensitivity classification of the 3 periods are consistent with an accumulated drought affected area of agricultural crops in 2012, 2014, and 2015 of about 47.03%, 54.93%, and 47.03%, respectively. Likewise, the ROC values for the best fit test of agricultural drought sensitivity classification of the 3 periods are 0.891, 0.923, and 0.912, respectively (Table 9). Thus, the classification of the agricultural drought sensitivity of the 3 periods is acceptable.

From the results, it can be observed that the sensitivity of agricultural drought at the district level in the 3 periods is rather high but at the provincial level the sensitivity of agricultural drought in the 3 periods is rather low. This finding indicates that the specific severity of agricultural drought sensitivity exists to a specific extent. In other words, agricultural drought sensitivity varies from place to place and from time to time. This phenomenon is similar to drought exposure hazard. Additionally, agricultural drought sensitivity has a non-specific spatial extent or location and temporal starting and ending periods. In this study, the time period is significant for the agricultural drought sensitivity assessment.

Adaptive Capacity Assessment

The adaptive capacity assessment was derived from the integration of the indicators (factors) on the adaptive capacity at the sub-district level (Figure 9) using ACI. The spatial

Table 8. Percentages of agricultural drought sensitivity classification at district level of 3 periods

District	Agricultural drought sensitivity classification (% of area)														
	3M7 (May-July)					3M10 (August-October)					6M10 (May-October)				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
Ban Lueam	0.1	8.62	32.3	47.2	11.7	0.86	8.56	32.6	46.6	11.4	1.21	13.7	36.8	43.2	5.13
Bua Lai	1.47	12.3	24	52.3	9.94	0.04	0.92	10.7	33.8	54.5	0.44	6.81	26.6	54.4	11.8
Bua Yai	3.48	8.31	27	48.6	12.6	0.46	2.67	6.66	30	60.2	2.83	7.04	27	48.8	14.4
Chakkarat	0.91	14.8	50.9	31.1	2.29	0.17	2.12	32.6	51.7	13.4	0.27	5.2	42.3	43.6	8.71
Chaloem Phrakiat	6.29	27	45.4	20.2	1.07	6.46	28.2	53.9	9.11	2.34	8.14	28.9	49.8	10.7	2.48
Chok Chai	17	26.4	39.9	15.7	1.05	17.8	29	34.7	17.2	1.3	19.9	34.7	36.9	8.01	0.8
Chum Phuang	15.7	39.3	31.3	13.1	0.65	1.48	9.08	28.8	41	19.6	9.58	30.5	35.2	21.1	3.6
Dan Khun Thot	0.39	2.25	4.61	29.1	63.6	2.7	3.65	14	41.3	38.3	2.11	2.78	7.88	35.4	51.8
Huai Thalaeng	12.5	34.3	30.5	18.5	4.23	4.31	20.2	38.4	31.3	5.72	3.36	13.4	30.2	40.5	12.5
Kaeng Sanam Nang	0.18	7.72	29.3	42.8	20	0.43	8.4	14.1	37.6	39.5	0.3	8.22	20.3	50.5	20.7
Kham Sakae Saeng	1.02	23.1	52.2	22.5	1.22	0	1.59	29	52	17.5	2.5	27.1	59.1	11.1	0.27
Kham Thale So	0.9	5.74	27.9	49	16.8	4.21	20.9	51.2	21	2.76	1.35	8.43	34.2	46.8	9.27
Khon Buri	9.75	57.8	30.2	2.21	0.04	28.5	56.6	14.2	0.7	0	24.4	62.8	12.2	0.57	0.02
Khong	5.6	21.5	45.7	25.1	2.08	0.06	1.71	16.6	44.1	37.6	2.59	11.3	40.6	40.7	4.83
Lam Thamen Chai	45.5	46	8.02	0.5	0	12.3	30.5	39.4	17	0.77	33	44.5	20.5	2.05	0.02
Mueang Nakhon Ratchasima	8.01	27	39.6	22.8	2.48	19.4	42.3	30.8	6.88	0.58	9.34	30.6	38.7	18.7	2.63
Mueang Yang	11.5	14.5	43.1	30.7	0.28	5.63	14.6	52.4	26.8	0.59	7.34	11.6	46.3	34.3	0.52
Non Daeng	5.66	25.4	31.9	34.6	2.46	1.61	11.1	26.7	33.8	26.8	3.55	19.2	33.2	36.8	7.24
Non Sung	5.24	21.8	35.2	33.2	4.58	2.09	14.4	45.8	32.2	5.57	1.47	7.89	25.5	44.6	20.6
Non Thai	0.01	3.1	16.7	37.8	42.5	0.22	7.56	27.1	38.3	26.9	0	1.02	10.9	34.3	53.8
Nong Bunnak	0.09	5.28	42.5	49	3.1	0	3.32	40.2	51.5	4.95	0.29	12.9	46	37.9	2.94
Pak Chong	32.1	45.7	18.8	3.08	0.3	52.5	37.3	9.06	1.07	0.04	45.1	37.8	15.4	1.58	0.03
Pak Thong Chai	8.94	36.5	40.9	12.2	1.42	7.97	46.8	31.2	12.3	1.79	5.98	32.5	44.1	15	2.37
Phimai	54	39.4	5.73	0.81	0.1	8.16	32.3	46.2	12	1.34	20.9	41.8	29.8	6.54	1
Phra Thong Kham	0	0.65	15.2	66.6	17.6	0	0.37	17.3	59.6	22.8	0	0.08	6.28	58.6	35
Prathai	1.57	8.1	21.3	47.7	21.3	0.32	4.94	17	49.6	28.2	1.74	7.96	26	52.3	12
Sida	8.78	20.1	39.5	31.6	0.11	0.53	7.15	18	64.8	9.53	8.02	17.4	45.5	28.8	0.33
Sikhio	4.24	21.9	31.7	30.8	11.4	29.7	32.6	25.2	11.5	1.04	17.3	28.6	28.2	20.8	5.16
Soeng Sang	0.35	24	56	18.8	0.9	17.8	56	24.6	1.44	0.13	14.3	57.2	26.3	2.1	0.12
Sung Noen	0.17	5.47	29.1	52.6	12.7	2.48	17.9	39.4	35	5.26	0.94	8.56	29.4	40.2	20.9
Tepharak	0.32	3.71	20.3	39.8	35.8	3.79	22	20.1	31.8	22.4	4.8	21.4	32.2	34.4	7.17
Wang Nam Khiao	3.67	42.3	41.3	11.8	0.96	16.3	58.5	21.2	3.9	0.13	35.9	41.2	19.7	3.08	0.08

Table 9. Comparison between agricultural drought sensitivity classification of 3 periods and drought effected areas on agricultural crops

Period	Percent of consistency between agricultural drought sensitivity classification and drought effected areas on agricultural crops					ROC value
	VL	L	M	H	VH	
3m7	4.92	17.94	30.11	30.03	17.00	0.891
7m10	5.35	14.84	24.87	34.49	20.44	0.923
3m10	4.92	17.94	30.11	30.03	17.00	0.912

distribution of the adaptive capacity classification is displayed in Figure 10 while the percentage of its classification at the provincial and district levels is presented in Table 10.

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

Likewise, at the district level, the very low and low adaptive capacities to affect agricultural drought are dominant in 18 districts which are Bua Lai, Bua Yai, Chaloem Phrakiat, Chok Chai, Chum Phuang, Dan Khun Thot, Kham Sakae Saeng, Kham Thale So, Khon Buri, Lam Thamen Chai, Mueang Yang, Non Daeng, Non Thai, Nong Bunnak, Prathai, Sida, Soeng Sang, and Tepharak. On the contrary, the high and very high adaptive capacities to affect agricultural drought are dominant in 6 districts which are Khong, Pak Chong, Pak Thong Chai, Phimai, Sikhio, and Sung Noen. Meanwhile, the moderate adaptive

capacity to drought effect is found in 8 districts which are Ban Lueam, Chakkarat, Huai Thalaeng, Kaeng Sanam Nang, Mueang Nakhon Ratchasima, Non Sung, Phra Thong Kham, and Wang Nam Khiao.

The results reveal that the adaptive capacity classification (at the district level) that plays an important role in mitigating the agricultural drought effect varies from place to place. It implies how well people can adapt

themselves to reduce the drought effect since all adaptive capacity indicators directly relate to human activity. Thus, some indicators of adaptive capacity can be improved or enhanced to reduce the effect of agricultural drought, such as illiteracy and information accessibility by the corresponding agencies.

Agriculture Drought Vulnerability Assessment

The results of the agricultural drought vulnerability assessment which were combined from the drought exposure hazard, agricultural drought sensitivity, and adaptive capacity classifications are displayed in Figure 11 and the percentages of its classification at the district level are comparatively summarized in Table 11.

The spatial distribution patterns of the agricultural drought vulnerability classification of the 3m7 and 6m10 periods are similar and they are rather different from the 3m10 period (Figure 11). As a result, the most dominant agricultural drought vulnerability classification of the 3m7 period is very low and

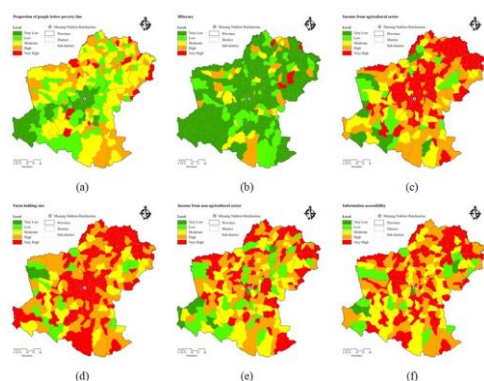


Figure 9. Factor maps for adaptive capacity assessment: (a) Proportion of people below poverty line, (b) Illiteracy, (c) Income from agricultural sector, (d) Farm holding size, (e) Income from non-agricultural sector, and (f) Information accessibility

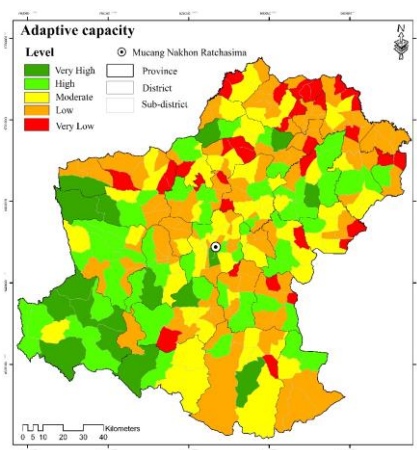
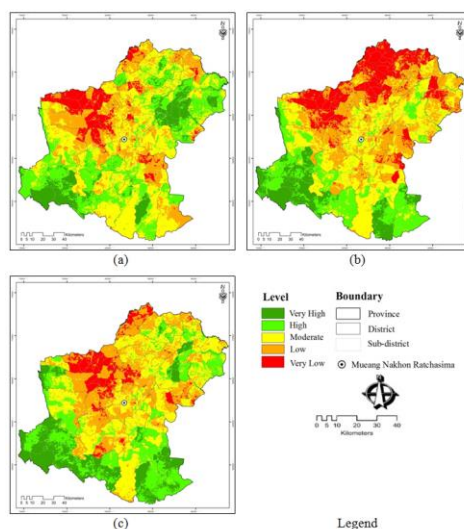


Figure 10. Spatial distribution of adaptive capacity classification



Period	Agricultural drought vulnerability classification (% of area)				
	Very low	Low	Moderate	High	Very high
3M7 (May-July)	10.38	25.45	35.40	20.36	8.42
3M10 (August-October)	10.14	18.28	29.22	23.34	17.01
6M10 (May-October)	14.95	22.96	30.44	24.02	7.62

Figure 11. Spatial distribution of agricultural drought vulnerability classification of 3 periods: (a) 3m7, (b) 3m10, and (c) 6m10

Table 10. Percentages of adaptive capacity classification at district and provincial levels

Districts/Province	Percentage of adaptive capacity classification (% of area)				
	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
Kham 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
Nakhon Ratchasima	7.53	31.20	23.45	24.91	12.90

low and covers an area of 35.83%, whereas the moderate, and high and very high agricultural drought vulnerability classes cover areas of 35.40% and 28.78%, respectively. Likewise, the most dominant agricultural drought vulnerability classification of the 6m10 period is very low and low and covers an area of 37.91%, while the moderate, and high and very high agricultural drought vulnerability classes cover areas of 30.44% and 31.64%, respectively. In contrast, the most dominant agricultural drought vulnerability classification of the 3m10 period is high and very high and covers an area of 42.35%, whereas the very low and low, and moderate agricultural drought vulnerability classes cover areas of 28.42% and 29.22%, respectively (Figure 11).

In addition, the severity levels of agricultural drought vulnerability at the district level of the 3 periods differ from each other. There are 8 districts comprising Ban Lueam, Bua Lai, Dan Khun Thot, Kaeng Sanam Nang, Kham Thale So, Non Thai, Phra Thong Kham, and Sung Noen that display high and very high agricultural drought vulnerability in the 3 periods. Likewise, there is only 1 district, Pak Chong, that shows very low and low agricultural drought vulnerability in every period while moderate agricultural drought vulnerability is only found in Chok Chai district. On the contrary, there are 22 districts which are Bua Yai, Chakkarat, Chaloem Phrakiat, Chum Phuang, Huai Thalaeng, Kham Sakae Saeng, Khon Buri, Khong, Lam Thamen Chai, Mueang Nakhon Ratchasima,

Table 11. Percentages of agricultural drought vulnerability classification at district level of 3 periods

District	Agricultural drought vulnerability classification (% of area)														
	3M7 (May-July)					3M10 (August-October)					6M10 (May- October)				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
Ban Lueam	0.03	0.21	32.4	62.3	5.02	0	0	0.08	16.9	83	0	0.01	1.93	80.4	17.6
Bua Lai	0.04	10.4	42	43.1	4.52	0	0	0.02	11.1	88.9	0.02	0.8	45.1	54.1	0
Bua Yai	5.74	26.8	57.7	9.68	0.02	0	0	2.35	15.8	81.9	4.7	22.2	45.9	27.1	0.06
Chakkarat	0.06	16.2	68.7	15	0.03	0	0.01	18.8	64.7	16.5	0.01	13.2	47.5	29.7	9.56
Chaloem Phrakiat	0	9.06	71.2	19.7	0	0	3.43	23.3	68	5.32	0	15.7	54.3	28.9	1.02
Chok Chai	1.24	23.6	45.5	23.5	6.16	0	4.36	54.2	37.7	3.73	9.61	29.5	50.9	10	0
Chum Phuang	4.04	60.6	32.5	2.86	0	0	1.7	28.6	36.9	32.8	0.08	24.9	59.1	15.8	0.09
Dan Khun Thot	0	2.55	9.26	37.4	50.8	2.68	7.41	11	23.2	55.7	4.65	11.9	11.4	29.5	42.6
Huai Thalaeng	14.6	53.9	17.8	10.6	3.19	0	13.2	56.3	29.6	0.9	0.02	1.62	27.4	62.5	8.54
Kaeng Sanam Nang	0	0.11	17.2	52.5	30.2	0	0	0	6.73	93.3	0	0	1.39	50.9	47.8
Kham Sakae Saeng	0.01	0.46	36.7	43.3	19.6	0	0	0.38	23.1	76.6	0	3.31	51.7	44.7	0.23
Kham Thale So	0	0.36	18.8	43.6	37.3	0	0	17.3	64.1	18.5	0	0	7.48	61.4	31.1
Khon Buri	12.8	28.4	55.9	2.94	0	22.5	21.2	52.7	3.67	0	21	36.3	38.1	4.67	0.01
Khong	9.57	44.3	36.3	9.82	0.05	0	0.19	18.5	49.5	31.9	0.24	7.6	66.2	25.4	0.63
Lam Thamen Chai	28.9	57.2	13.8	0.06	0	0	0.15	39.7	55.3	4.87	0.9	79.4	19.7	0.08	0
Mueang Nakhon Ratchasima	0.02	7.84	53.7	35.1	3.33	0	7.32	62.5	29.5	0.68	0	3.68	43	51.2	2.11
Mueang Yang	7.82	51	41	0.13	0	0	2.87	44.6	52	0.53	0	12.1	72.8	15.2	0
Non Daeng	0.09	18.1	76.5	5.3	0	0	0.15	22.4	71.6	5.77	0.13	2.09	58.7	39.1	0.08
Non Sung	1.58	26.6	52.2	15.7	3.94	0	4.5	43.8	37.6	14.1	0.01	5.65	39.1	46	9.23
Non Thai	0	0.32	31.1	48.9	19.6	0	3.41	35.7	48.4	12.5	0	0.15	7.12	47.9	44.8
Nong Bunnak	0	0.13	17.9	65.5	16.4	0	0.03	33.2	40.1	26.7	0.05	41.2	45.2	13.1	0.45
Pak Chong	43.1	46.5	10.1	0.29	0	63.2	35.6	1.19	0	0	67.6	32.3	0.17	0.03	0
Pak Thong Chai	4.67	50.6	37.5	7.12	0.14	0.04	23.4	48.2	27.2	1.15	0.09	7.73	54.3	30.6	7.21
Phimai	67.4	28.2	4.39	0.02	0	0.14	25.6	61.5	12.5	0.3	27.4	33.3	33.6	5.74	0.01
Phra Thong Kham	0	0.21	38.6	40	21.2	0	0.01	2.62	59.7	37.6	0	0	1.12	61.2	37.7
Prathai	0.38	8.29	26.7	58.2	6.51	0	0.9	23.9	43.1	32.1	1.55	24.8	45.1	27.1	1.42
Sida	3.57	43.4	39	14	0	0	0	5.72	70	24.3	2.91	42.4	40.2	14.5	0
Sikhio	0.62	19	45.7	28.2	6.43	12.9	29.3	36.9	20.4	0.63	0.05	36.3	41.3	21.8	0.54
Soeng Sang	0.19	18.9	46.9	33.8	0.24	13.2	79.1	7.73	0.01	0	40.7	58.5	0.83	0	0
Sung Noen	1.43	21.6	28.9	31.8	16.3	0.02	12.4	31.8	50.4	5.41	0	7.49	26.8	57.4	8.28
Tepharak	0	2.86	31.1	25.3	40.7	0.05	9.31	48.5	20.6	21.6	33.6	24.6	28.5	13.3	0.07
Wang Nam Khiao	9	38.2	48.7	4.09	0	15.8	62.5	21.4	0.24	0	45.1	38.7	6.88	9.31	0.04

Mueang Yang, Non Daeng, Non Sung, Nong Bunnak, Pak Thong Chai, Phimai, Prathai, Sida, Sikhio, Soeng Sang, Tepharak, and Wang Nam Khiao that have different severity levels of agricultural drought vulnerability during the 3 periods (Table 11).

The results indicate that agricultural drought vulnerability has a non-specific spatial extent and temporal dependency similar to the exposure to drought hazard and agriculture drought sensitivity, as mentioned earlier.

Furthermore, it can be concluded that adaptive capacity plays an important role in the agricultural drought vulnerability assessment. The agricultural drought vulnerability assessment firstly combined the drought exposure hazard and agricultural drought sensitivity using the additive operation to present the potential impact, and it was then combined with the adaptive capacity using the subtractive operation to evaluate the severity of the agricultural drought vulnerability. This observation is consistent with the previous work of Yusuf and Francisco (2009) who

studied the vulnerability of climate change in Southeast Asia. They claimed that the adaptive capacity plays an important role in changing the spatial pattern of vulnerability.

Conclusions

A systematic assessment of the agricultural drought vulnerability characteristics for Nakhon Ratchasima Province, northeastern Thailand, was fruitfully performed in this study through direct integration of 3 fundamental factors: exposure to drought hazard, agricultural drought sensitivity, and the adaptive capacity of the area to drought impact; several remote sensing and GIS tools were implemented and the selected geospatial models fulfilled each task. It was evident from this work that a large portion of the area in the province has a high to very high vulnerability level to agricultural drought impact for each considered time period, particularly the short term period during August to October. This

knowledge is essential for the responsible authorities or state agencies, especially the Nakhon Ratchasima Provincial Agricultural Extension Office, as it can aid more effective warning and management of the drought impact over the area, especially those areas identified with a noticeably high vulnerability (at district level). In addition, this work also demonstrates the efficiency and usefulness of selected geospatial models in the comprehensive assessment and mapping of drought hazard exposure, agricultural drought sensitivity, and local adaptive capacity to drought impact that eventually serve as key input data to fulfill the need in the agricultural drought vulnerability assessment.

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