Evaluation of Drought in the North of Thailand using Meteorological and Satellite-Based Drought Indices

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Abstract

This research attempts to evaluate drought impact on vegetation dynamics using various drought indices including the vegetation condition index (VCI), the temperature condition index (TCI), the vegetation health index (VHI) and The standardized precipitation index (SPI). Monthly VCI, TCI and VHI values were obtained from multi-temporal Terra/MODIS products from 2000 to 2017. Temporal and spatial scales of drought occurrences were detected from seasonal variations and drought severity maps generated from these drought indices. The correlation analysis was analyzed to identify the dominant factors that control vegetation variability. The results found that VHI was better to detect vegetation health in the mountainous areas at higher altitudes and lower temperatures. VCI and SPI captured drought occurrences for paddy fields in the southern part of the region where there was lower rainfall and vegetation cover. The result can be applied for crop and drought early warnings in the region.

Keywords: Vegetation condition, drought monitoring, Vegetation Health Index (VHI), Vegetation Condition Index (VCI), Standardized Precipitation Index (SPI)

1. Introduction

Drought affects environmental degradation, water shortage for agricultural activities, and the economy as a whole. The integration between various drought indices can improve drought management and reduce the impact of severe drought occurrences. Drought severity has been observed based on various drought indices from both station-based and satellite-based drought indices which characterize and monitor drought events in terms of drought severity, frequency and occurrence.

The standardized precipitation index (SPI) was used to identify rainfall deviation from the mean of the observed precipitation at several time scales (Mckee et al., 1993). SPI was better to determine the difference between wetness and dryness than the traditional Palmer Drought Severity Index (PDSI) (Giddings et al., 2005). SPI can be used for drought monitoring in terms of severity, duration and frequency at temporal differences in several areas such as Australia, China, India and Greece (Khan et al., 2008, Zhang et al., 2009, Dutta et al., 2015 and Karavitis et al., 2011). The advantage of station-based drought indices can be used to analyze drought severity and frequency based on the precipitation alone. The limitation is a low accuracy due to a small number of rainfall stations and short-term recording of rainfall.

Satellite-based drought indices have been introduced to overcome station-based indices deficiencies as they can monitor drought severity more frequently and continuously (Jain et al., 2010). The Normalized Difference Vegetation Index (NDVI) has been first introduced to monitor the variation of vegetation greenness and wildly applied for global change studies such as land use and land cover change detection and classification and drought monitoring (Glenn et al., 2008). Another Satellite-based drought index, the Vegetation Condition Index (VCI) has been used to observe the impact of climate variability on vegetation conditions (Li et al., 2013).

VCI was developed to detect the vegetation condition from extremely poor to optimal conditions from the relative change in the NDVI values (Kogan 1995 and Karnieli et al., 2010). A combination of drought indices and climate variables has been applied for monitoring vegetation condition response to climate variability and identifying agricultural drought for early warning. Vegetation response to rainfall variation was found to correlate differently depending on climatic zones and land use types (Li et al., 2018; Thavorntam and Tantemsapya, 2013). VCI and SPI have been applied in several areas for better monitoring and assessment of the impact of drought on vegetation (Dhakar et al., 2013).

The integration with NDVI and land surface temperature has been developed to generate the Temperature Condition Index (TCI) and Vegetation Health Index (VHI) for better agricultural drought identification from vegetation and temperature condition (Kogan, 1995). The integration between VCI, TCI and VHI has been used for monitoring vegetation activity and the findings could be applied for monitoring vegetation growth under diverse climate conditions (Bhuiyan et al., 2017, Thenkabail and Rhee 2017 and Pei et al., 2018). Crop yield and insurance estimation were also applied using VHI to estimate the rice yields before the harvest (Rahman et al., 2009 and Amalo et al., 2016).

In northern Thailand, the forest area has declined significantly due to deforestation for agricultural land expansion and the impact of climate change (Walker, 2002). Drought severity and frequency have increased and the most serious negative consequence has occurred for agricultural activities in the lower part of the region (Chinnarasri et al., 2016). Understanding how drought could impact agricultural and forest areas can fill the gap in drought management in drought-prone areas. This research attempts to assess drought impact on forest and agricultural areas in northern Thailand using SPI, VCI, and VHI. The performance of each drought indices was compared for their suitability in drought-prone areas. Drought severity maps were generated to identify drought extent and significant agricultural activity and forest area impact from drought. The correlation between drought indices was analyzed to identify the dominant factors that control vegetation growth and variability.

2. Study Area and Data Used

2.1 Study Area

The study area was located in the northern region of Thailand. The region is mountainous with an area is about 165,356 km^2 and is located between coordinates 97° 20′ E to 102° 3′ E and 15° 5′ N to 20° 32′ N as shown in Figure 1(a). Forest in the region is more located at higher latitudes and classified into two major types, evergreen and deciduous forests. The forest areas were located in the mountainous area in the northern and western parts of the region while there were paddy and crop fields in the lower part of the region as shown in Figure 1(b). The climate of the region is a monsoon climate controlled by the Northeast monsoon from October to March and the Southwest monsoon from April to October.

There are three main seasons in the Northern region start from the summer in the middle of February until May and followed by the rainy period until the end of October. The winter period starts from November to February. The temperature is varied between 26 °C to 34°C while the higher elevation is cooler than the lower elevation (Maxwell, 2004).

The annual rainfall surface in the north of Thailand from 2000 to 2017 was obtained by ordinary kriging methods (Figure 1(c)). The Gaussian model with box-cox data transformation provides the most representative stochastic interpolation. The overall annual rainfall in the region has increased from the middle to the north and southwest parts of the region. Annual rainfall records varied from a minimum of about 1,000 mm in the middle part of the region to a maximum of about 1,800 mm in the northern part. The amount of rainfall in the north is much higher than in the south and middle parts for this period because of the influence of the monsoon that the northeast region receives from September to October. The study area for the whole northern region was used to assess drought severity pattern and extent. To study the impact of drought on specific vegetation at the temporal scales, four sample sites in forest and agricultural areas were selected. The selected sites were located in 4 provinces including Chiang Rai, Mae Hong son, Lam Phun and Kamphaeng Phet province and the detail of each site follows.

Site 1 and site 2 were located at 99° 49′ N 20° 3′ E and 97° 51′ N 18° 10′ E in Chiang Rai and Mae Hong Son province, respectively. The land use type for these sites was a mixed deciduous forest with the dominant tree types for this forest are teak trees and bamboos. The altitudes for site 1 and site 2 were about 500 m and 520 m, respectively. Site 3 was located at 99° 9′ N 18° 40′ E in Lamphun province with an altitude of about 340 m. The land use type was a crop field where the longans (*Dimocarpus longan*) plantation site was selected.

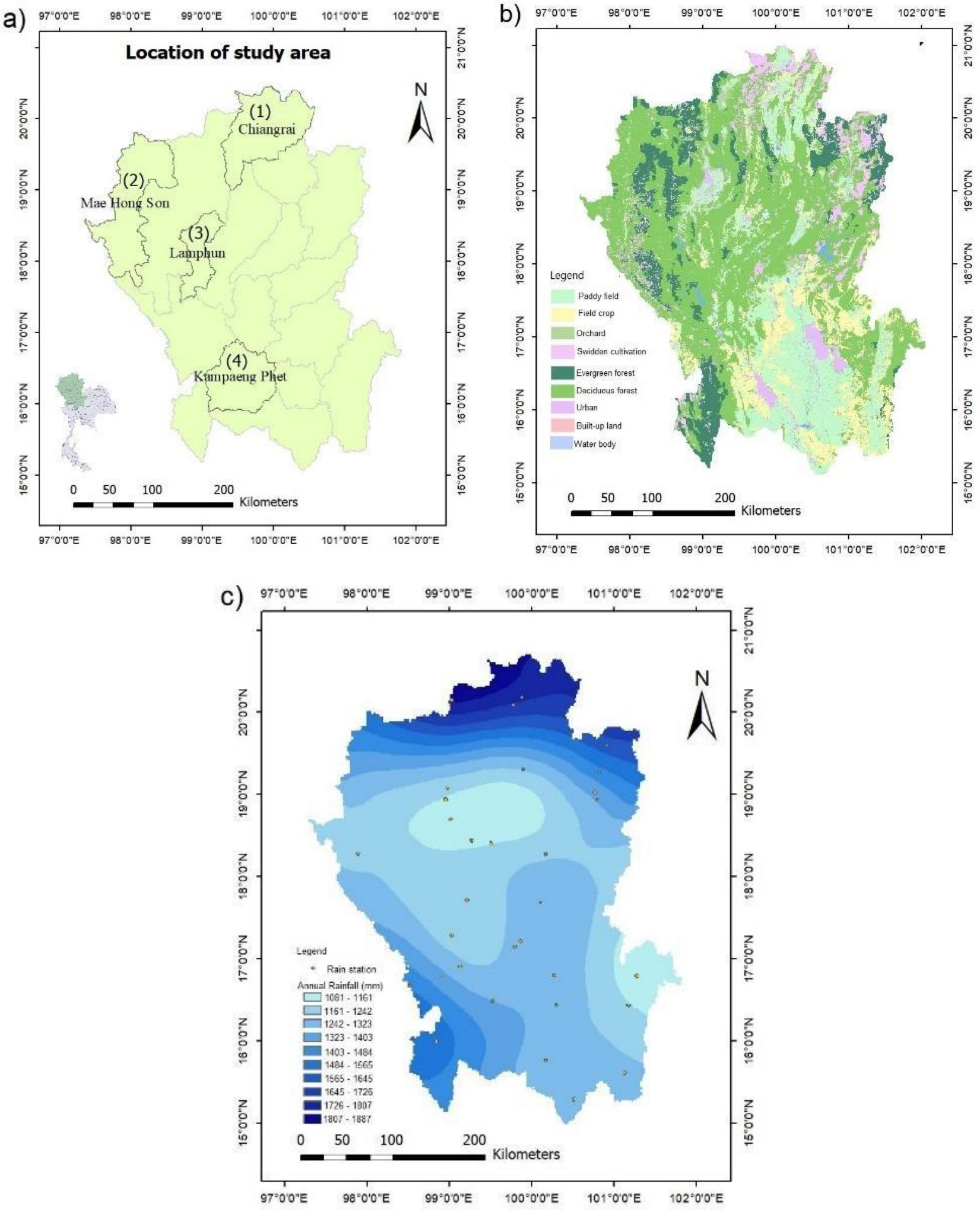

Figure 1: (a) Study area (b) Land use map and (c) Mean annual rainfall in Northern Thailand from 2001 to 2017

The longan tree requires lower temperatures for flowering from late December to February and starts to harvest in late June to August. The mature longan tree can grow to 12 meters in height and its branches are long and thick. Pruning was done after harvesting to allow light penetration.

Longan production is the major economic crop in this region and the plantation area has increased every year. However, productivity varies year by year due to climate variation and field management (Choo, 2000).

Site 4 was a paddy field located at 99° 25′ N 16° 30′ E in Kamphaeng Phet province. The altitude for this site varies between 90-100 m. Rice was grown in a rainfed agricultural area starting from May and harvested from September to October.

2.2 Remote Sensing Data

The remotely sensed data used for this study were NDVI and Land Surface Temperature (LST) which were obtained from the Terra/MODIS satellite during 2001-2017. These products were applied in this study because of the advantages of monitoring vegetation conditions and its variation due to climate change. The data were downloaded from the Earth data website https://earthdata.nasa.gov/. NDVI data were obtained from the Terra MODIS vegetation indices (VIs) product (MOD13Q1). The spatial resolution for NDVI was 250 m and the compositing period is 16 days. LST was retrieved from MODIS Land Surface Temperature and Emissivity (MOD11) product using a daytime algorithm with a resolution 1 km. The resolution of 1 km of Land surface temperature was downscale to 250 m with the same resolution of NDVI. The 16-day composite of NDVI data was aggregated into monthly data for correlation analysis with LST and station-based drought indices

2.3 Meteorological Data

Monthly rainfall data was obtained from the Thai Meteorological Department from 2000–2016 and linked with the rainfall station locations located throughout the region. Monthly rainfall data at the stations were interpolated to create continuous surfaces using Geostatistical analysis. Kriging technique was applied to examine data distribution and spatial autocorrelation. Modeling semivariogram, fitting a model, performing cross validation, and comparing the models were done to generate the rainfall surface across the region. The performance of the model was evaluated from the mean error and the root-mean-square standardized error which should be close to 0 and 1, respectively.

3. Methodology

This study focused on the evaluation of drought impact on vegetation dynamics using satellite-based and station-based drought indices in forest and agricultural areas. Figure 2 shows the conceptual framework for this research. The remotely sensed data used were NDVI and LST which were obtained from the Terra/MODIS satellite from the year 2001 to 2017. VCI and VHI were later calculated from NDVI and LST. Muti-temporal analysis for VCI and VHI values at all sample sites has been processed to derive the temporal trend of vegetation conditions over time. Spatial patterns of drought severity occurrence and extent in the study area were analyzed from monthly VCI and VHI values. SPI at the 3-, 6- and 12-month time scales were calculated from monthly rainfall data in the same period with remotely sensed data.

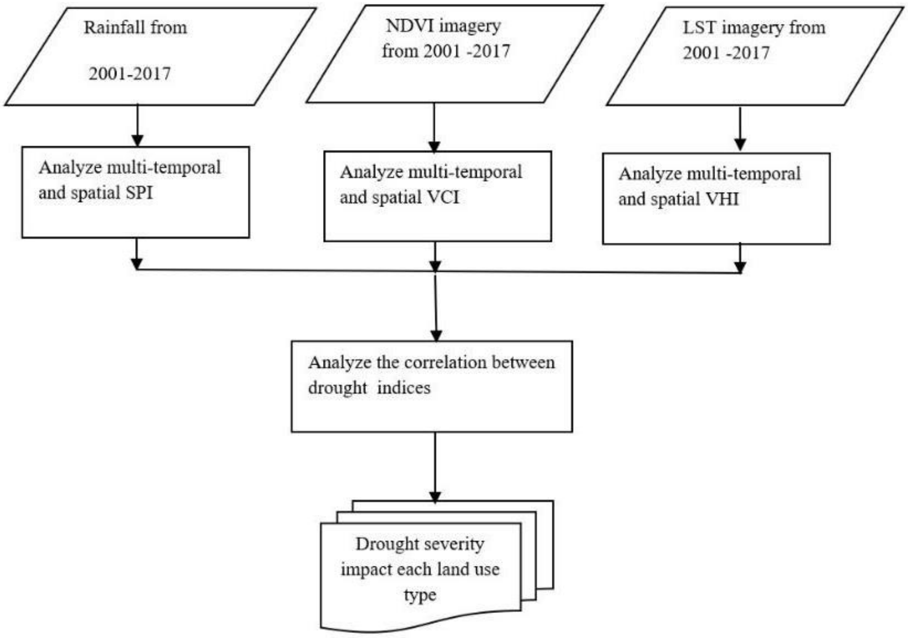

Figure 2: Flowchart of the methodology

Trend analysis of SPI at all sample sites was applied to observe drought occurrence. SPI surfaces were generated from SPI values at each station using the Kriging technique to identify drought severity and spatial extent. The correlation analysis between these drought indices was applied to characterize drought severity impact on each land use type. The details of each step are as follows.

3.1 Satellite-Based Drought Indices Analysis

The NDVI is a spectral transformation between the red and the near-infrared reflectance and the values range from -1 to 1 where the higher values refer to dense vegetation and the lower values are sparse vegetation. The formula for NDVI calculation is:

$$NDVI = [\rho NIR - \rho Red] / [\rho NIR + \rho Red]$$

Equation 1

Where ρNIR and ρRed are reflectances in the NIR and Red, respectively (Pettorelli et al., 2005). The VCI was further developed to monitor vegetation conditions by comparing the current vegetation indices with the maximum and minimum values in the observed period. Vegetation indices that could be applied for VCI calculation are NDVI and the Enhanced Vegetation Index (EVI). This study applied NDVI for VCI calculation and the formula for VCI calculation is:

$$VCI = 100*(NDVI- NDVI_{max})/ (NDVI_{max}- NDVI_{min})$$

Equation 2

where $NDVI_{max}$ and $NDVI_{min}$ are the absolute maximum and minimum NDVI from the period 2000 to 2016 (Pei et al., 2018).

VHI was developed from a combination between VCI and Temperature Condition Index (TCI) to estimate vegetation stressed by temperature. TCI was developed to capture the vegetation responsive at different temperatures obtained from the thermal channel of the earth observation satellite. The TCI and VHI were calculated by the following equation:

$$TCI = 100*(LST_{max}-LST)/(LST_{max}-LST_{min})$$

Equation 3

$$VHI = a*VCI+(1-a)*TCI$$

Equation 4

Where LST was the land surface temperature at the current month, LST_{max} and LST_{min} were the maximum and minimum land surface temperature of the study period, respectively; a is the coefficient value of the share proportion between moisture and temperature condition to vegetation health and a is assumed to be equal between this condition (a= 0.5) (Kogan et al., 2011). The value of satellite-based drought indices including VCI, TCI, and VHI vary from 0 to 100, from normal to severe drought conditions. The values of VCI and VHI were classified into five categories to identify vegetation conditions include; extreme drought (0-10), Severe drought (10-20), moderate drought (20-30), mild drought (30-40), and no drought (> 40) as shown in Table 1 (Bhuiyan, 2017).

3.2 Station-Based Drought Indices Analysis

SPI was used to quantify precipitation deficits at the 3-, 6- and 12-month time scales from the year 2001 to 2017 both temporal and spatial analysis. For temporal analysis, SPI values of each station were calculated to identify drought frequency occurrence for the study period in which drought occurs when SPI values are less than -1. For the analysis of the spatial pattern of drought, the Kriging technique was used to generate the SPI surface from SPI values at each station. The SPI surface at the 3-, 6- and 12-month time scales were used to identify drought severity and spatial extent across Northern Thailand. SPI values were classified into 5 categories for drought intensity analysis as shown in (Mckee et al, 1993).

Table 1: Categories of drought according to VCI, VHI, and SPI classification

Drought Category	VCI values	VHI Values	SPI Values
Extreme drought	< 10	< 10	≤ −2.00
Severe drought	10 to 20	10 to 20	-1.99 to -1.49
Moderate drought	20 to 30	20 to 30	-1.49 to -1.00
Mild drought	30 to 40	30 to 40	-0.99 to 0.99
No drought	> 40	> 40	≥1.00

3.3 Correlation Analysis between Satellite-Based and Station-Based Drought Indices

The temporal correlation analysis between satellite-based and station-based drought indices was examined to evaluate the impact of the climatic condition on vegetation at different time scales. Monthly VCI, VHI, and SPI values at the 3-, 6- and 12-month time scales were collected from January 2001 to December 2017, thus there were 204 samples for each site. Correlation coefficient (*r*) and *p* values from The Pearson correlation analysis were performed to identify the relationship between satellite-based and station-based drought indices which might be varied by land use type, seasonal variation of vegetation and time scale.

4. Result and Discussion

4.1 Inter-Annual Variation of VCI and VHI

Vegetation stresses from drought were observed through monthly VCI and VHI values from 2001 to 2017 at different land cover types. The selected land use types were mixed deciduous forest, longan crop, and paddy field. All sample sites were surveyed and confirmed that there was the same land use type during the study period. The monthly VCI and VHI time series data from 2001 to 2017 at all sample sites were represented in Figure 3.

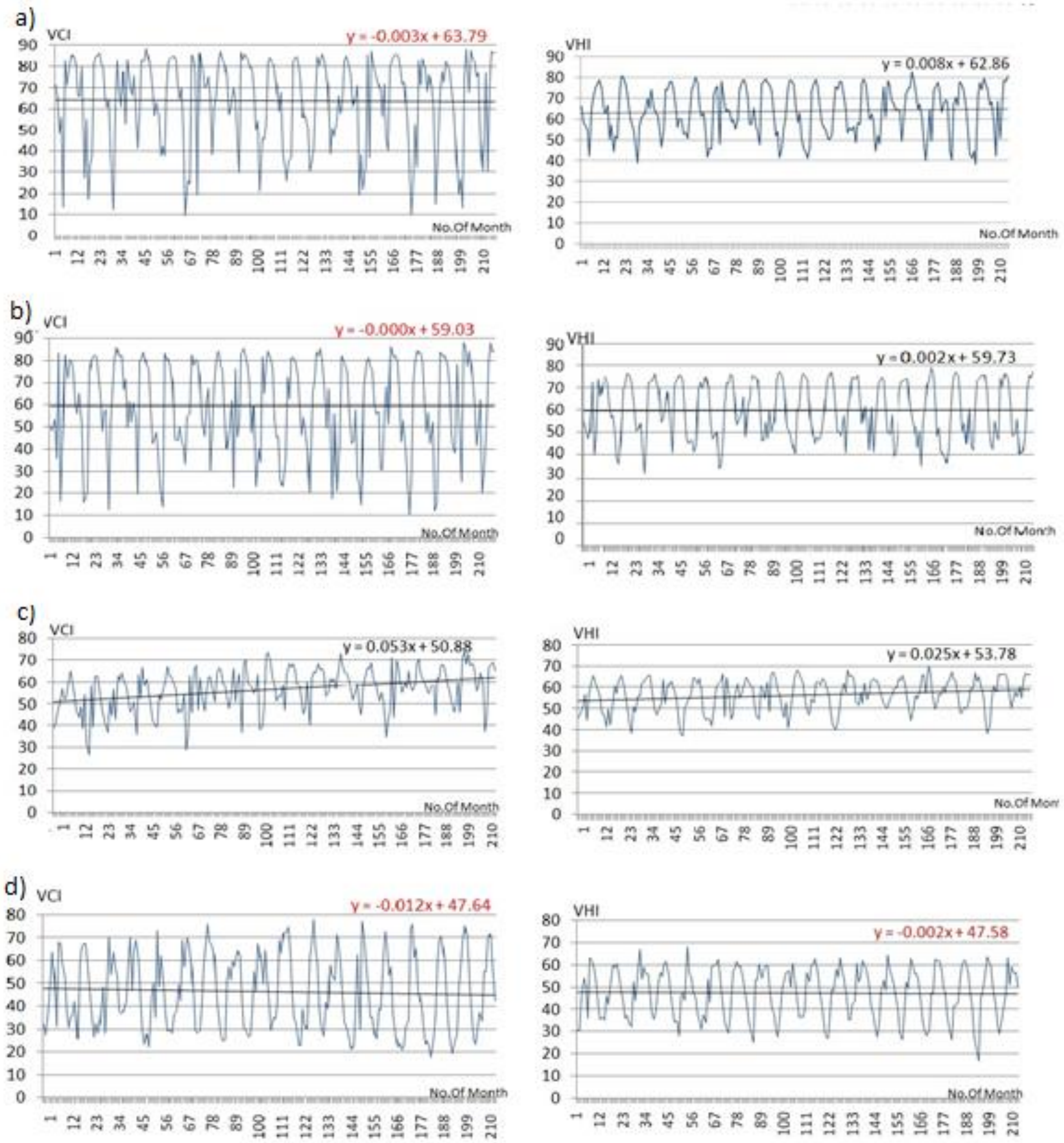

Figure 3: VHI and VCI trend from the year 2001 to 2017 a) Mixed deciduous Forest in Chiang Rai province b) Mixed deciduous Forest in Mae Hong Son province c) Longan crop at Lamphun Province and d) Paddy field at Kamphaeng Phet province

The variation and trend of multi-temporal VCI and VHI values were analyzed using the least square method. The positive equation represents an increasing trend while the negative equation represents a decreasing trend in VCI and VHI values over the study period. The vegetation variation and stresses from drought can be identified by a decreasing trend in VCI and VHI values.

In Figure 3(a) and Figure 3(b), deciduous forest for both sites in Chiang Rai and Mae Hong Son province in the northern part of the region represented a slight decrease in VCI but a slight increase for VHI for the study period. The seasonal variations of VCI and VHI for this forest type were also governed by rainfall where the VCI and VHI values decreased in the dry season and start to increase in the rainy season. Drought frequencies detected by VHI were less than VCI for the deciduous forest at both sites. Drought detected from VCI occurred almost every year during the dry season for the mixed deciduous forest in Chiang Rai province and Mae Hong Son province. However, droughts year were detected from VHI only in 2016 in Chiang Rai province and in 2002, 2004, and 2013 in Mae Hong Son province.

Longan crop in Lamphun province displayed a slight increase in VCI and VHI (Figure 3(c)). There were some drought occurrences for this Longan plantation area detected by VHI in 2002, 2004, and 2016 during the dry season. Drought years occurred more frequently detected by VCI values in 2001, 2002, 2003, 2004, 2005, 2008, 2013, and 2017 and mostly occurred in the dry season. The worst drought year was detected from VCI and VHI values in 2001 and 2004 with the VCI and VHI values were 26.5 and 36.90, respectively. VCI and VHI decreased for the Paddy field in Kamphaeng Phet province in the southern part of the region as shown in negative data trend equations (Figure 3(d)). The variation of VCI and VHI values for this paddy field was controlled by rainfall where the VCI and VHI values were found lower than 40 during the dry season from December to April almost every year.

4.2 Multi-temporal SPI

Figure 4 represents the comparison of the 3-, 6- and 12- month SPI values at four stations close to the sample sites, in the north at Chiang Rai and Lamphun station, in the west at the Mae Hong Son Station, and in the south at Kamphaeng Phet station. Temporal analysis of drought occurrence and frequency were observed during the study period from the SPI values at the multiple time scales as shown in Figure 4. Short-term drought occurrence can be captured based on a 3-month SPI and a 6-month SPI. A 12-month SPI was calculated to describe long-term drought occurrences.

For the station in the northern area, there were moderate to extremely dry years occurred in 2001, 2003, 2004, 2005, 2007, 2009, 2010, 2013, 2015, and 2016 at Chiang Rai station (Figure 4 (a)) with the worst 6-month SPI value was -3.03 in October 2016. For Lamphun station (Figure 8(b)), the moderate to extreme drought years (SPI < -1) occurred in 2000, 2004, 2007, 2008, 2010, 2013, 2015, and 2016 where the worst drought year was in October 2015 with the 6-month SPI value was -2.68. At the western station in Mae Hong Son (Figure 4 (c)), the moderate to extremely dry years were 2003, 2004, 2006, 2010, 2013, 2014, 2016, and 2016 with the worst 6-month SPI value was -2.48 in May 2016. At the southern station in Kamphaeng Phet province (Figure 4 (d)), there were more likely to have drought occurrences except in the years 2011, 2012, and 2017. The worst drought year occurred in April 2016 with a 3-month SPI value was -3.07.

From the observation of rainfall deficit from the meteorological stations located across the region, a drought event is more likely to occur at the south station and it was observed by 6-month SPI. The worst dry years for all stations during the study period occurred in 2004 and 2016 and were captured by 3-month and 6-month SPI at the beginning and the end of the rainy season. The erratic distribution of rainfall-affected agricultural activities could be characterized by a shorter scale of SPI due to plants is not responsive to rainfall immediately but it tends to lag behind rainfall by a couple of months (Sönmez et al., 2005 and Bachmair et al., 2018).

4.3 Spatial Variation of VCI, VHI and SPI

VCI and VHI were used to analyze the spatial distribution of drought condition impact from vegetation conditions and thermal stress in northern Thailand from 2001 to 2017. The spatial variation of VCI, VHI and SPI were observed in the El Nino event in 2016 which there caused a severe drought impact in much of the country. From the VCI map in Figure 5(a), extremely to moderate droughts occurred during the dry season from January to May and were found mostly in the agricultural area in the southern part of the region. However, extreme to moderate drought conditions was also found at the beginning of the rainy season from May to August in the southern and western parts where were agricultural and forest areas, respectively.

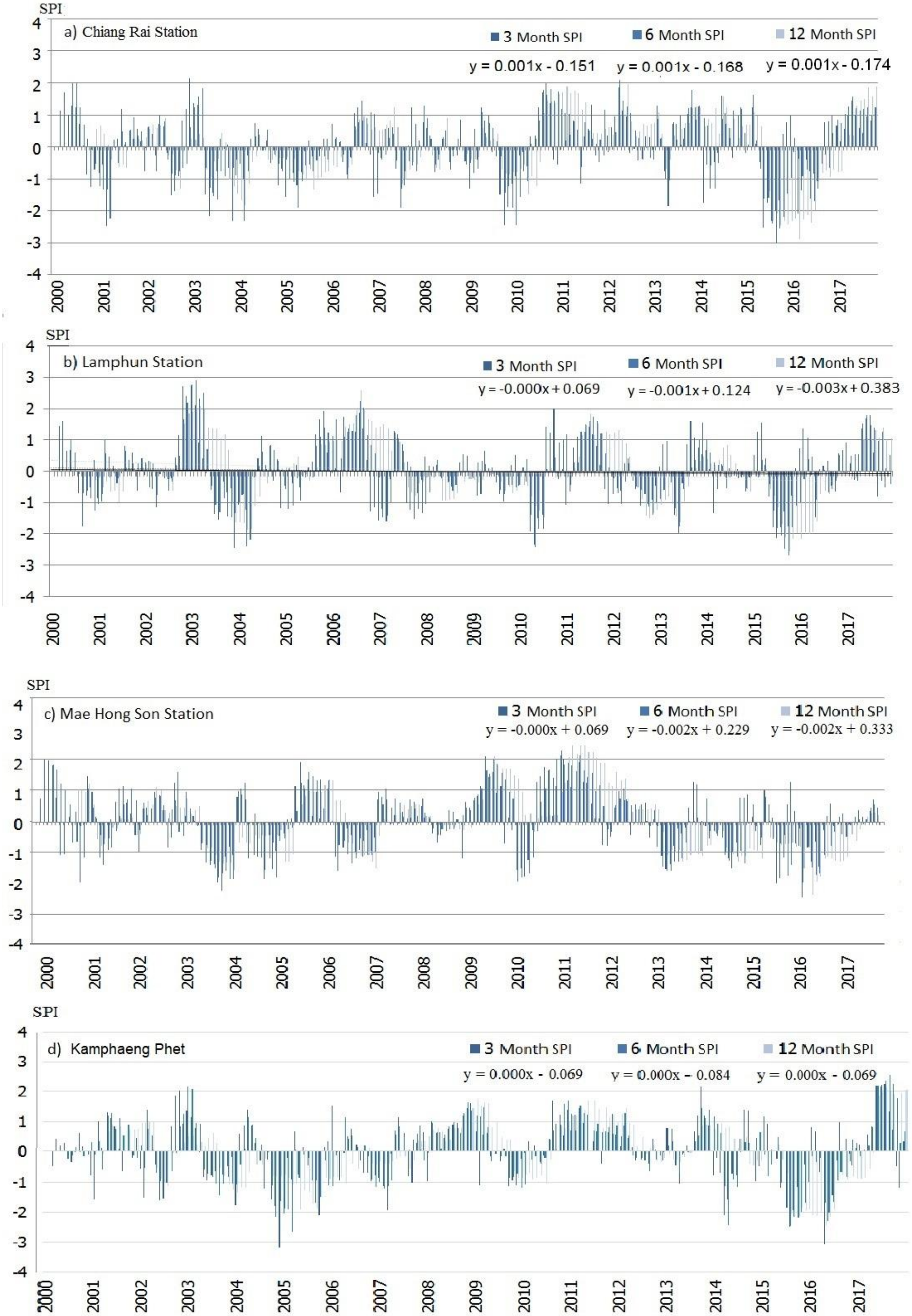

Figure 4: Multi temporal and multi-time scale of SPI at a) Chiang Rai station b) Lamphun station c) Kamphaeng Phet station and d) Mae Hong Son station

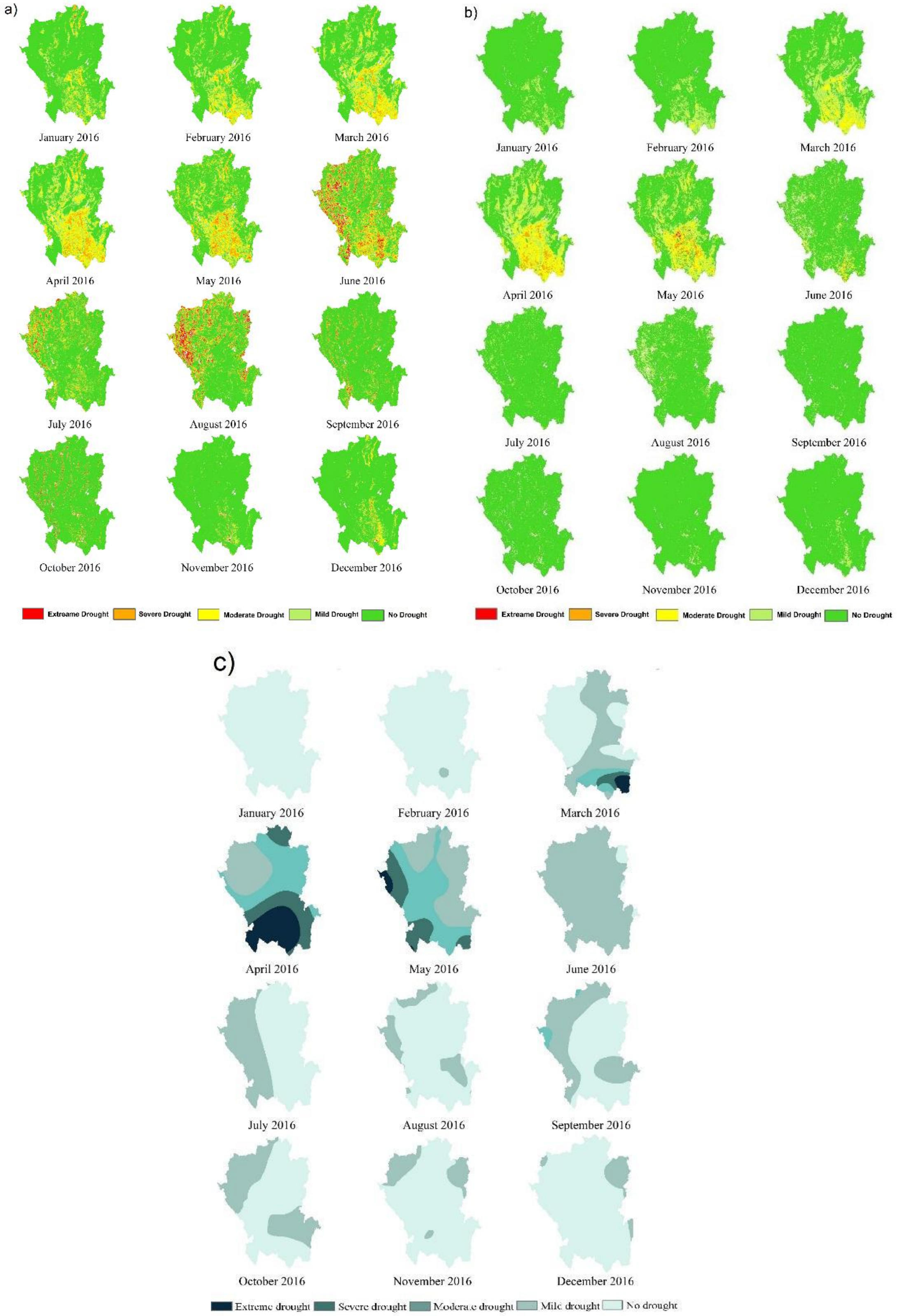

Figure 5: Spatial pattern of VCI (a), VHI (b) and 6-month SPI (c) for drought year in 2016

At the end of the rainy season in September and October, moisture availability can reduce the vegetation stress and there was fewer drought condition detected from VCI. These drought conditions detected from VCI reveal that the canopy greenness and moisture conditions were influenced by rainfall accumulation from the previous months.

The thermal stress conditions on forest areas and crops were observed through VHI (Figure 5(b)). The moderately to severe drought from the VHI map were mostly found in the southern part of the region where there were crop and paddy field during the dry season. Agricultural areas in the southern part of the region were impacted by drought from dry to the beginning of the rainy season, from February to May, for these drought years which were observed from both indices.

From the multi-temporal observation, drought occurrences at all sample sites were captured by a shorter scale of SPI. Thus, spatial patterns of SPI maps were generated from 6-month SPI to observe drought impact on vegetation at the beginning of the rainy and cropping season. The intensity of drought occurrence was observed in the worse dry year in 2016 (Figure 5(c)). The area most affected by drought occurred in the west and southwest of the region with drought severity associated with the pattern of rainfall, decreasing from the drier south to more humid north areas of this region. At the beginning of the rainy season, there was a drought occurring covering the entire region. In the late rainy season in August and September, mild to extreme drought occurred in the western of the region while. The previous study also reported a more arid area was more prone to drought than a humid area (Li et al., 2013). Drought spatial extent and severity can be described from SPI maps which were varied by location.

In Figure 6, VHI areas of each drought category from VHI maps were calculated to observe seasonal drought occurrence in droughts year in 2001, 2004, 2013, and 2016 for the northern region. The proportion of no drought area was higher than the drought area for this region. However, there were mild to extreme drought areas were found in the dry period from January to the beginning of the rainy season from May to July. At the end of the rainy season, there were fewer drought areas found compared with the beginning of the rainy season. The most drought-affected area was in March 2014 with an area of about 73,029 km2 or 44% of the whole region.

4.4 VHI, VCI, and SPI Correlation

Satellite-based drought indices, VCI and VHI, were used to monitor drought conditions on vegetation from moisture and thermal condition. A station-based drought index, SPI, was used to monitor drought conditions on vegetation status and quantify precipitation deficits at several time scales. The drought occurrence and spatial extent vary by drought indices and locations as represented in Figure 4.

Figure 6: The area of drought in each category in the drought year (2001, 2004, 2013, and 2016)

For monitoring drought-affected areas in spatial scales, the worst drought year occurred in 2004 and 2016 for VCI, VHI, and SPI maps as represented in Figure 5. The spatial extent of drought occurrence varies by drought indices and land use type. Paddy field in the southern part of the region has been impacted by moderate to extreme drought in the dry and beginning of the rainy season which can be observed from VCI and SPI. For forest areas in the western part of the region, the extreme to moderate drought-affected areas were observed by VCI and SPI at the beginning of the rainy season from May to August. This result indicates the vegetation condition for these forest areas was under stress even when rainfall starts. However, there were no drought occurrences for the entire region at the end of the rainy season. VCI and SPI be able to describe the moisture condition on vegetation in which a similar study reported the biophysical and biochemical parameters of the forest responding to VCI, TCI, and VHI were driven by precipitation in the previous month (Zou et al., 2020).

VHI can be used to identify drought-affected areas which were varied by land use type. VHI value assumes to be increased when lower in temperature. For the agricultural area in the southern region, the land was cleared for agricultural activity which increases in temperature and less VHI value. For the forest area in the western part of the region, extreme to moderate drought conditions was detected by VCI but there was no drought detected from VHI. Low temperature occurs in the forest area, especially in mountainous with high altitudes can result in high VHI values (Gomes et al., 2017).

For seasonal variation of vegetation health assessment, VHI maps revealed less drought extension and severity in the same area than VCI, for example in June 2016 (Figure 5). This was because more rainfall amounts at the beginning of the rainy season can reduce temperature and thermal stress on vegetation which was represented in mild drought from VHI and SPI map at the same period and same area. A similar study reported the impact of moisture on vegetation stress in India and that favorable thermal could maintain vegetation health (Bhuiyan et al., 2017). Another study in China revealed rare normal vegetation conditions observed by VCI but there were more normal vegetation conditions observed by VHI in the same area (Pei et al., 2018). These similar results could be used to identify the use of VCI and VHI for drought monitoring based on vegetation greenness and cooler conditions, respectively (Rahman et al., 2009).

Correlation analysis between VHI, VCI, and SPI at different time scales at all sample sites was done using the Pearson correlation method from the year 2000 to 2017. The correlation coefficients between VHI, VCI, and SPI at the different time scales varied by land use type and are represented in Table 2. VHI for a deciduous forest in Chiang Rai, deciduous forest in Mae Hong Son, and paddy field were highly correlated to VCI and the correlation coefficients were 0.83, 0.93, and 0.93, respectively. A significant positive correlation of VHI for crop fields in Chiang Mai and paddy fields in Kamphaeng Phet was found with 3-month SPI and the correlation coefficients were 0.21 and 0.17, respectively. The previous study also reported a significant drought impact on the crop that can be observed after the deficit of rainfall for three months (Prasad et al., 2005, Jain et al., 2010 and Ma'rufah et al., 2017). There was no significant correlation between VHI and 12-month SPI which means long-term drought occurrences cannot be detected by VHI. For the deciduous forest in the north and western parts of the region, there were mild and no drought occurrences detected from VHI maps at the beginning of the rainy season. Severe drought areas were detected from SPI maps during the same period resulting in a low correlation between VHI and SPI. Drought assessment for this forest area might not impact only soil moisture but also the cooler temperature in the high-altitude area.

Table 2: Correlation coefficient between VHI with VCI and SPI at the multiple time scales

Meteorological station	Land use type	VCI	3-month SPI	6-month SPI	12-month SPI
Lamphun	Crop field	0.24	0.21**	0.17*	0.16
Mae Hong Son	Deciduous Forest	0.93	0.07	0.06	0.05
Chaing Rai	Deciduous Forest	0.93*	0.05	0.09	0.09
Kamphaeng Phet	Paddy Field	0.91*	0.17*	0.15	0.10

5. Conclusion

The results from this study showed the advantages of satellite-based drought indices and station-based drought indices to identify drought characteristics in terms of frequency, occurrences, severity, and extent.

Multi-temporal VCI, VHI, and SPI were used to assess drought occurrence and frequency in the forest and agricultural areas. Drought more occurred from VCI values than VHI from 2001 to 2017. The negative trend of VCI was found in the mixed deciduous forest in the northern and the western and paddy fields in the southern part of the region. VHI values were also decreased at the paddy field in the southern part. Drought areas in the northern region of Thailand were found to increase in April, May, and July from 2001 to 2017 as shown in positive data trend equations. This result indicates that vegetation condition has been impacted by drought stress even in the beginning and middle of the rainy season. Multi-temporal SPI at the several time scales at the rainfall stations located close to the sample sites reveals drought occurred frequently during the study period. Shorter scales SPI captured drought occurrences better than 12-month SPI. The worst drought year was detected at the southern station in April 2016 with a 3-month SPI value was -3.07.

The worst drought year was found in 2004 and 2016 during the dry season to the beginning of the rainy season. The most affected area was found for paddy fields in the southern part of the region during the dry season detected from VCI maps and during the beginning of the rainy season detected from SPI maps. VCI maps show more drought-affected areas than VHI maps, especially in the deciduous area at the beginning of the rainy season in the western part of the region. Rainfall accumulation from the previous months can increase soil moisture and reduce thermal stress on vegetation. This condition can reduce drought occurrence, especially in the forest in mountainous areas where the temperature is cooler than the lower altitude resulting in a low correlation between VHI and SPI values at multiple time scales. VHI was found more appropriate for monitoring vegetation conditions in the forest area than VCI because this index could integrate the biophysical parameters responding to vegetation health.

The drought-prone area observed from VCI, VHI and SPI at the temporal and spatial scales mostly occurred in agricultural areas in the southern part of the region. The significance of drought occurrence was detected at the beginning of the cropping season in May. Effective adaptation strategies are needed for crops in this area, especially rice cropping even if there will be likely wetter in the wet season and drier in the dry season in the future but the drought will possibly occur (Maichandee et al., 2014). The Thai Rice Department had developed the new drought-tolerant glutinous rice, RD12, and the adaptation of this new rice was accepted by the farmer who was more exposed to drought (Orachos and Carl, 2014). Drought indices from Satellite-based drought indices and station-based drought indices provide better drought monitoring at various land use types for drought early warning and crop planning.

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