ANALYSIS AND INVESTIGATION ON SPATIO-TEMPORAL DYNAMIC PATTERN OF DROUGHT IN THAILAND

ARPAKORN WONGSIT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR MASTER OF SCIENCE
IN GEOINFORMATICS
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Drought over Thailand is a recurring natural phenomenon in different regions. Drought typically remains the crucial problem in Thailand that is merely not a recent issue but a severe recurring difficulty. Thailand experiences droughts every year throughout the dry season, although to wildly differing degrees of persistent intensity. Droughts can be produced by a variety of factors, the most common of which is an imbalanced and insufficient rainfall distribution to some areas. When insufficient rainfall is distributed unevenly, certain areas lack a sufficient water supply, causing problems for people and agriculture on a local level, as well as economic, social, and environmental consequences.

The primary goal of this study is to use main indices to analyze and investigate the evolution of the spatio-temporal pattern from drought indices that contributed to affecting transition flood and drought over Thailand from 1991 to 2020, as well as to analyze and investigate the relationship between meteorological drought, vegetation drought, soil moisture drought, and hydrological drought. The Standardized Precipitation Index (SPI) is a meteorological index that uses data from rainfall gauge sites to calculate precipitation. The Standardized Runoff Index (SRI) is the hydrological data obtained from the runoff, whereas the Standardized Soil Moisture Index (SSI) is soil moisture data collected from root zone soil moisture both of which were derived from the MERRA-2. The Vegetation Condition Index (VCI), derived from NDVI obtained from the NOAA Climate Data Record (CDR) of AVHRR Normalized Difference Vegetation Index, was also used. Assessment of drought using a common factor from remote sensing data. This can be easily monitored and can analyze drought-prone areas according to time series, which can

generate the best correlation-anticipation relationship for early signs of drought impacts and drought monitoring purposes.

This study analyzes and investigates the spatio-temporal dynamics of drought in Thailand, with four drought indicators analyzed from 1991 to 2020. The results of this study, the SPI index found that the years with the most severe droughts were 1992, 2004, 2012, 2016, and 2020, with the droughts starting in March to May and November to December on average. SSI, SRI, and VCI experienced the same drought in 1992, 2004, 2016, and 2020. The wetness and dryness of drought occurrences may now be easily noticed as a result of this research. In addition, the worst drought was in 2004, while the wetness year was 2017. The mean of each index is consistent with changes in rainfall but affects a distinct time connection, according to the results of the four indices analysis. The SPI index using meteorological data is useful for monitoring accumulated drought, but visual inspection only is insufficient to tell if the study area has become drier or wetter. This is likely to be beneficial, but it should be combined with other indices and data.

As a result, indices derived from satellite data represent an alternate method for evaluating and analyzing temporal and spatial drought that might be combined with meteorological data. It is simple and quick, and the results can be used on a regular basis. Drought is evaluated using indices obtained from satellite imagery on the different land use and land cover are also given the drought’s effect differently. Therefore, each area's drought database should be evaluated. In the meantime, data from other factors that influence drought occurrence should be incorporated to demonstrate the drought's decision-making.

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CHAPTER 1
INTRODUCTION

1.1 Statements and Significance of the Problems

The dynamic of the drought is a natural phenomenon that occurs recurringly in the regions (Thiruvengadachari & Gopalkrishna, 1993). Drought is difficult to accurately determine because drought is a natural disaster that gradually occurs in which is of different intensity. From variant environment and climate change effect to some areas and causing frequent droughts, or in some specific cases, increased rainfall to severe flooding. There are many causes of drought that occur to most of which are caused by the amount of rainfall that is unbalanced insufficiently and the inadequate distribution of rain in some areas. When the inadequate distribution of insufficient rainfall is a result, in some areas, there is no adequate water reservoir, and in some areas affect people and agriculture at the local scale as well as impacts on the economy, society, and environment (Hayes et al., 2012). Thailand is one of the countries in Asia that is vulnerable countries to variability and change in climate severity, weather, and disasters in the form of droughts and floods. This is because people's livelihoods and national development as a whole depend on natural resource bases and products that are highly vulnerable to variability and climate change, such as water resources, agricultural products, and coastal resources. In addition, large cities, which are centers of economic and commercial development and population, settle in dense plains, estuaries, rivers, and coasts (IGES, 2006). Currently, the significance of this point is that Thailand is facing a wide variety of extreme weather and climate events. In particular, droughts and floods, which are increasing with increasing intensity and frequency ((Yumuang, 2006); (Sukprachok, 2006), found that in the past 30 years, droughts and floods have occurred severe floods in Thailand more than 50 times. The Department of Disaster Mitigation and Prevention reported (Department of Disaster Prevention and Mitigation (DDPM), 2014), for example, in 2011, Thailand had flooded agricultural and industrial areas in 65 provinces, or popularly known as the Great Flood, was a severe flood that affected the area starting at the end of July and ending on January 16, 2012 has been affected to people. So, from 1991-2020 is a vivid example of the impact of climate change and severity on the development of a country's society, economy. ((Wilhite & Glantz, 1985); Kogan 1995; Mishra and Singh 2010; Thai Meteorological Department 2011; Hao and Singh, 2015; Du et al. 2018)

Thailand is located in the monsoon regions, spanning latitudes 5 to 21 degrees north, resulting in three distinct seasons. However, there are more when considering the link between wetness or dryness. The rainy season and the dry season are the two main seasons. As a result, drought is a common occurrence in Thailand, with one of the characteristics highlighted being the presence of deciduous forests in many regions of the country, as well as farmers' selection of species and cultivation times based on local wisdom, with drought-tolerant plant species in mind. Given current global climate change conditions and future trends, Thailand will unavoidably face natural catastrophes, one of which being drought and floods, and will need to take disaster management seriously. However, it must be analyzed and evaluated for drought indications from both sources by analyzing meteorological data and satellite observations to be assessed for drought and flood conditions in the region in order to keep up with the situation and efforts have been made to establish information and processing systems that deliver prompt responses.

Assessment of the drought from the satellite survey. The majority of them are based on data from earth-observing satellites that are linked to the area's drought. As a result, using satellite imagery-derived indices in combination with meteorological, soil moisture, hydrological, and vegetation data to assess drought in Thailand is appropriate. Satellite data are widely and effectively used for drought monitoring applications and to properly explore spatiotemporal drought patterns with satellite-derived indices that offer effective opportunities for collecting a large volume of data and amply filling lacking area data to cover Thailand completely. Satellite data products can be acquired directly from NASA for no cost and are accurately recorded at all the appropriate times. They are convenient and easy to use for planetary-scale geospatial analysis to store and proceed with geographic data sets. This will be used to establish the methodologies and types of data that will be used in nations with insufficient observation data. As a result, satellite data offers potential tools for comprehensive geographic data that are well-suited to drought monitoring. It includes the drought index group, which uses statistics or satellite image data in addition to remote sensing data for drought monitoring and surveillance. The previous drought research focused on the drought that is relevant to this study. Xiang Zhang et al. (2017) used monthly meteorological, hydrological, soil moisture, and vegetation data from 1981 to 2013 to study spatial-temporal distributions in India, drought, and lack of integration with specific crop phenology. The role of the Green Revolution on drought was analyzed evolution and trends was also investigated, as well as the correlation and evolutionary processes of the four types of droughts, the frequency, extent, and severity of the drought period. This study represents a new approach to drought studies from multiple perspectives and, combined with crop growth for provides useful valuable guidance for drought mitigation on a local level. Yao et al., 2020 used the standard index to study the evolution and propagation characteristics of three types of droughts over various periods in the sub-region of China. To compare drought index trends, the index comprises Standardized Precipitation, Soil Moisture, and Runoff Index (SPI / SSI / SRI) representing agricultural meteorological and hydrology drought. For SPI and SSI correlation coefficients were closer to SPI than SRI. These studies provide important information and guidance for developing regional to national drought management strategies and critical timeframes well for the rest of the world. As a consequence, for this study, a dataset from meteorological, vegetation, soil moisture, and hydrological sources that provide drought indices by Standardized Precipitation Index (SPI) as precipitation data from rainfall gauge stations. The Standardized Runoff Index (SRI) was calculated from runoff, while the Standardized Soil Moisture Index (SSI) was calculated from root zone soil moisture, both of which were derived from the MERRA-2 data. The NOAA's Vegetation Condition Index (VCI) was used to calculate the NDVI. These data were used for the spatio-temporal analysis of drought in Thailand over a thirty-year period from 1991 to 2020. Drought assessment using a common factor from remote sensing data can be easily monitored, and the best correlation-anticipation relationship for early signs of drought impacts (Measho et al., 2019) and drought monitoring purposes can be generated by analyzing drought-prone areas according to time series. However, in order to use satellite data, it must be data from a group of satellites to which Thailand has continuous access, satellite data from which derivatives related to the nature that appears in the country can be derived, and satellite data that can be used to create an index that reflects the variability of the drought that occurs in Thailand. Drought conditions are usually gradual and can be seen over a large area, but the extent of the occurrence is not as pronounced as floods. Drought is a spatially distributed drought that is produced by a variety of variables and has to do with environmental elements that vary by region. As a result, the use of meteorological data in conjunction with satellite imaging datasets is becoming increasingly popular in Thailand's efforts to track the country's drought.

1.2 Research question

1. How does the evolution of spatio-temporal drought based on the drought indices analysis?

2. What are the phenomena of drought and flood in Thailand from the drought indices analysis?

3. How does the relationship between meteorological, vegetation, soil moisture, and hydrological droughts based on analysis of drought indices over Thailand during 1991 - 2020?

4. What factors contributed to affect the drought in Thailand?

1.3 Objective

1. To analyze and investigate the relationship between meteorological, vegetation, soil moisture, and hydrological droughts based on analysis of drought indices over Thailand during 1991 - 2020.

2. To investigate the evolution of the spatio-temporal pattern from drought indices contributed to affect transition flood and drought over Thailand during 1991 – 2020.

1.4 Scope of the Study

This research aims to analyze and investigate the spatio-temporal drought pattern utilizing drought indices in order to reflect Thailand's drought from 1991 to 2020 utilizing drought indices generated from meteorological, vegetation, soil moisture, and hydrological data. Figure 1 depicts the conceptual framework of extensive research in this study.

Thailand has covered a region, with 77 provinces and a population of about 69 million people. This country is located in the tropics and is located in the center of mainland Southeast Asia. Thailand is made up of diverse ecosystems, including the hilly forest areas of the northern frontier, fertile rice fields in the central plains, the broad plateau of the northeast, and the rugged coastline along the narrow southern peninsula. Thailand has a land area of 513,115 square kilometers with a boundary within 5 ° 37'N - 20 ° 27′N latitude and 97 ° 22′E - 105 ° 37′E longitude. Thailand has naturally bordered on the west by Myanmar and the Andaman Sea, on the northeast by Laos, on the southeast by Cambodia, on the southeast by the Gulf of Thailand, and on the south by Malaysia. (Wikipedia, 2021). The study area map is shown in Figure 2.

1.5 Thesis structure

The following is the structure of the five chapters that constitute this thesis: Firstly, Chapter 1 contains an introduction to the statements and significance of Thailand's drought problems, as well as the general background of the study, objectives of the research, characteristics of the study area, and the scope of the study. Chapter 2 is presented the background for this study followed by a thorough literature review on the definition and characteristics of drought, drought indicators and indices, and a researches review related to the previous research. Chapter 3 describes the techniques used in this study, the data in use, methodology, and the process of the whole research. chapter 4 represents the experiment result of drought indices from meteorological, hydrological, soil moisture, and vegetation, spatial distribution analysis, and characterized drought dynamics. Finally, Chapter 5 is the last section a summary of the dissertation, including general conclusions and suggestions for future research in this regard.

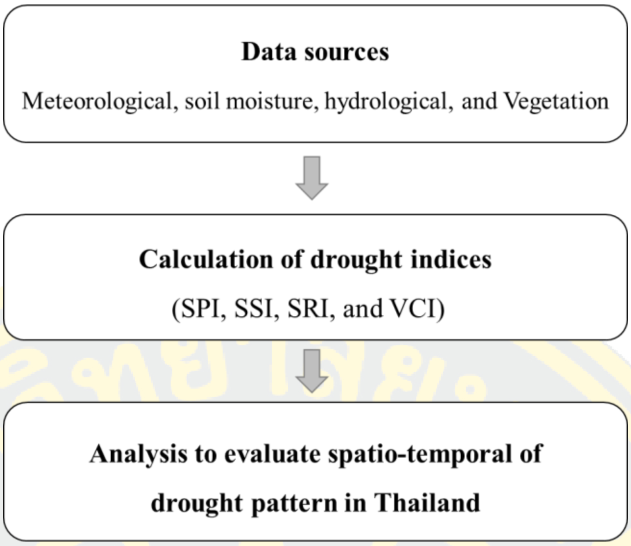


Figure 1 Diagram framework in this study

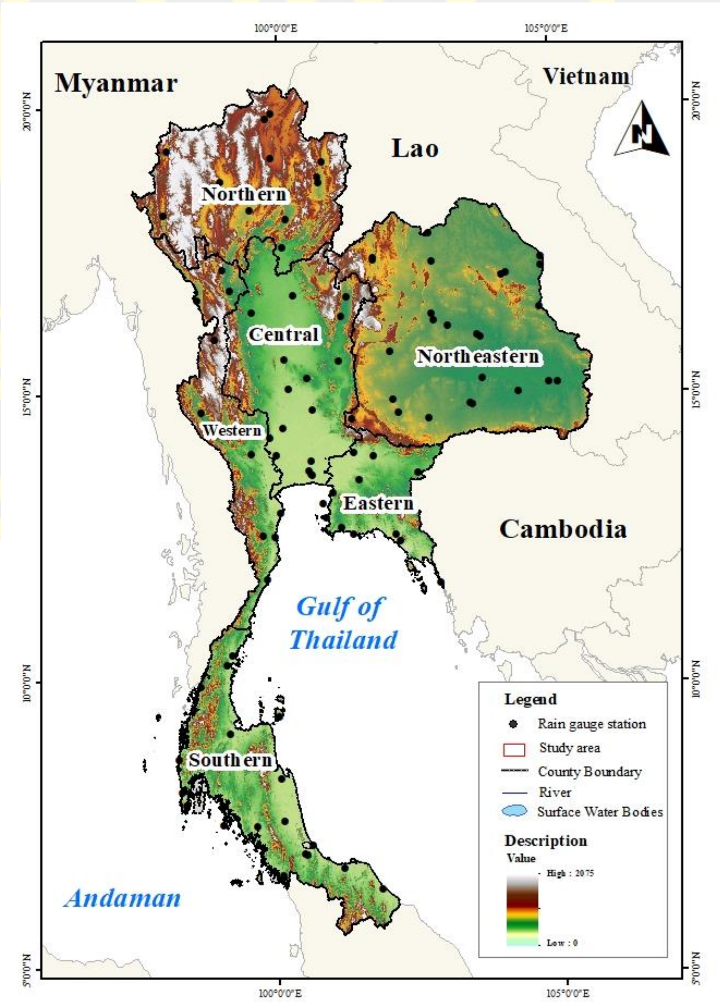


Figure 2 Topography map of Thailand.

CHAPTER 2
LITERATURE REVIEW

The literature review in this chapter has studied the theoretical concept from the theories and the relevant research results as follows background for this study followed by a thorough literature review on the definition and characteristics of flood and drought, drought indicators and indices, and research review related to the previous research.

2.1 Background of this study

2.1.1 Climate and topography of Thailand

Thailand is a country in the center of Southeast Asia and is located near the equator in the tropics. The topography of each part of Thailand is quite different can be divided according to meteorological characteristics into 5 regions (Wikipedia, 2021) as follows Northern, Northeastern, Central, Eastern, and Southern Parts. The climate of Thailand is under influence of the northeast monsoon and the southwest monsoon is the main determining of the climate in the country (Thai Meteorological Department, 2015). The northeast monsoon influence is between October and February which is winter the weather is generally cold and dry air by brings the anticyclone from China's mainland over especially the upper parts of Thailand. For southern monsoon also has mild weather and rain along the coast of the eastern part. The southwest monsoon begins in May brings warm, moist air from the Indian Ocean to Thailand, causing rains in almost the country which generates a large amount of rainfall.

2.1.2 The season of Thailand

Thailand is divided the climate characteristic into three seasons (Climatological Group Meteorological Department, 2015) as follows

- Rainy season which is abundant rain that occurs over the country especially from August to September is the wettest time of the year except for the southeast coast where rain until the end of the year.

- Winter season during October to February for the most part of Thailand was experienced dry weather with mild temperatures with the upper part of Thailand having a cold but the Southern region has a lot of rainfall.

- Summer season starts from February to May are warm for a long time, with temperatures rising especially in the north, northeast, central and eastern parts of the region.

2.1.3 Temperature of Thailand

Temperature is generally hot and very unchanged with the nationwide average of 27 degrees Celsius, the highest average of 32 degrees Celsius, and the lowest 22 degrees Celsius. The temperature varied according to the topography. The temperature varied according to the topography, namely the northern and the northeastern regions were hotter and colder than the other region, with a large difference between the mean maximum and the lowest temperatures, the average high temperature of 37 degrees Celsius in summer, and the average lowest temperature in winter is about 21 degrees Celsius. The central and eastern regions have parts of the area adjacent to the sea, so the temperature does not change, the average temperature is about 28 degrees Celsius, with the lowest temperature averages about 23.4 degrees Celsius. The southern regions have surrounded both sides by the sea. The temperature does not change, the average temperature is about 27.3 degrees Celsius, the average low temperature 23.2 degrees Celsius, the average maximum temperature 31.7 degrees Celsius (Thai Meteorological Department, 2015).

2.1.4 Rainfall in Thailand

In general, according to the spatial Annual rainfall of the country ranging from 1,200 - 1,600 mm per year and a total average rainfall value of 1,650 mm per year (Thai Meteorological Department, 2015). The variations of the rain are based on topography and the seasons. Although upper Thailand often experiences cold and dry in the winter season due to the northeast monsoon, causing slight rain in winter in some areas. In the summer, has rain showers or the appearance of gradually increasing rain and thunderstorms. The onset of the southwest monsoon causes heavy rains from May to October and the highest rainfall is in August or September. The difference in the rainy season between the South and the upper part of Thailand is that it rains heavily in both monsoons by the southwest monsoon, which receives a lot of rain in September and the northeast monsoon receives a lot of rain in November remains until January of the following year.

2.2 Definition/ characteristics/ the nature and types of floods

The meaning of floods is broadly defined by many researchers. Overall, flood refers to the perils or hazards arising from flooding or the dangers arising from the state of overflowing water, riverbanks, streams, or floodways. Areas that are normally not below the water level are broad areas, where the level and flow rate of water exceeds the storage capacity of rivers and waterways or is caused by water accumulation over an area that cannot be drained in time, causing the area to be covered. With water, its severity depends on the amount, duration and current, and the water level, consistent with Satterand and Adams (1992), who said that floods were caused by the flow rate of the water in a stream that exceeded the potential of the river, so flooding is said to be dangerous. This is caused by the state of overflowing water, riverbanks, streams, and waterways inundating the area when the water is not drained in time, causing the area to be covered with water. Flooding refers to the state of water in the stream runoff is abnormally high, causing flooding in areas such as agricultural areas, roads, and cities, causing direct and indirect loss of property. Floods are caused by prolonged heavy rains, floods from the mountains, upstream streams, crooked waters, and dams, etc. Floods are the result of complex interactions between climatic and hydrological processes that can occur. In spatial and temporal scales, flooding events can take many forms, including events of slow rising and overflowing at the riverbank, flash flooding, and flooding. The nature of the floods that occurred can be divided according to the conditions of occurrence in 2 types:

1) Flood conditions caused by natural events consisted of flooding caused by flooding from mountains to flash floods caused by heavy rains in the upstream and streams and overflowing banks due to the excess amount of forest water flowing into the river. The capacity of the river can be tolerated and the normal flooding conditions of the estuary rivers during high tide.

2) Man-made flood conditions such as flood conditions due to dams collapse. Flood conditions caused by buildings blocking the waterways. And flooding conditions caused by rainfall, flooding in the community and urban areas in case of heavy rain.

When considering the pattern of the flood. Can be divided into 5 types: River Flood, Flash Flood, Storm Surges, Drainage Flood, and Dam Break. In the past 30 years (Department of Disaster Prevention and Mitigation (DDPM), 2011), there have been many flooding events in Thailand. Most of the floods in Thailand are caused by storms, heavy rains, or prolonged rain flash flood.

2.3 Definition and characteristics of drought

2.3.1 Temperature of Thailand

Drought represents a phenomenon of shortage of water due to lack of rain for a long period of time that there is no water used on-demand (Thai Meteorological Department, 2015) as a result of the drought of the weather caused by less rain or the rain does not have to be seasonal for a more extended period of time and covering a large area, causing a lack of shortage of drinking water, lack of water causing plants do not grow normally affect the crop yield cause damage and general famine Impact on livelihood including economic and social aspects. Drought caused by a prolonged lack of water in a particular area until it was a drought which remains a type of natural disaster that occurs annually. The severity of the drought depends on many factors such as air humidity, soil moisture, temperature, duration of drought, and the spatial extent of the drought area (Eden, 2012). There are four types of definitions and classifications of drought characteristics as shown in Figure 3 (Wilhite & Glantz, 1985). The first three types of droughts are physical droughts and the latter type are the effects of the first three types of droughts on socioeconomic conditions as follows:

- Meteorological drought refers to the amount of precipitation that is lower than normal due to climate in conditions where there is little or no rain at all for a period of time, which should normally have rain depending on the location and the season at that location.

- Agricultural drought refers to a situation in which the moisture content of the soil is insufficient for crops.

- Hydrological drought depends on physical water shortages such as runoff, river flow, and dam level which appears when surface water and groundwater conditions are lower than normal.

- Socioeconomic drought refers to a situation where the state of water scarcity begins to affect people.

Causes of drought TMD referred to two causes of drought (Thai Meteorological Department, 2007) as fellow:

1. Naturally including global temperature changes, climate change, sea-level change, and natural disasters such as earthquakes.

2. Human actions including ozone depletion, greenhouse effect, industrial development, and deforestation.

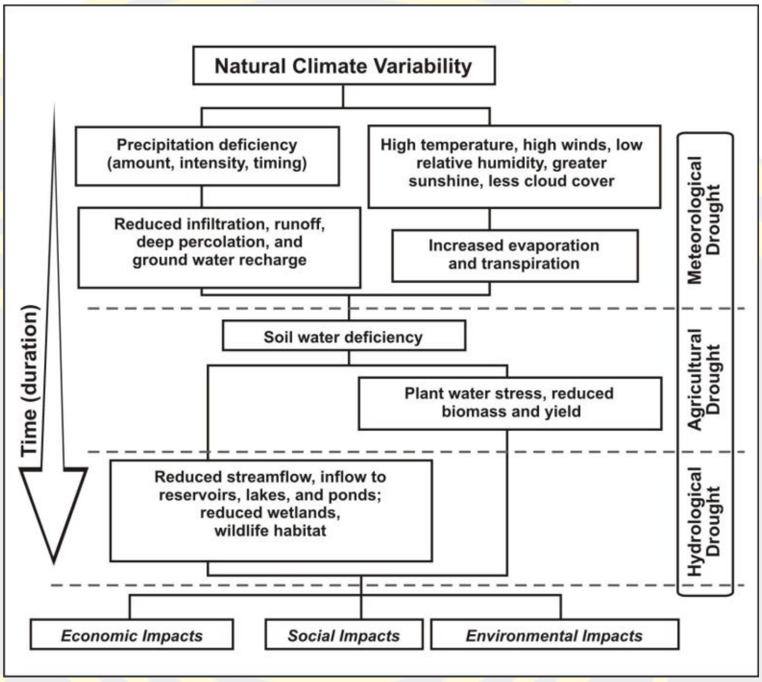


Figure 3 Series of drought categories
(Source: University of Nebraska Lincoln, (2009))

2.3.2 Drought in Thailand

The unquestionable fact correctly is that Thailand has been encountered drought every marked year. Most of the upper part of Thailand consistently receives below-average precipitation that causes the water's storage within major reservoirs to decrease unusually and abruptly, which contributes to the lack of surface water and groundwater depletion Furthermore, the development, and expansion of the population and urban communities in the countryside, resulting demand for water consumption, agriculture, and in various activities is a growing which still belongs to the problem of the country almost during the dry season every year (Department of Disaster Prevention and Mitigation (DDPM), 2011).

DDPM (Department of Disaster Prevention and Mitigation (DDPM), 2014) informed about the drought that often occurred due to no prolonged rain in the river basin, along with the expansion of community areas, agricultural areas both within and outside the irrigation zones, the development of agriculture, and the economy are causing the demand for fresh water during the dry season to continue to increase but while the capacity of water development projects such as large, medium, and small reservoirs or natural water sources by less rainfall in the upper north has also affected the amount of water in dams and reservoirs across the country. In addition, resulting rainfall is lower, affecting the river and groundwater potential in the long term that is insufficient for agriculture, consumption, and industry, and the situation of climate change has a serious impact on the environment. Certainly, there is an insufficient water supply for consumption and agriculture, especially non-irrigated water sources (Luedi, 2016) especially farmers in the agricultural faced short rainfall prolonged drought by less rainfall.

Most of the drought in Thailand is caused by inadequate seasonal and long-term rainfall, resulting in water shortages during the dry season, the rainfall is lower, affecting the river and groundwater potential in the long term that is the most often cyclical according to climate change. Over the past several decades, Thailand was faced severe problems and impacts from drought, especially in agriculture for decades. Historical data from 1967-1993, there was drought in many areas due to the rains in the middle of the rainy season for a longer period of time from July to September. The affected area is a wide area which is North to the whole central region, upper and west to the northeast, and upper south to the east coast (Thai Meteorological Department, 2007). During the years 1981-2014 (Hydro Informatics Institute (Public Organization), 2016), which includes less rainfall than the years in which Thailand experienced severe drought, such as 1994, 1999, 2005, 2010 and after that Thailand experienced a severe drought in large areas of the country that affected agriculture again in 2016. It was found that there was very little rain in the middle of the country in a wide area. Covering the North, Central, West, Northeast, and Upper South, this area has had low rainfall continuously from 2014 until 2016. Most drought period of Thailand occurs in 2 phases (Thai Meteorological Department, 2007): spatial changes very well. For example, studies by Shafiee, Ahmad, and Kadir (2000) studied the flooded areas in Peninsular, Malaysia. Using the satellite Radarsat image data to show the flood boundary for 6 time periods together with the water source boundary from Landsat satellite imagery together with various statistical data, that including the numerical height model The results showed a great up-down of flooding, as well as studies (Honda, Cannisius, and Prasad, 1997) which monitors the movement of floods occurring in the central region of Thailand by using data from JER-1 satellite, the SAR system can divide the image acquisition into 3 periods which are normal water phase, flooding period and the flooding period that spread more widely. The result is able to summarize the value of the damage of the flooded area to the property. To find that the data from satellite images is very useful in studying the flooded areas.

- During winter continues to summer Starting from the second half of October onwards in upper Thailand (North, Northeast, Central, and Eastern regions) rainfall decreases respectively until the rainy season is entered in mid-May of the following year. This drought occurs every year.

- In the middle of the rainy season, around the end of June to July, there will be some rain when it occurs. This type of drought occurs in local areas or sometimes covers a large area of the country.

Most of the drought-affected areas in Thailand have an impact on agriculture. It is a drought caused by a lack of rain during the rainy season and the drought occurs during June and July. The areas most affected by the drought were the northeast and central regions because the influence of the southwest monsoon able not to reach and in any year, there is no tropical cyclone passing in that line, it will cause more severe drought. In addition to these areas, there are also other areas that often suffer from drought and frequent rain (Thai Meteorological Department, 2007), as shown in Table 1.

2.4 Drought indicators and indices

The drought index correlates with factors influencing accumulated drought over a long period of time and with reduced humidity disorders. Niemeyer, 2008; Mishra and Singh, 2010 studied and classification of drought index which grouped similar drought indexes. It is divided into 6 groups as follows:

1) Meteorological drought indices such as Rainfall Anomaly Index (RAI), Drought Severity Index (DSI), Standardized Precipitation Index (SPI), Effective Drought Index (EDI), and Reconnaissance Drought Index (RDI), etc.

2) Comprehensive drought indices such as Palmer Drought Severity Index (PDSI), Palmer Modified Drought Index (PMDI), Keetch–Byram Drought Index (KBDI), Aggregate Drought Index (ADI), etc.

3) Agricultural drought indices such as Crop Moisture Index (CMI), Soil Moisture Drought Index (SMDI), Soil Moisture Deficit Index (SMDI, Evapotranspiration Deficit Index (ETDI), etc.

4) Hydrological drought indices such as Reclamation Drought Index (RDI), Surface Water Supply Index (SWSI), Palmer Hydrological Drought Index (PHDI), Regional Streamflow Deficiency Index (RDI), etc.

5) Remote sensing-based drought indices such as Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), The Normalized Difference Water Index (NDWI), Vegetation Health Index (VHI), The Enhanced Vegetation Index (EVI), Normalized Difference Drought Index (NDDI), etc.

6) Combined drought indices combine field data such as meteorological data or weather data with remote sensing data for drought measurement, namely Vegetation Drought Response Index (VegDRI) (Wardlow et al., 2012) as a new way of monitoring drought from vegetation, and it was introduced in the US (US National Drought Mitigation Center: NDMC)

Evaluation of the drought index based on meteorological and hydrological data has been in progress since 1965, with Palmer in 1965 (Palmer, 1965) developing the PDSI index as the first index, and more indices were developed up to the SPI. It was created by McKee and others, 1993, 1995 (World Meteorological Organization (WMO), 1987) and is the most widely used index. The remote sensing drought index found that the NDVI was a pre-developed index by Rouse and others, 1974 (Rouse, J. W., 1976) as an index used to characterize vegetation before it stopped its development. This index, due to the fact that no more new resource exploration satellites have not been developed until 1995 onwards, the drought index was developed using more remote sensing data as it has more developed resource satellites, especially NOAA and MODIS.

Table 1. The area experienced drought in each period.

Region / Month	Northern	Northeastern	Central	Eastern	Southern	
					East side	West side
January						Drought
February		Drought	Drought			Drought
March	Drought	Drought	Drought	Drought	Drought	Drought
April	Drought	Drought	Drought	Drought		Drought
May						Drought
June	Lack of Rain	Lack of Rain	Lack of Rain	Lack of Rain		
July	Lack of Rain	Lack of Rain	Lack of Rain	Lack of Rain		

Source: Thai Meteorological Department, 2007

2.4.1 Standardized drought Index

Standardized Precipitation Index (SPI), Mckee et al. (McKee et al., 1993) developed an SPI method to define and monitor climate drought conditions, which are now operated by different agencies. The index is widely used by the Colorado Climate Center, the Western Regional Center, and the National Drought Mitigation Center to track drought in the United States.

The nature of the SPI can analyze prolonged event drought conditions or analyze abnormal hydration conditions at the time of interest at any stage of any location where statistics are measured and precipitation recorded by looking at the cumulative rainfall in each period of interest, which can range from 1 month, 2 months, 3 months, up to 72 months. Precipitation is generally distributed in the form of a gamma distribution function (Gamma distribution), but since the study for the SPI index requires the total precipitation, it was determined using the cumulative probability density function of the total rainfall. Then transform (Transform) to standard Z, which will get the required SPI, and then form the intensity indicating the level of hydration and drought of the precipitation in each area.

The SPI drought index analysis can be calculated from the difference of the normalized seasonal precipitation of the observing stations and the long-term seasonal mean of all stations divided by the fraction. Standard deviation with the form of the equation as follows:

$$SPI = \frac{Xij - Xim}{\sigma} \tag{1}$$

Where Xij is the result of the monthly average rainfall measurement at the station, i as of the month (mm), Xim is the average monthly rainfall over the year (mm), and σ is standard deviation.

For Standardized Runoff Index (SRI) and Standardized Soil Moisture Index (SSI) indices which are widely used in many areas and are useful (Zhang et al., 2017) in the study for used to quantify hydrological and soil moisture droughts, respectively (McKee et al., 1993; Shukla & Wood, 2008, 2008; Hao et al., 2014; Chen et al., 2020). These drought indices were calculated by using a Gamma model which was as like SPI

2.4.2 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI), proposed by Kriegler et al. (1969), is proportional to the two wavelengths adjusted to the normal distribution, the near-infrared wavelength minus the wavelength. Red and divide by the sum of the near-infrared and visible wavelengths of red. NDVI is an indicator of biomass density.The larger the NDVI, the larger the vegetation density, the NDVI is between –1 and 1. (Bosworth et al., 1998). NDVI plant index (Kogan, 1995) analysis is shown in the following equation:

$$NDVI = \frac{\rho NIR - \rho Red}{\rho NIR + \rho Red} \tag{2}$$

Where ρ NIR is near infrared reflectance; ρ Red is red reflectance

2.4.3 Vegetation Condition Index (VCI)

Vegetation Condition Index (VCI) method is a color indication index. Vegetation conditions (Kogan, 1990, 1995), which are updated and developed from NDVI are an indicator of the status of vegetation to make the classification more accurate. Vegetative indices were proposed for examining dry areas where climate values were also required and the lowest to the highest monthly NDVI values from 1985-1990 were studied to compare the differences in each year, which 1988 had the lowest mean, so it was calculated for each image pixel point with the following equations:

$$VCI = \frac{\text{NDVI}-\text{NDVImin}}{\text{NDVImax}-\text{NDVImin}} \times 100 \quad (3)$$

The minimum of VCI value (less than 30 percentage) indicates the high severity of drought while more VCI value means the high healthy of vegetation. In the other word, high VCI value indicates less problem occurs of drought.

2.5 Research Review

The application of remote sensing for drought assessment is often a derivative analysis of Earth-observing satellite images that can reflect the drought conditions of an area, such as Normalized Difference Water Index (NDWI), Enhanced Vegetation Index (EVI), Vegetation Condition. Index (VCI), etc. This is because the different biological characteristics of the vegetation cover the area are related to the spatial and temporal patterns of drought. This is because the plants respond to the lack of water. Thailand is located in a region with distinct wet and dry seasons. The occurrence of drought in a particular year is normal. This can be observed from the fact that almost every region of the country is covered with deciduous forest. In addition, many indigenous crops that farmers choose to grow according to their accumulated wisdom reflect on the ability of plants to tolerate dehydration differently due to annual drought, so a drought assessment can be used. The appearance of the flora as measured by satellite observations is indicative. In addition, it was found that in many countries, remote sensing is used as a tool to assess drought. This can be found in research reports by Anyamba et al. (2001), Kogan (1993), Nicholson et al. (1994), Seiler et al. (2000), Son et al. (2012), and Wang et al. (2001), for example. These studies suggest that Satellite sensing technology is a good choice for tracking spatial and time-sensitive drought patterns.

This literature review has studied relevant research that provides a general research overview method and results of previous research and appears in Thailand. From a review of relevant documents and research, there are several studies. For example, the study by Yingxin et al. (2007), which assessed drought in the United States, has applied MODIS wave indices to analyze and assess spatial dryness. By using the NDVI and NDWI indices to create the NDDI index (where NDDI = (NDVI - NDWI) / (NDVI + NDWI)), it was found that during the dry period, the NDVI and NDWI values were lower than normal. And using the NDDI index to determine the dryness was better than using either NDVI or NDWI, a study by Jie Zhang et al. (2016) using ET and PET values from the MOD16 ET algorithm. / PET and NDVI from the MOD13 algorithm to create the Drought Severity Index and found that the method was able to provide the appropriate data for expressing regional spatial drought. A study by Sawaid et al. (2014) that used NDVI and LST values to assess drought in Yunnan, China, using these values as NVSWI indexes, found that the data-based drought assessment the above vegetation and temperature were consistent with the rainfall distribution situation from TRMM (TRMM Rainfall Data) satellite data, which can be used to assess agricultural drought or agricultural drought conditions.

Kassa, (1999) researched the risk area of drought in Sudan by the geographic information technology to observe the relation between the rainfall data and the Normalize Difference Vegetation Index – NDVI in 1982 and 1993

GISTDA (2000) studied and analyzed the drought in Northeastern part of Thailand by classifying the causes of drought. The specialists determined the factor and variables to analyze the drought in this area as rain shortage, soil's water absorption, irrigation area, groundwater volume and raining opportunities and land use. These factors used by weight ratio to generate the model to study the drought area based on Matrix Overlay theory which have been overlaid the data. That resulted the drought area in several terms.

K. Prathumchai, Kiyoshi Honda, and Khaew Nualchawee (2001) studied the risk area of drought in Lopburi by remote sensing, geographic information technology and Normalize Difference Vegetation Index – NDVI) from satellite data JERS-1 OPS in 1997 which was faced the heavy drought and 1999 as normal event. The physical meteorological data from the Ministry of Science Technology and environment was used to calculate as well.

Sompis Nithiyanun (2003) studied the drought analysis and the risk area in Nakhon Ratchasima (Sompis, 2003). This research studied the risk area of drought with rainfall volume, raining days, hydrology and agricultural factors. The information technology is a tool to analyze the area and overlay the data with the determination of risk area of drought.

Seesai Yeesunsaeng (2004) examined Application of information technology to study the drought area in Pitsanulok (Seesai, 2004). The study emphasized the environmental factors that caused the drought and used the primary and secondary data in spatial format and characteristics to generate the relative model. The database in the information technologies to be applied contains 15 factors with 4 parts; raining data, Groundwater and river basin, distance from the water resources, geography and soil. It has been analyzed by using 3 methods; 1) expertise method 2) statistics relationship 3) classification statistics. The method 2) and 3) based on the statistical analysis. These 3 methods resulted the mathematical equation to address the risk level of drought every 40x 40 m2. The risk level of drought classified to be 4 levels as no risk, low risk, intermediate risk and high risk which were completely corrected by interviewing

Kanlayanee Suwanprasert, (2005) researched Application of information technology to study the drought area in Thailand (Suwanprasert, 2005) and aimed to analyze the risk area of drought by suing GIS and Remote Sensing. It was compared the risk area from data analysis to field survey data. There are 3 main factors to be considered the risk area of drought; Meteorological, hydrological and physical properties including NDVI from MODIS. This study presented how to use the geographic information technology and proceed the information technology with relative humidity, rainfall volume, temperature, water resource density, wet land, irrigation, soil height, land use and NDVI from satellite data to be overlaid with weight ratio.

Weerasuk Udomchok and Poonsiri Choocheep (2005) determined the risk area of drought in eastern part of Thailand (Udomchok & Chuchuep, 2005). It was studied the factors caused the drought by analyzing the spatial relationship between several factors with the information technology to prepare the database, analysis and mapping. The factors to be considered by weight ratio are rain index, soil water's absorption, irrigation area, groundwater volume, average annual raining days and land use with the weight ration 3: 2.5: 2: 1.5: 1: 1 respectively. the study determined the risk area into 4 levels; no risk, low risk, intermediate risk and high risk

Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), southen part, (2006) studied to ascertain the area which is possibly considered to be the drought area in Satun by using the satellite technology and geographic information technology with weight ration and score based on physical priority to cause the drought as rainfall volume, raining days, distance from water resources, groundwater volume, water flowline's density in river basin, soil drainage, area inclination and land use. All factors from the satellite technology and geographic information technology are useful to classify the drought area and apply to be area's management tool (Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), 2006).

Wichai Pantanahiran, Nurut Koonphol and Sombut Tancharoen (2007) analyzed the risk area of drought in Rayong. by Normalized Difference Vegetation Index (NDVI), soil group, land use and water resource. These factors were overlaid in the geographic information technology and finally generate the model to indicate the risk area of drought.

Suraphan Asawajintajit (2008) exposed the acceptable and practical drought indices theologically in Yom river basin case study by using average method, decile method, Standardize Precipitation Index (SPI), Generalized Monsoon Index (GMI) and Average Seasonal Change Index (ASCI) (Asawajintajit, 2008). It was calculated the monthly raining change in the determined season compared to the change in the past. The result with higher than average was indicated as higher risk of drought. The monthly rainfall volume during 1975-2005 in 45 rain gauge stations in Yom river and neighborhood was mainly calculated. The annual rainfall volume and seasonal rainfall volume (November to April, September to December, September to November and June to September) were analyzed as well. Among the calculation methods compared to the drought report in 1997, 1998, 1999, 2002, 2003 and 2005 by Department of Disaster Prevention and Mitigation, average method, decile method and SPI are more appropriate to the annual rainfall data than seasonal rainfall data but given the spatial accuracy 37 percent, 35 percent and 34 percent respectively. While GMI method used the seasonal rain fall data during June to September provides the spatial accuracy 40 percent. Also, ASCI is properly applied to the seasonal rainfall data in last 4 months of raining season (September to December) which provides the most spatial accuracy up to 63 percent compared to other methods. However, only the rainfall volume is unable to indicate the drought in all events. Therefore, several factors should be determined to get the better accuracy e.g., number of raining days, number of raining delay days, water volume, water requirements in the area and the distance from the water resources etc.

Patanun Phothisan (2009) examined the agricultural drought indices in upper Mun river basin (Patanan, 2008). The Standard Precipitation Index (SPI) was calculated together with monthly rainfall volume from 27 rain gauged stations in upper Mun river basin and neighborhood during 1975-2005. From the SPI calculation by the annual and seasonal rainfall volume and cultivate season compared to the actual drought occurred, it found that the annual rainfall volume better indicated the drought than the seasonal rainfall volume (May to October) for Rice and dry crop with 72 percent special accuracy. Whereas, the rainfall volume only is not be able to indicate the agricultural indices in Irrigation area. Therefore, the raining days and raining duration which were implied to soil water absorption should be calculated as well.

CHAPTER 3
METHODOLOGY

This chapter is describing the detail of methods that were used different drought indices produced from satellite data and ground station data which the establishment of the relationship's drought indices between Standardized Precipitation Index, Soil Moisture Index, Runoff Index, and vegetation indices. The purpose includes data collection, data preparation, and data analyzed the Spatial-temporal distribution of drought patterns in the 30-years period (1991-2020) in Thailand. The methodological diagram of the framework in this study is shown in Figure 4

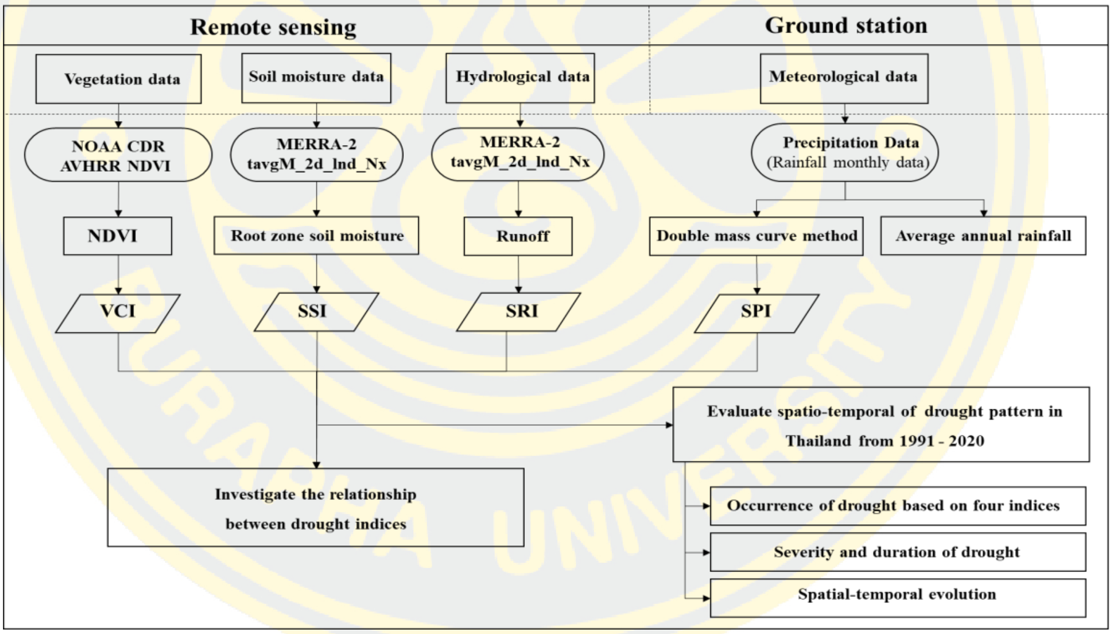


Figure 4 Methodological diagram of a framework in this study

3.1 Data Acquisition

Datasets analyzed the Spatial-temporal distribution of drought conditions in Thailand is shown in Table 2. The integration of remotely sensed data with ground station the period of 31-years from 1990 to 2020. Meteorological data for calculate SPI derived from precipitation 126 rain-gauge, soil moisture and hydrological derived from MERRA-2 tavgM_2d_lnd_Nx, and vegetation from NOAA CDR. Data analysis was conducted in Google Earth Engine and R studio. Spatial distributions were mapped in

ArcGIS 10.2 software. SPI would be able to identify the pattern of drought and flood through the index. Also, which could be used at monitoring and predicting drought by comparing between SSI, SRI, and NDVI.

Table 2. Dataset characteristics and source used in this study

Data sources	**Variables**	**Index**	**Spatial resolution**	**Temporal resolution**	**Period**	**Source**
Rain gauge stations	Precipatation	SPI	95 stations	Monthly	1991-2020	TMD
MERRA-2	Root zone soil moisture/ runoff	SSI/SRI	0.5°x0.625°	Monthly	1991-2020	NASA
AVHRR NDVI	Vegetation	NDVI, VCI	0.05°	Monthly	1991-2020	NOAA

3.2 Data preprocessing

3.2.1 Meteorological data from ground station

1) The average annual rainfall

The precipitation data in This study was used monthly rainfall data from rain gauge stations of the Thai Meteorological Department (TMD) over Thailand was shown in Figure 5. There are 95 rain gauge stations from 126 stations (showing station data in the appendix) which were complete data full 30 years from 1991-2020 for calculating SPI and monthly rainfall data of 95 stations used to analyze and generate the average annual rainfall contour map. This data used for consideration with the meteorological evaluation of drought level and vegetation evaluation of drought degree from satellite data.

2) Double mass curve method of average annual rainfall

The test of consistency of the rain data will be used to study to prove the reliability of the precipitation data before the rainfall data is used in the next analysis. Data validation using the double mass curve method (Searcy & Hardison, 1960), which is the annual precipitation at the rainfall station that to test the density of the precipitation data, although there is some discrepancy but not affect with the average rainfall from the rainfall data of stations surrounding the tested. Comparisons of the cumulative annual rainfall of each station were examined with the cumulative average annual rainfall of all stations located in the study area of 95 stations in the period 1991-2020.

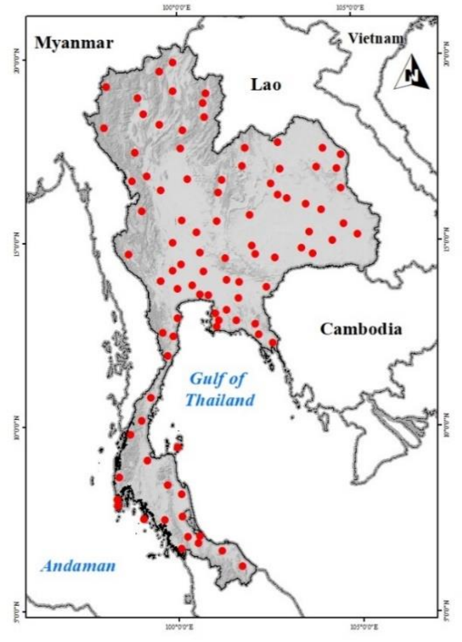


Figure 5 Distribution of Thai Meteorological Department rain gauge stations

3.2.2 Soil moisture data

For Standardized Soil Moisture Index (SSI) was calculated based on monthly mean root zone soil moisture derived from MERRA-2 tavgM_2d_lnd_Nx: 2d, service by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC) or GES DISC on the website https://disc.gsfc.nasa.gov/datasets/M2TMNXLND_5.12.4/ (Figure 6) (Global Modeling and Assimilation Office (GMAO), 2015), the file format was netCDF spatial resolution at 0.5 ° x 0.625 ° and the product was then resampled to 0.05° by ArcGIS and extract by mask to select the study area which was shown in Figure 7.

3.2.3 Hydrological data

For Standardized Runoff Index (SRI) was calculated based on monthly mean runoff derived from MERRA-2 tavgM_2d_lnd_Nx: 2d, service by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC) https://disc.gsfc.nasa.gov/datasets/M2TMNXLND_5.12.4/ (Figure 8) (Global Modeling and Assimilation Office (GMAO), 2015), the file format was netCDF spatial resolution at 0.5 ° x 0.625 ° and the product was then resampled to 0.05° by ArcGIS and extract by mask to select the study area which was shown in Figure 9.

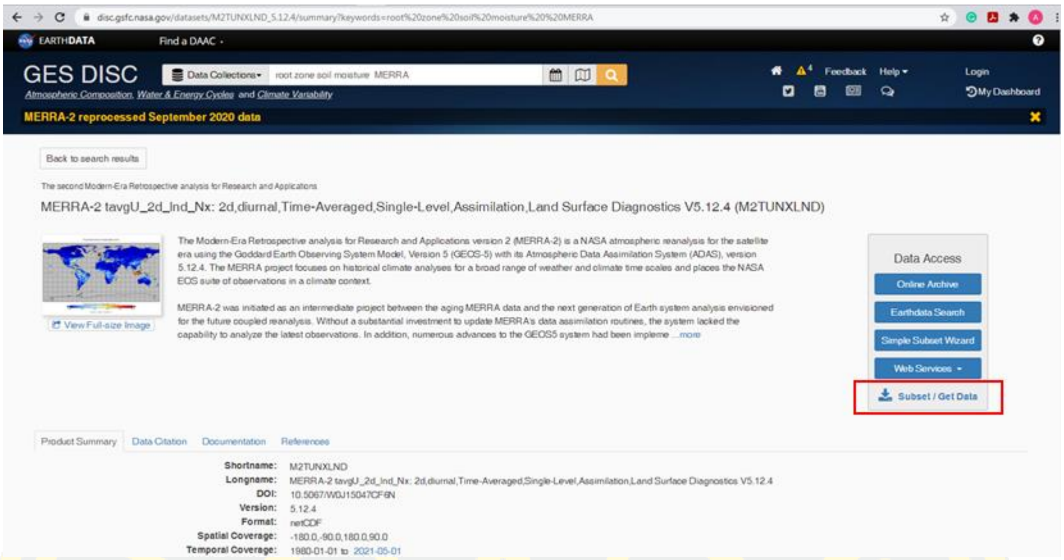
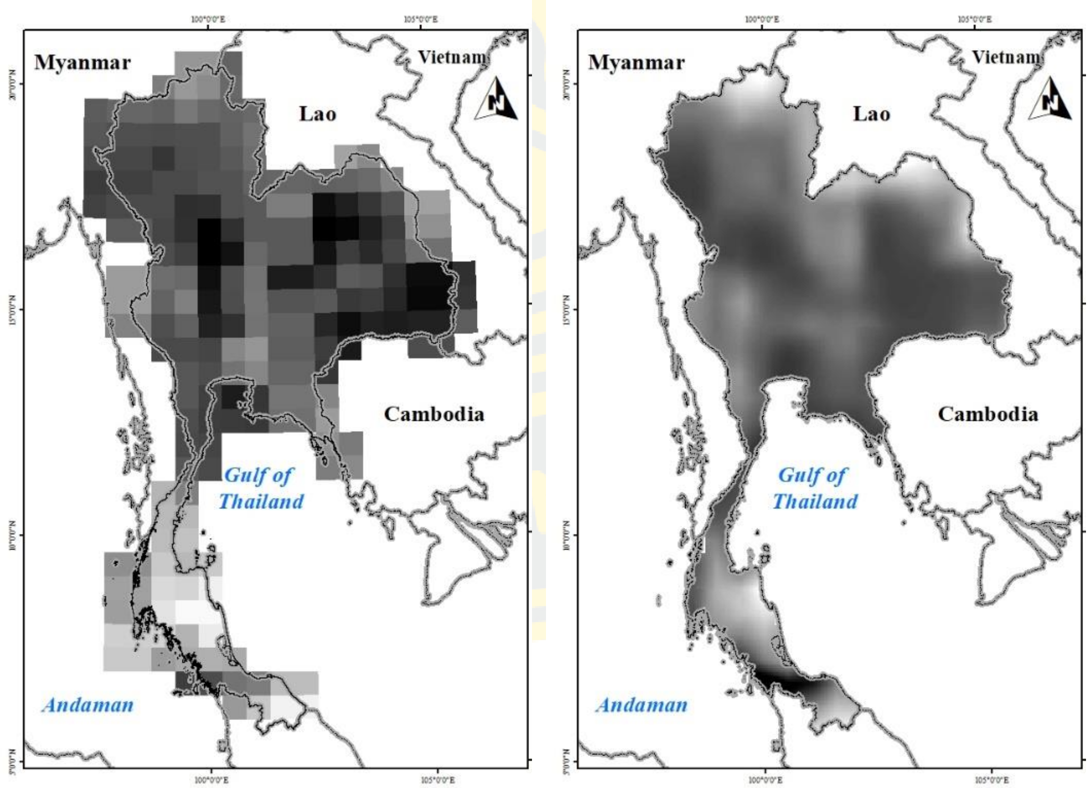


Figure 6 The GES DISC website for downloads root zone soil moisture data.



(a) spatial resolution at 0.5 ° x 0.625 °　　　(b) spatial resolution at 0.05°

Figure 7 Example of MERRA-2 Root zone soil moisture data in NetCDF format and the spatial resolution was resampled.

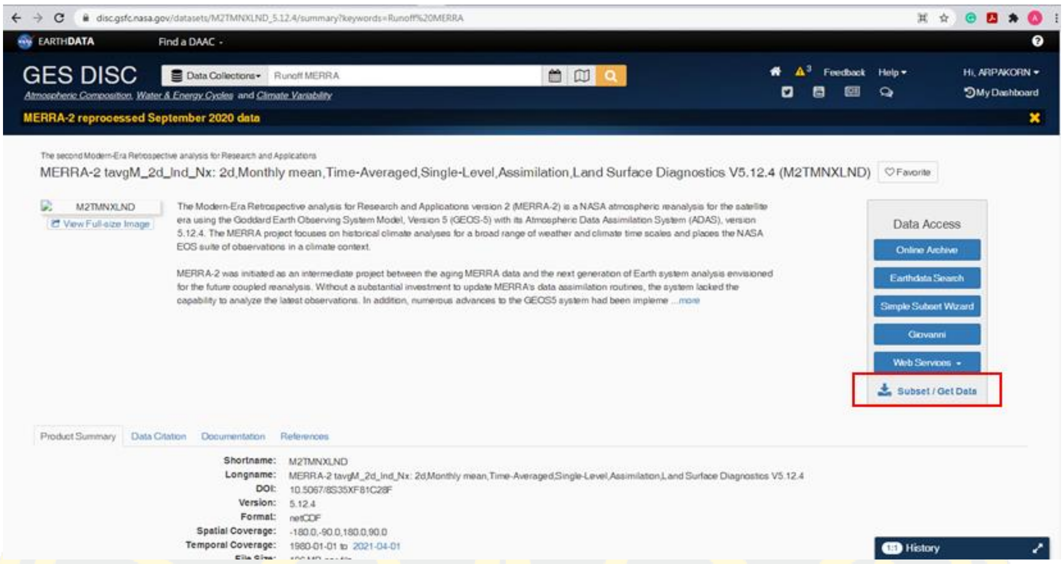
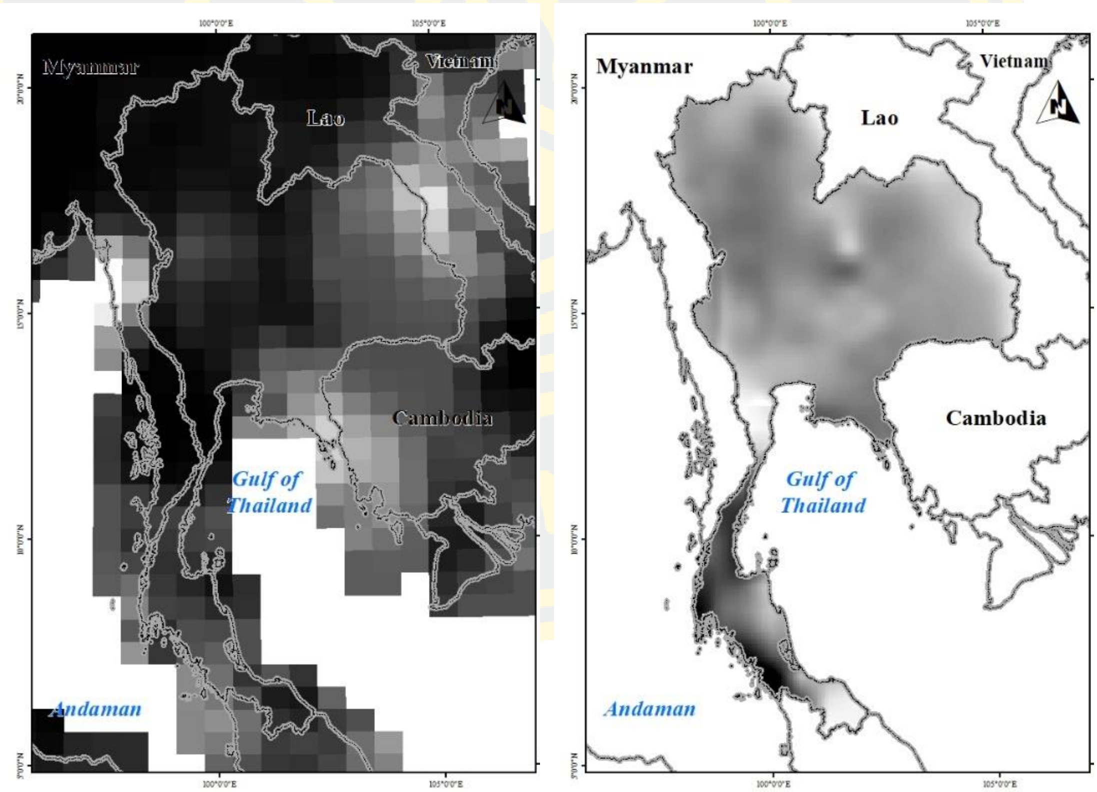


Figure 8 The GES DISC website for downloads Runoff data.



(a) spatial resolution at 0.5 ° x 0.625 °   (b) spatial resolution at 0.05°

Figure 9 Example of MERRA-2 Runoff data in NetCDF format and the spatial resolution was resampled.

3.2.4 Vegetation data

The NOAA Climate Data Record (CDR) of AVHRR Normalized Difference Vegetation Index (NDVI) (Vermote et al., 2014) contains gridded daily NDVI obtained from the NOAA AVHRR Surface Reflectance product (Eric et al., 2014). It provides a measurement of surface vegetation coverage activity with a resolution of 0.05° and computed globally over terrestrial surface. Collected satellite data for pre-processing of NDVI by download MODIS from GEE (Figure 10), which is a cloud-based data processing program capable of analyzing and processing large images on that platform, so it saving time in getting the data for image analysis and visualize datasets. In this study, satellite data is used data derived on a monthly was collected and downloaded NOAA CDR AVHRR NDVI data from https://earthengine.google.com for use in the analysis of vegetation indices covered Thailand from January 1991 until December 2020. For the processes of download, the file format obtain GeoTIFFs files were saved each file on Google Drive directly which was shown in Figure 11. The GEE steps and code samples for downloading the dataset are provided in the appendix (Google Earth Engine (GEE), 2021).

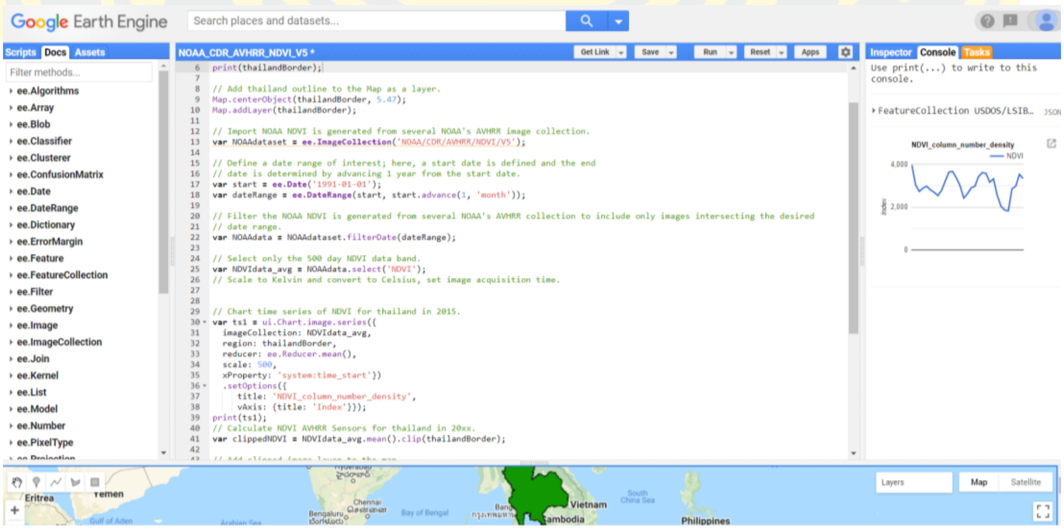


Figure 10 Google Earth Engine usage patterns Figure 9: Example of MERRA-2

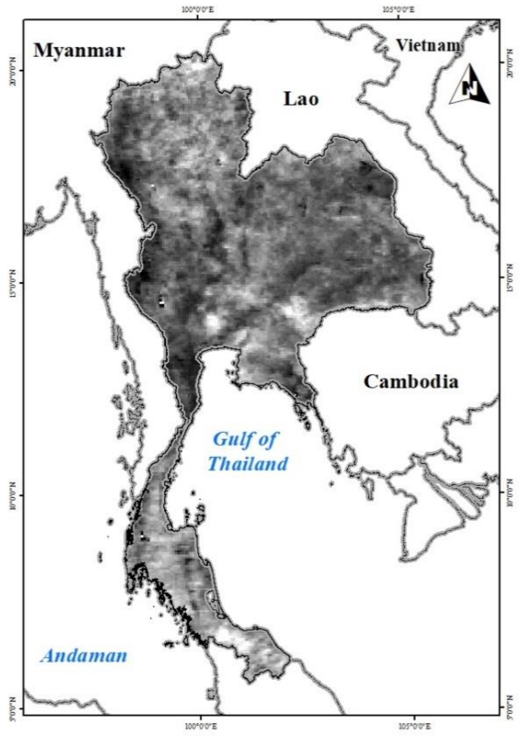


Figure 11 Example of data from the NOAA CDR AVHRR NDVI product

3.3 Calculation of drought indices

3.3.1 Standardized Precipitation Index (SPI)

There are three indices which the same calculated were Standardized Precipitation Index (SPI), Standardized Soil Moisture Index (SSI), and Standardized Runoff Index (SRI). By the analysis of SPI was calculated based on monthly rainfall data for the period of 30 years (1991-2020) from 95 rainfall stations. For computation of SRI and SSI were similar to SPI computation.

The SPI can be calculated in the monthly period of 3 months, 6 months, 9 months, 12 months, and 24 months or more this according to the study to focus on any time scales. To calculate the SPI from the monthly rainfall, bring the monthly rainfall data into the form of Microsoft Excel tables separated by each station and use a program called SPI_SL_6 This program is a program created and published by the United States National Drought Mitigation Center (National Drought Mitigation Center, 2018), available for download at the website https://drought.unl.edu/droughtmonitoring/SPI/SPIProgram.aspx and R studio software, available for download at the website https://www.rstudio.com/products/rstudio/download. The method was calculated from the difference of monthly average rainfall of observing stations and the monthly average rainfall of all stations divided by standard deviation, rainfall of all stations covered the study area with the form of equation (1).

Drought mapping based on SPI, this analysis defined SPI used ArcGIS to estimate the data cover the study area by ordinary interpolation technique (IDW) for mapping SPI of each station and classification of SPI according to McKee et al. (1993) as shown in Table 3 which was shown example of SPI monthly map in Figure 12 (a).

Table 3. Drought classification levels using SPI

SPI Value	Drought Category
≥ 2.00	Extremely wet
1.50 to –1.99	Very wet
1.00 to –1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.00 to −1.49	Moderately drought
−1.50 to −1.99	Severely drought
≤− 2.00	Extremely drought

3.3.2 Standardized Soil Moisture Index (SSI)

This study calculated SSI 1-month time scale because used for agricultural drought. After download root zone soil moisture data from MERRA-2 tavgM_2d_lnd_Nx: 2d, service by NASA, the file format was netCDF spatial resolution at 0.5 ° x 0.625 ° and the product was then resampled to 0.05° by ArcGIS and extract by mask to select the study area. Extract values to point from raster and export to CSV file for calculating SSI from mean root zone soil moisture data in R studio. After calculated SSI in R studio were processing CSV file to vector and rasterize (vector to raster) in QGIS were finalized SSI map which was shown example of SSI monthly map in Figure 12 (b) and the drought classification level of SSI according to SPI in Table 3.

3.3.3 Standardized Runoff Index (SRI)

This study calculated SRI 1-month time scale because used for hydrological drought. After download runoff data from MERRA-2 tavgM_2d_lnd_Nx: 2d, service by NASA, the file format was netCDF spatial resolution at 0.5 ° x 0.625 ° and the product was then resampled to 0.05° by ArcGIS and extract by mask to select the study area. Extract values to point from raster and export to CSV file for calculating SRI from runoff data in R studio. After calculated SRI in R studio were processing CSV file to vector and rasterize (vector to raster) in QGIS were finalized SRI map which was shown example of SRI monthly map in Figure 12 (c) and the drought classification level of SRI according to SPI in Table 3.

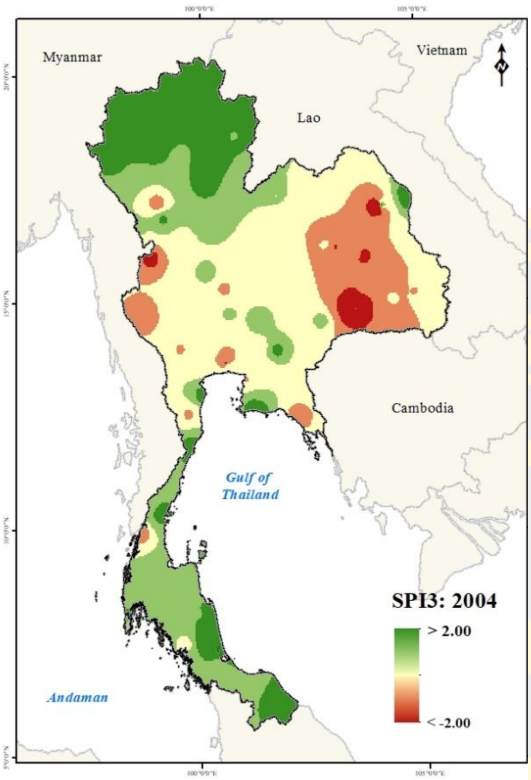
3.3.4 Analysis of the drought index of vegetation from satellite

Preparing index data from NOAA satellite remote sensing data used from the NOAA CDR AVHRR NDVI product is the NDVI Index data, which was chose this satellite data set because it is a data set that has been around for more than 30 years to date and widely used indicator for the determination of vegetation dynamics. The Vegetation Condition Index (VCI) is an NDVI developed index by Kogan (1990, 1995) that relies on the red wavelength to reflect chlorophyll characteristics of plants and near-infrared wavelengths to reflect the moisture characteristics in the structure of plants. Therefore, VCI be used as the drought index which provides the current status of vegetation by was used the deviation of each pixel from the historical NDVI values compared with the NDVI maximum and NDVI minimum, the following equation (3) The VCI value as a percentage is between ranges from 0 to 100. VCI value able to indicates drought condition, the value is below 35% represent severe drought condition, and the value above from 35 to 100% indicates the normal condition of vegetation. The classification of VCI value shown in Table 4. which calculated by the Model Builder function on the ArcGIS program. The VCI index shows how the vegetation changes over time with each pixel or indicates the variability of NDVI in the period of study was shown example of VCI monthly map in Figure 12 (d).

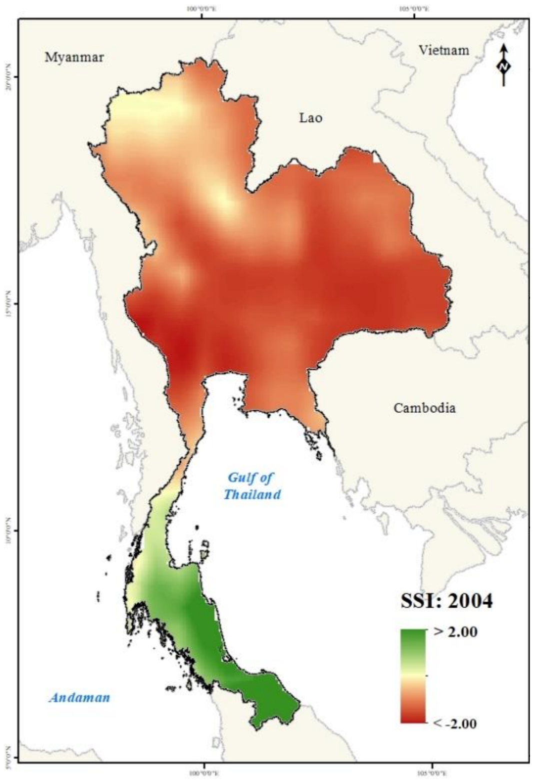
Table 4. Drought classification levels using VCI

VCI Percentage	Drought Severity Level
> 40	No drought
30 to 40	Low drought
20 to 30	Moderately drought
10 to 20	Severe drought
< 10	Extreme drought

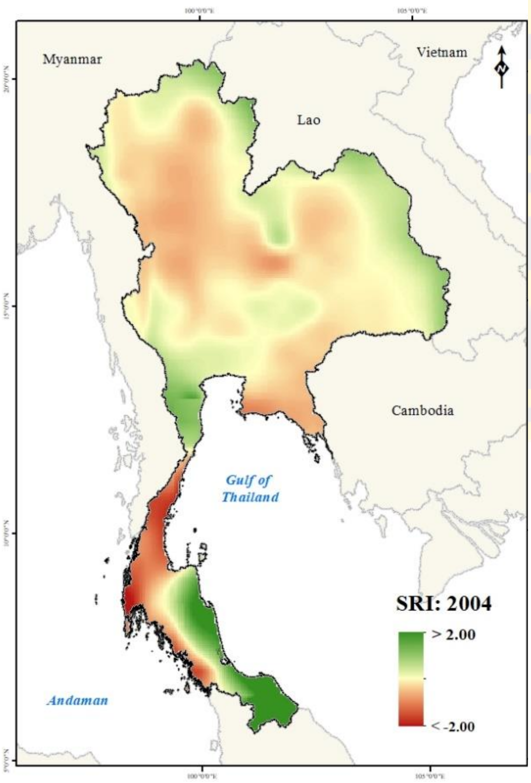
Source: Frans Persendt (2008). Drought Risk Assessment using RS & GIS: A case study of the Oshikoto region of Namibia. (Online). (Bhuiyan et al 2006; Mckee 1993 & Kogan (2009).)



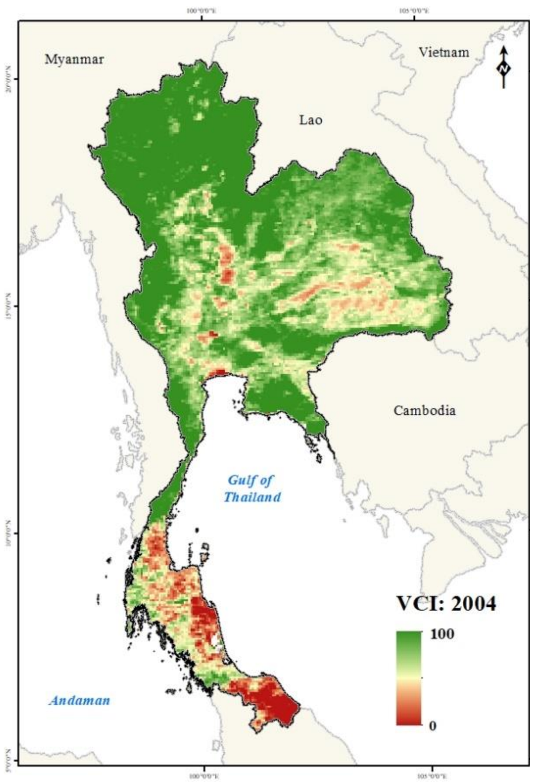
(a) SPI monthly map



(b) SSI monthly map



(c) SRI monthly map



(d) VCI monthly map

Figure 12 Example of four drought indices monthly map

3.4 Data analysis for spatio-temporal drought

3.4.1 Correlation of drought indices

Analysis of correlation from the meteorological index and vegetation index for correlation coefficient (r) from Pearson Correlation to comparison relationship of the drought index. The correlation analysis between the average value of SPI, SSI, SRI, and VCI.

3.4.2 Evaluation for spatio-temporal drought

In addition, the drought index analyzes have been mapped for details and to compare monthly drought conditions based on the area of SPI, SSI, SRI, and VCI to observe the percentage or comparison ratio of the area that has been drought from the classified values to represent drought, normal or moderate areas, and non-drought areas. For evaluation for spatio-temporal drought which are;

1) Occurrence of drought based on four indices

For spatial and temporal of drought based on indices uses five classifications from The National Drought Mitigation Center (The National Drought Mitigation Center, n.d.) such as abnormally dry (D0), showing areas that may be going into or are coming out of drought. D0 areas are not in drought but are experiencing abnormally dry conditions that could turn into drought or are recovering from drought but are not yet back to normal, and four levels of drought: moderate (D1), severe (D2), extreme (D3) and exceptional (D4). D1 is the least intense level and D4 the most intense. Drought is defined as a moisture deficit bad enough to have social, environmental, or economic effects. For determining the drought classification level for temporal and spatial drought analysis, determined in Table 5

Table 5. The Classification of spatial drought levels analysis

Spatial drought levels	**Category**	**SPI/SSI/SRI**	**VCI**
Near normal/No Drought	D0	More -1.00	More 40
Moderate Drought	D1	-1.0 to -1.2	30-40
Severe Drought	D2	-1.3 to -1.5	20-30
Extreme Drought	D3	-1.6 to -1.9	10-20
Exceptional Drought	D4	-2.0 or less	Less 10

2) Severity and duration of drought

The number of years with meteorological, hydrological, soil moisture, and vegetation drought (severity of D1 or higher) by extracting values to point from raster monthly during January 1991 to December 2020 and exporting to CSV file in QGIS were determined by analyzing the temporal and spatial extent of droughts for each month using four indices. Table 6 classifies the spatial extent or severity of drought, with two categories based on the National Drought Mitigation Center's drought classification for the classified spatial extent of drought and no drought. After assessing and counting the severity and duration of drought were processing CSV file to vector and rasterize (vector to raster) in QGIS were finalized severity and duration of the drought map. The data was ingesting into ArcGIS to generate a displayed map color layer.

Table 6. The Classification of spatial extent

Spatial drought levels	**SPI/SSI/SRI**	**VCI**
No Drought	More -1.00	More 40
Drought	-1.00 or less	40 or less

3) Spatial-temporal evolution

Monthly maps of SPI, SSI, SRI, and VCI were used to compare temporal and spatial characteristics in order to evaluate the spatial extent area of drought and the spatial percentage of four indices from drought severity classification 1991-2020.

CHAPTER 4
EXPERIMENTS AND RESULTS

This chapter reports the experiment and result of meteorology data and remote sensing data to evaluate the spatio-temporal of drought described in chapter 3 over Thailand. The results are the following.

4.1 Meteorological data analysis

Due to this precipitation data used as data from the ground station needs to prepare the data for the meteorological index calculation, which is compiled as follows:

1) Double mass curve method of average annual rainfall

The analysis showed that the 30-year rainfall data used in the study was reliable. It was determined by the relationship between the cumulative annual rainfall of the studied rain gauge stations and the cumulative annual rainfall from the nearby rain gauge stations of 95 stations with a straight line and a constant slope. The R2 from the graph has a value in the range 0.9982 - 0.9996, as shown in Figures 13 which shows an example result from the double mass curve method of average annual rainfall.

2) Precipitation data analysis

Precipitation data collected rainfall data, from 126 stations of the Thai Meteorological Department which were complete data full 30 years from 1991-2020. The total monthly rainfall data of 95 stations from January 1991 until December 2020 showed in Figure 14 (showing average rainfall of station data in the appendix). The average monthly rainfall was between 20 - 250 mm and the highest monthly average rainfall between May to October (180-250 mm). The average of 30-year annual precipitation from TMD (1991-2020) is more than 1,600 mm per year shown as Figure 15. and the average precipitation is in the range of 1,300-1,900 mm per year, with the highest average in 2017 at 1,995 mm. and the lowest mean value in 2004 at 1,329 mm. below the average over the last 30-years as shown in the map in Figure 16.

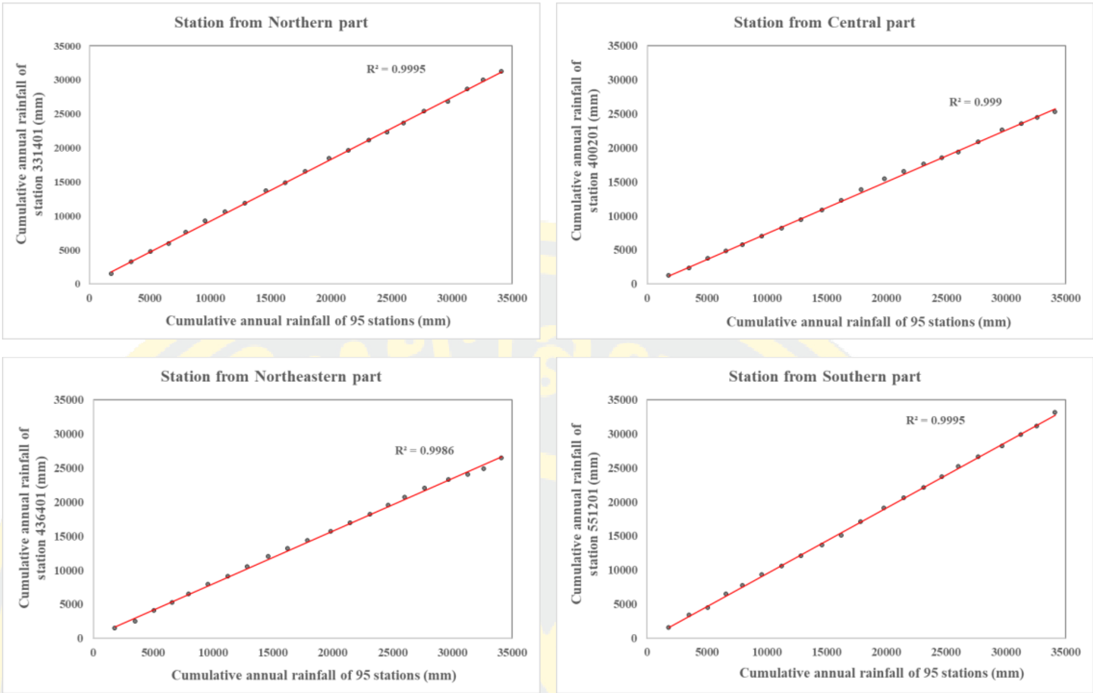


Figure 13 Double mass curve method of average annual rainfall at station.

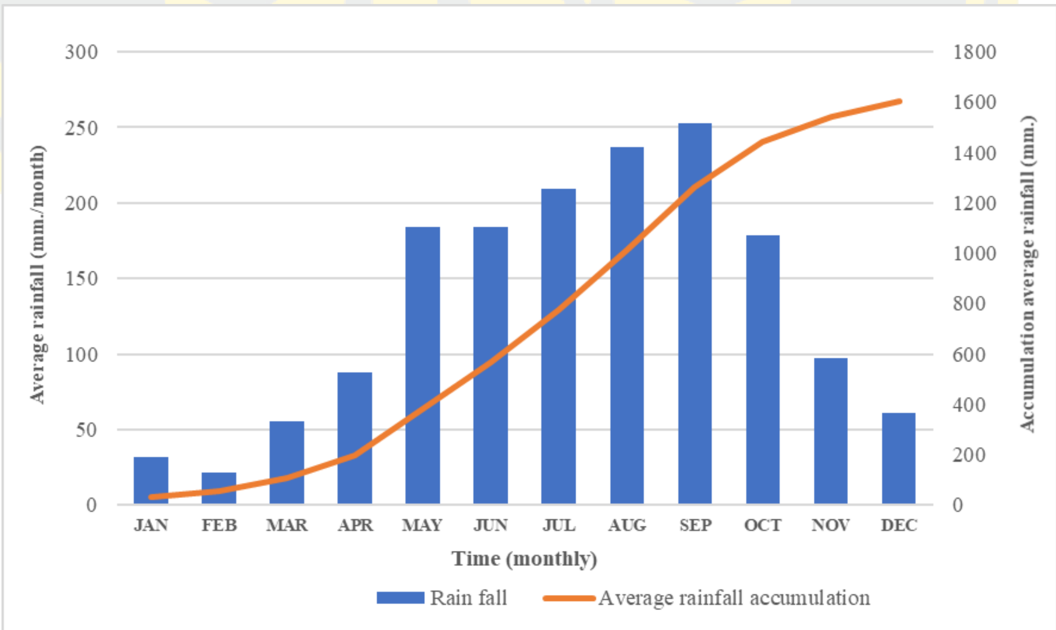


Figure 14 The average monthly rainfall from TMD (1991-2020).

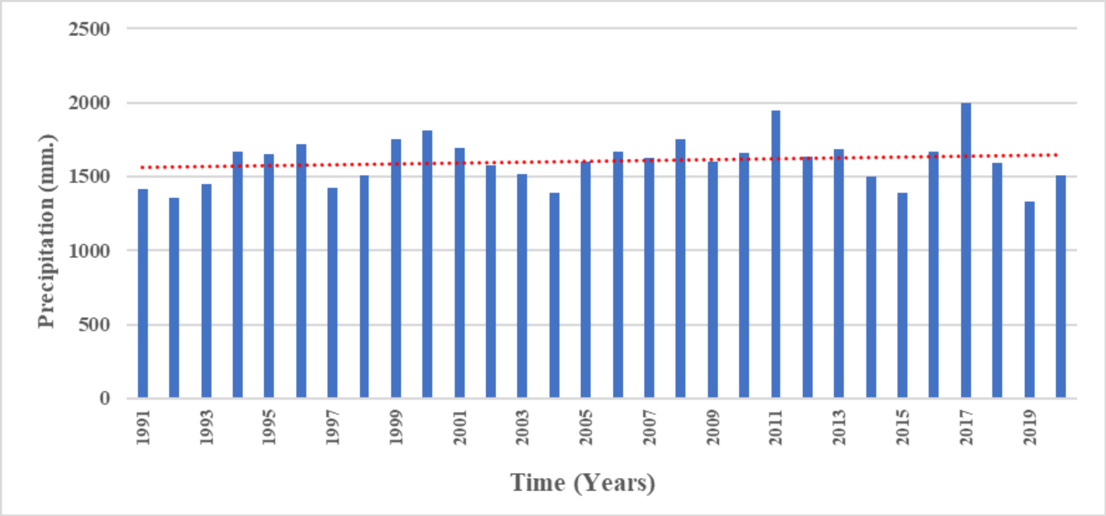


Figure 15 Average annual precipitation from TMD (1991-2020).

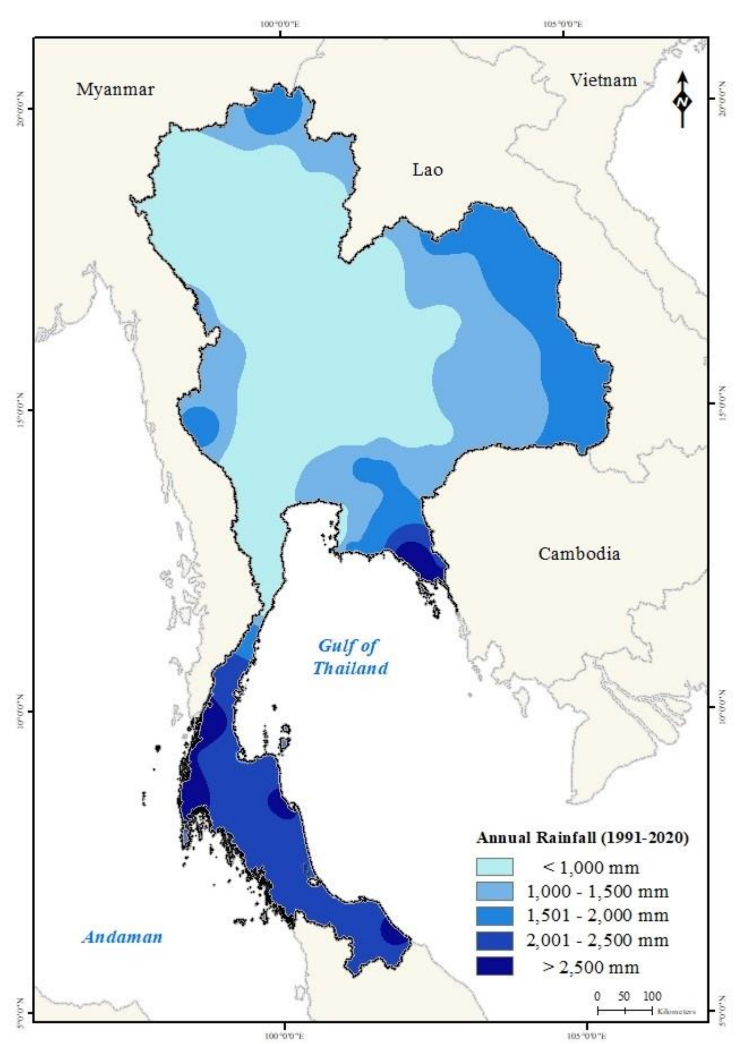


Figure 16 The average of 30-year annual precipitation map from TMD

4.2 Drought indices analysis

Analysis of retrospective 30 years droughts from drought indices during 1991–2020. In this study, historical droughts in Thailand used ground observed precipitation stations with remotely sensed data: runoff, soil moisture, and vegetation. The occurrence of droughts for different years was listed in Table 7 was shown the top drought year based on drought severity estimated using average drought indices value for every month in 1991–2020 from the sequence of SPI, SSI, SRI, and VCI. From the indices of the average values that high of the year in monthly found the top value of four indices October to December in 2004 and February 2005.

Table 7. The top average drought indices values from 1991-2020

Month	**SPI**		**SSI**		**SRI**		**VCI**	
	Year	**Values**	**Year**	**Values**	**Year**	**Values**	**Year**	**Values**
January	2005	-0.9(D1)	2005	-1.1(D1)	2020	-0.6(D0)	2020	30(D2)
February	2005	-0.9(D1)	2005	-1.3(D2)	2005	-0.6(D0)	2005	32(D1)
March	1992	-1.2(D1)	1998	-1.3(D2)	1992	-0.6(D0)	1994	16(D3)
April	2016	-1.5(D2)	2016	-1.4(D2)	1992	-0.6(D0)	1992	23(D2)
May	1992	-1.1(D1)	1992	-1.1(D1)	2015	-0.5(D0)	2001	21(D2)
June	2015	-1.0(D1)	2015	-0.8(D1)	2015	-0.4(D0)	1994	11(D3)
July	2015	-0.8(D1)	2015	-0.4(D0)	2002	-0.1(D0)	1997	4(D4)
August	2012	-0.5(D0)	1993	0.1(D0)	1993	0.1(D0)	1991	10(D3)
September	1992	-0.4(D0)	2015	0.6(D0)	2015	0.5(D0)	1996	25(D2)
October	2004	-0.9(D1)	2004	0.5(D0)	2004	-0.3(D0)	1992	35(D1)
November	2004	-1.1(D1)	2004	-0.2(D0)	2004	-0.5(D0)	2004	47(D1)
December	2004	-2.1(D4)	2004	-0.6(D0)	2004	-0.6(D0)	2004	45(D1)

4.2.1 Standard Precipitation Index (SPI)

The drought index SPI is the short-term drought index (Edwards and McKee, 1997; WMO, 2012), which represent continuous drought over period. As for the past 30 years of drought, there are varying degrees of severity. It was found that the years with the most drought were the years 1992, 2004, 2012, 2016, and 2020, for the drought caused by the SPI, the drought usually started from March to May and

November to December showed in Figure 11. The average monthly SPI value was between -2.21 to 1.26, the lowest in December 2004 was -2.21where the drought severity level, and the highest SPI in June 2000 was 1.12 moderate to extreme wet with the no drought severity level. The SPI values are positive (+), meaning that most areas have higher wet areas than normal at near normal to moderate precipitation. According to studies, there was a high SPI in the years 2000 and 2017, and the rainfall in that period was also much higher, which occurred between June and October.

4.2.2 Standardized Soil Moisture Index (SSI)

The analysis of SSI found that most of the values were related to precipitation during that time, similar to SPI, indicating dry and wet areas from soil moisture in the area, along with other indices to indicate the frequent drought of the area. The analyzable values are between -1.43 and 2.18 according to the analysis, there were droughts in 1992, 2004, 2016, and 2020, mostly during March to May and November to December, and positive SSI was most in 1995, 2011, 2017, and 2020 during June and October which similar to the SPI value (Figure 12).

4.2.3 Standardized Runoff Index (SRI)

From the analysis of the mean SRI, it was found that most of the values affected by precipitation during that time ranged from -0.66 to 4. However, when analyzing the monthly specifics, it was found that the value was less than -0.66 at some time, with the SRI representing the drought analysis of hydrological values, along with most other indices. It was high value during the rainy season between June and October, similar to earlier indices (Figure 13).

4.2.4 Vegetation Condition Index (VCI)

For VCI derived from NDVI the results of VCI, it was found that it can be analyzed in conjunction with the standardized indices referred above which vegetation conditions appeared in 2000 were the highest VCI at 89% and the lowest was 10% in 1997 (Figure 14).

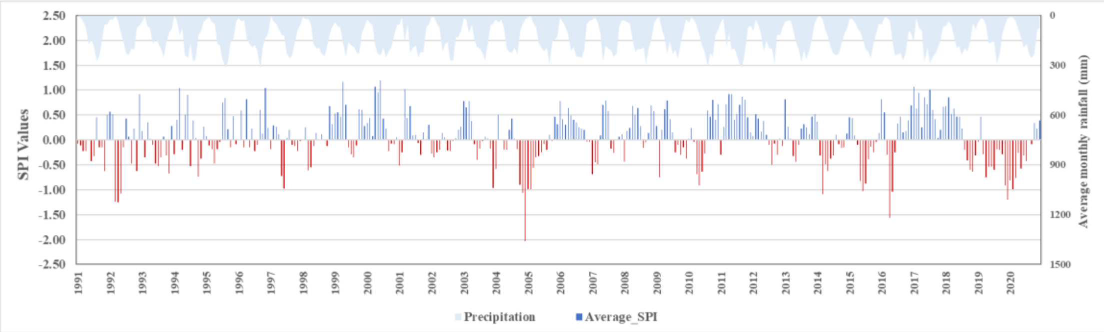


Figure 17 Average SPI (1991-2020).

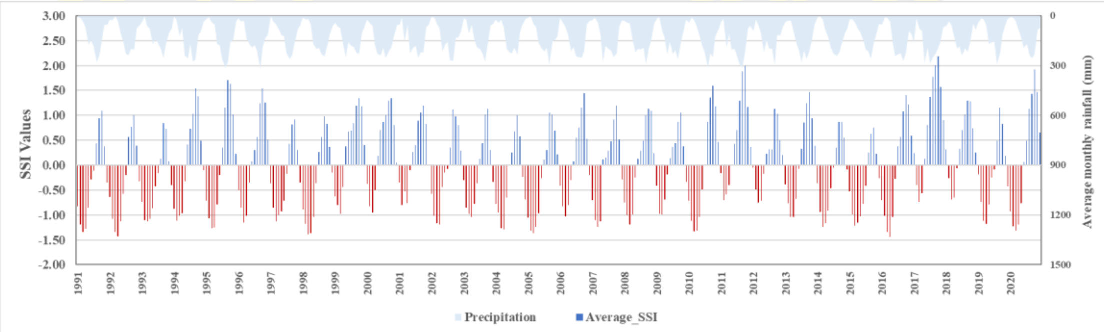


Figure 18 Average SSI (1991-2020).

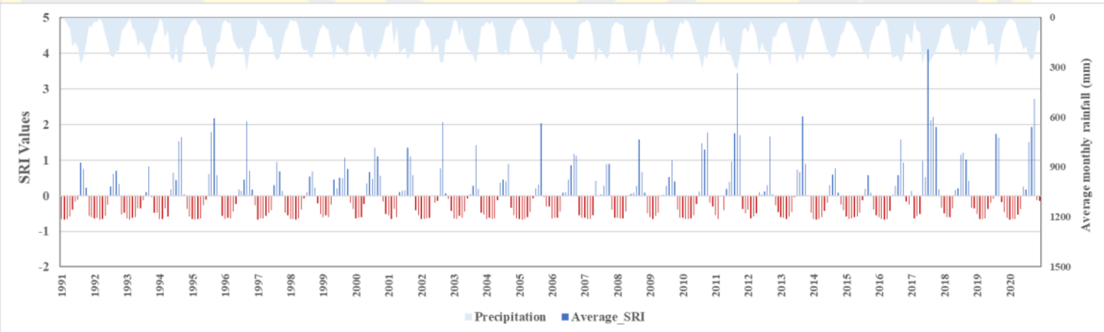


Figure 19 Average SRI (1991-2020).

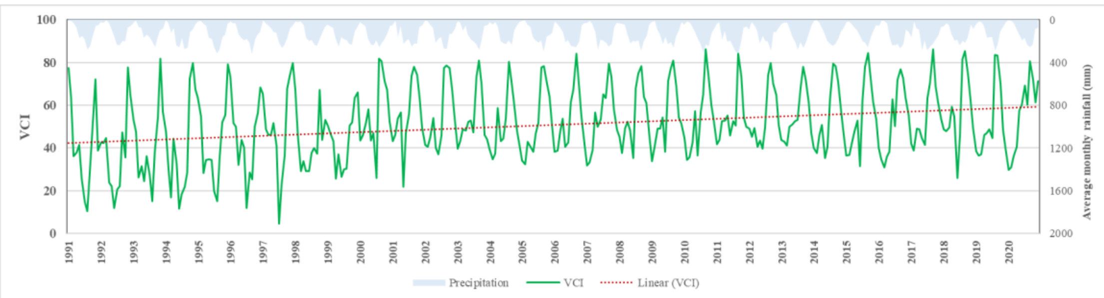


Figure 20 Average VCI (1991-2020).

4.3 Evaluation for spatio-temporal drought

4.3.1 Correlation of drought indices

The correlation analysis of drought indices is shown in Table 8. The correlation analysis between the average value of SPI, SSI, SRI, and VCI with 360 reference points. The results of the Pearson Correlation Coefficient between the average value variables four indices over a 30-year data period were found to be correlated well at SSI and SRI had a Pearson correlation of 0.776 and the significance of 0.000 means that there is a very positive correlation, using the correlation coefficient that r is closer to 1 and the significance is less than 0.05. Moderately correlated variables were SSI and VCI with a Pearson correlation of 0.492, the significance of 0.000, and SRI and VCI with a correlation coefficient (r) of 0.357 significant of 0.000. The least correlated variables were SPI with SSI, and SPI with SRI, with a correlation coefficient (r) of 0.239, 0.237, respectively, and a significant value of 0.000. For SPI and VCI have a correlation coefficient (r) of 0.0015, significant was greater than 0.05, meaning that both indices have a low correlation.

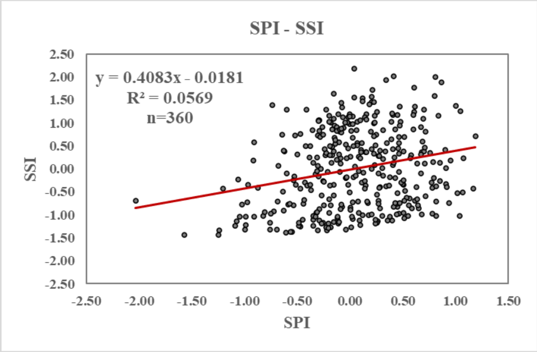
Pearson Correlation between four indices during 1991-2020 showed in Figure 15 that the relationship was related to the correlation and low correlation. Where SPI, SSI, and SRI are correlated similarly, but SPI and VCI were low correlation. Due to VCI used as the indicator of the status of vegetation variations during that drought time that could show a slower drought than other indices.

Table 8. correlation coefficient (r) of indices

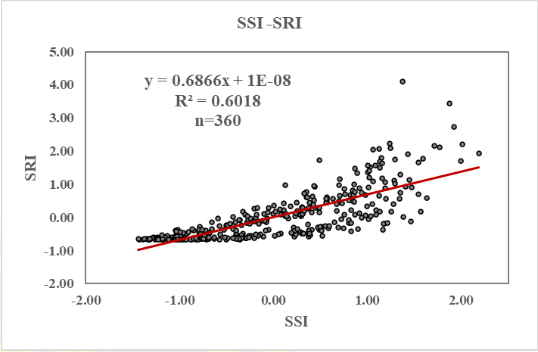
Index		SPI	SSI	SRI	VCI
SPI	Pearson correlation		0.239^{**}	0.227^{**}	0.015
	Significance (2-tailed)		(0.000)	(0.000)	0.781
SSI	Pearson correlation			0.776^{**}	0.492^{**}
	Significance (2-tailed)			(0.000)	(0.000)
SRI	Pearson correlation				0.357^{**}
	Significance (2-tailed)				0.000
VCI	Pearson correlation				
	Significance (2-tailed)				

* Correlation is significant at the 0.05 level (2-tailed).

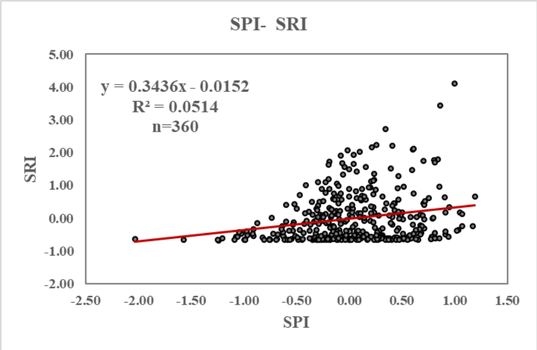
** Correlation is significant at the 0.01 level (2-tailed).



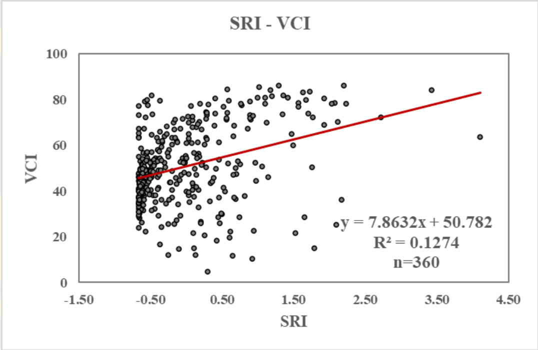
(a) SPI-SSI



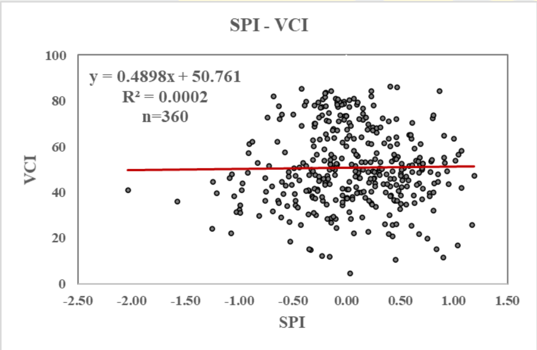
(b) SSI-SRI



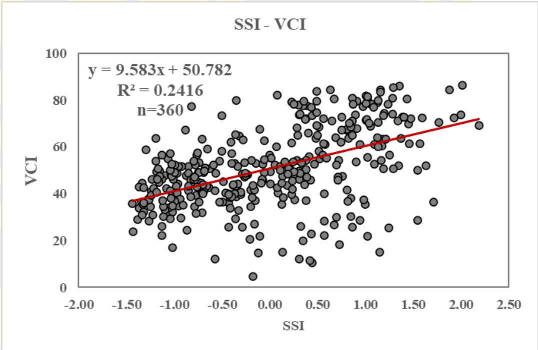
(c) SPI-SRI



(d) SRI-VCI



(e) SPI-VCI



(f) SSI-VCI

Figure 21 Relationship between average value monthly of four indices

4.3.2 Spatio-temporal of drought based on indices

1) Occurrence of drought based on four indices

From drought indices analysis found that the drought indices analyzed were mainly dependent on precipitation (Figure 16), the differences in dry and wetness were observed area that occurs at each time clearly the area that occurs at each time clearly.

For determining the drought classification level for temporal and spatial drought analysis, determined in Table 5, according to drought classification of the National Drought Mitigation Center where the Drought Monitor map identifies areas of drought and labels them by intensity. SPI, SSI, SRI corresponds to the increased rainfall reductions over different periods of time. VCI values cannot directly determine arid areas, as plants depend on a number of other factors. Therefore, when comparing the same period of drought to observe the temporal and spatial, as shown in Figure 17-19, to show the area during the same period of the drought map. There were 30 consecutive periods of intense droughts, which were 1992, 2004, and 2016, and on the contrary, it was possible to analyze flood areas, especially in 2017 due to storms and there have been heavy rains for a long time, causing Thailand to have some areas affected by the floods.

2) Severity and duration of drought

The spatial extent or severity is classified from Table 6 which was 2 classifications follow from drought classification of the National Drought Mitigation Center for the classified spatial extent of drought and no drought. The temporal and spatial extent of droughts for every month from four indices were analyzed found that the number of years with meteorological, hydrological, soil moisture, and vegetation drought (severity of D1 or higher) shown in Figure 20. It was found that almost all study areas experienced more than 1 times the average number of droughts during the 30-year period.

3) Spatial-temporal evolution

The spatial percentage of four indices from drought severity classification 1991-2020, the top drought year by spatial extent or severity is classified as shown in Table 9 and Figure 21. The most influential droughts occurred in 2004 and 2016 when at least four of the top droughts occurred with the maximum areal extent or highest severity. It is interesting in December 2004 and April 2016, the largest area of four indices as meteorological, soil moisture, hydrological, and vegetation drought. In terms of severity, meteorological and vegetation drought are usually more severe than soil moisture and hydrological. This difference is also valid in terms of spatial extent, the most severe meteorological droughts in the study area are mainly featured by local and impact, with averaged 58%. Vegetation drought impacts, with an average of 61%, soil moisture average of 34%, and the less impact was the hydrological average of 4%

On the other hand, it is interesting in 2000, 2011, and 2017 found the less spatial extent of the drought of the four indices. It can be assumed that in some areas, which appear no drought, there might be flooding in some areas, which requires additional data.

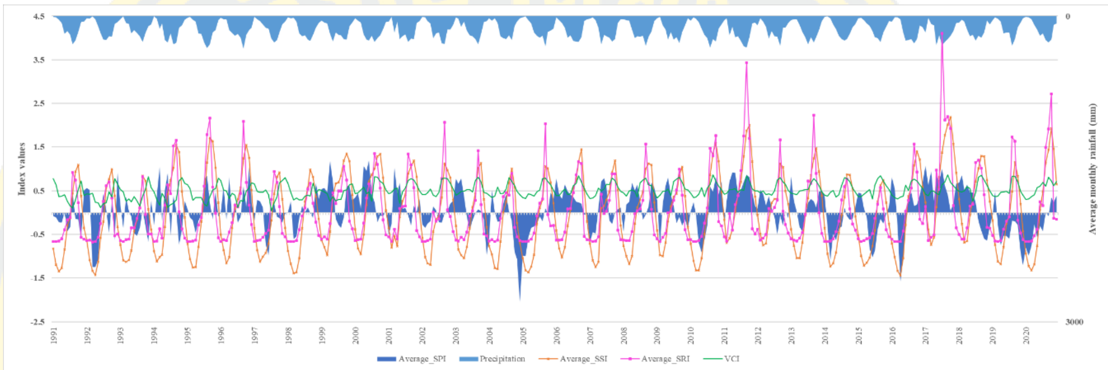


Figure 22 Time series of four drought indices (1991-2020)

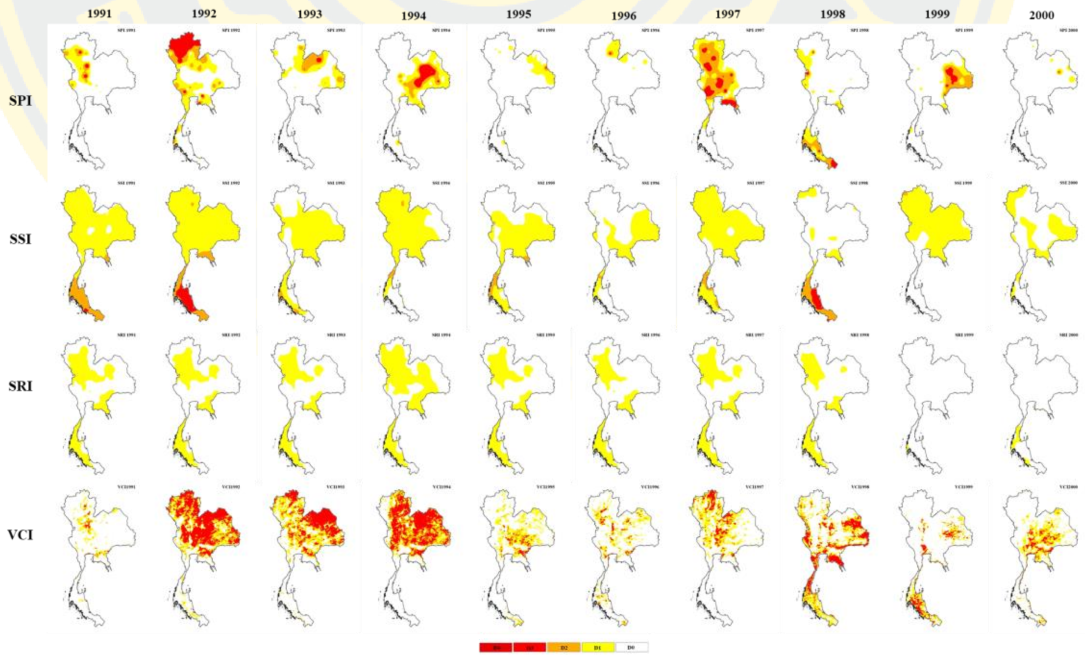


Figure 23 The spatial and temporal from the drought indices (1991-2000)

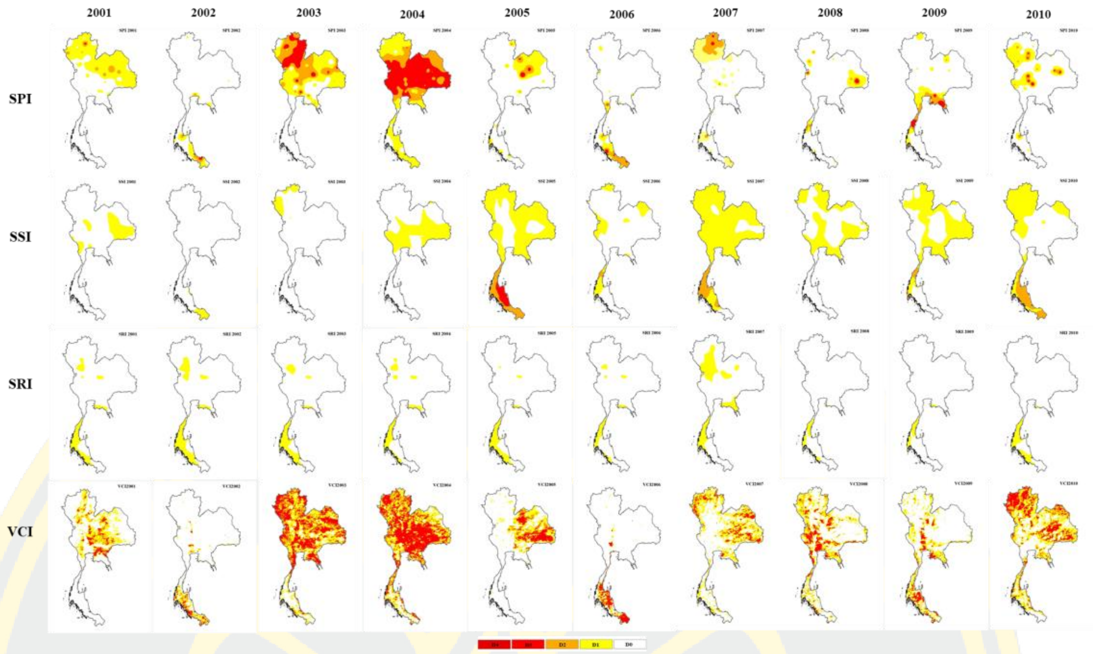


Figure 24 The spatial and temporal from the drought indices (2001-2010)

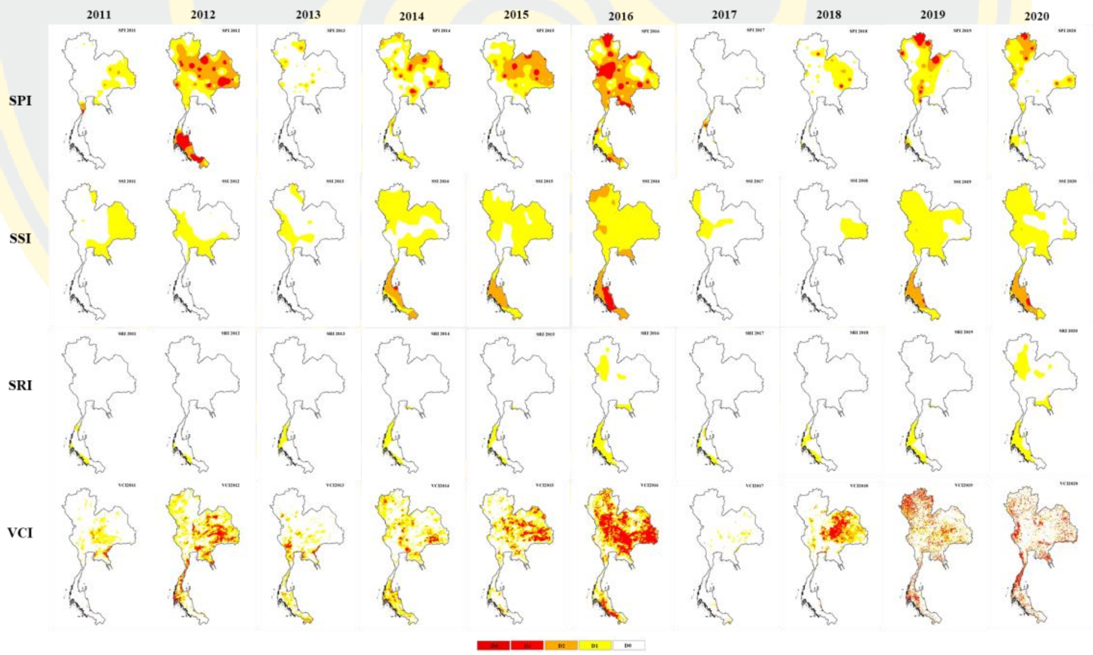
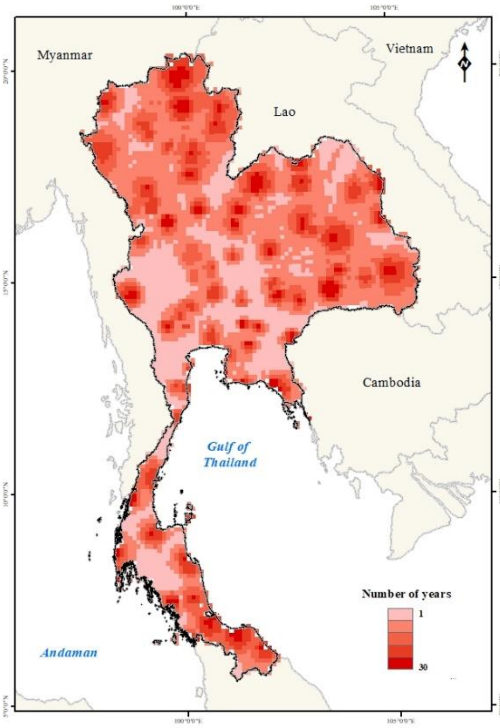
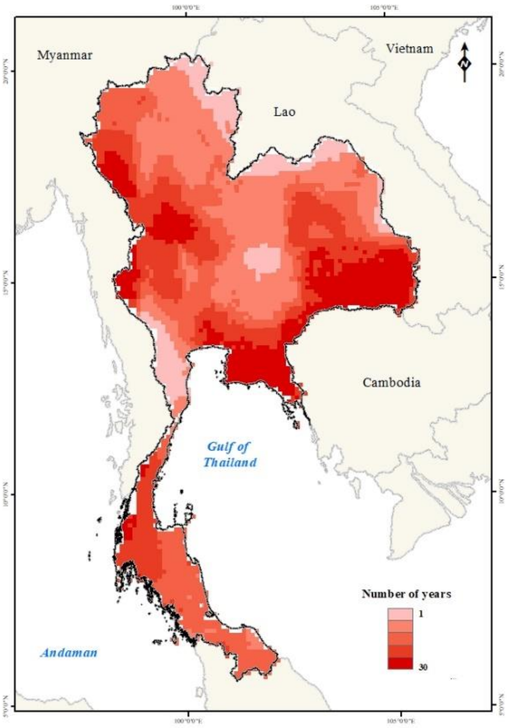


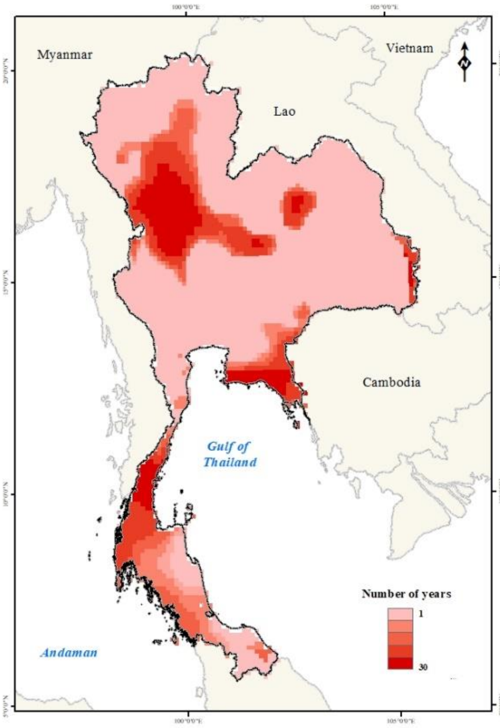
Figure 25 The spatial and temporal from the drought indices (2011-2020)



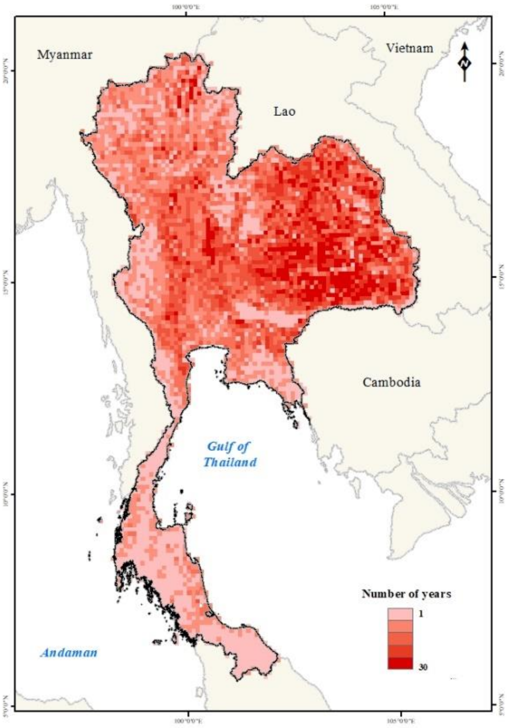
(a) SPI



(b) SSI



(c) SRI



(d) VCI

Figure 26 The number of years temporal and spatial extent of droughts

Table 9. The top spatial extent of drought (%) from 1991-2020

Month	**SPI**		**SSI**		**SRI**		**VCI**	
	Year	**Values**	**Year**	**Values**	**Year**	**Values**	**Year**	**Values**
January	2005	54.0	2005	61.9	2020	7.8	2020	51.5
February	2020	59.8	2020	75.0	2014	8.1	2020	63.5
March	1992	75.2	2010	79.0	1992	8.1	1994	59.8
April	2016	89.0	2016	72.5	2016	8.0	2016	61.4
May	2016	57.1	1992	59.3	1992	3.0	1992	67.6
June	2015	61.6	1992	14.2	2009	1.1	1992	76.4
July	2015	48.6	1992	7.4	2002	0.5	1992	79.5
August	1999	21.0	1992	2.7	1992	0.0	1992	77.5
September	1999	18.1	1992	3.0	1992	0.0	1994	63.8
October	2004	61.6	2002	0.2	1992	0.0	1992	55.9
November	2004	61.4	1998	2.9	2006	0.1	1998	38.8
December	2004	96.0	2004	34.8	2004	4.7	2004	42.1

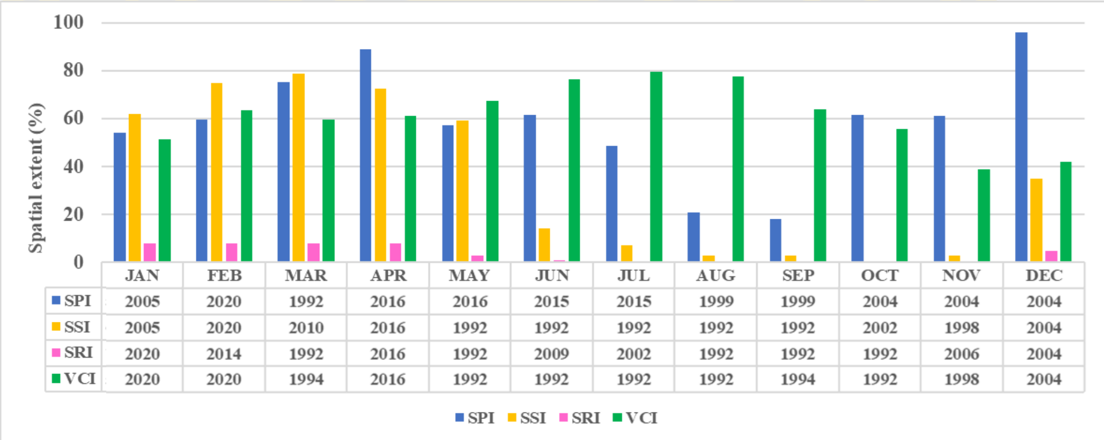


Figure 27 The top spatial extent of drought (%) from 1991-2020

4.4 Summary of experiments and results

From the study of the spatio-temporal dynamic pattern of drought in Thailand from 1991 to 2020, the region experienced multiple droughts, the largest of which occurred during the dry season or lack of rain for a long time between March and May and November and December. According to the analyses, the years 1992, 2004, 2012, 2016, and 2020 were the most drought-hit, whereas 1995, 1999, 2000, 2011, and 2017 were the most flood-affected.

Searching for information from reports from relevant drought and flood organizations in Thailand, it was observed carried out data on drought in Thailand from the Hydro-Informatics Institute (Public Organisation) (Hydro-Informatics Institute, 2021) that in 1992, 2004, 2005, 2009, 2010, 2012, 2013, 2014, 2015, 2016, 2019, and 2020. Concerning the dryness change in the last 30 years (DDPM, 2021), averaging five years every cycle, it was discovered that during the first 25 years from 1989-2013 the areas impacted with drought stabilized. In the last 7 years between 2014 to present the most severely in 2015-2016 was the El Niño in Thailand (Center for Disaster Knowledge Linking and Innovation Research, 2019), In 2017, the drought was quite small and in 2018 there was no drought data, a drought occurred but there were few drought data.

Data for Flood (DDPM,2021) Like the drought, changes over the previous 30 years have demonstrated that over the past 10 years floods have started to fall dramatically. During the first 20 years, between 10 and 1 encounters every year, to just 5 per year. However, the affected areas are no reduced because floods almost occur every year but not all areas are found only in some areas where monsoon winds blow more than frequent. The southern part of Thailand and northeastern part most frequently occur and some areas where were large rivers flowing through it. The area was the most affected by flooding, especially during 2009-2013 from flood statistics 1994, 1995, 2002, 2003, 2006, 2011, 2012, 2013, 2014, 2017, 2018, 2019, and 2020 (Hydro-Informatics Institute, 2021).

The information gathered was consistent in the same direction compared to the study results achieved. In order for some inaccuracies might have to be gathered and checked in various factors for future research to make the data more accurate.

CHAPTER 5
CONCLUSION AND FUTURE WORKS

5.1 Conclusion

The spatio-temporal dynamic of drought in Thailand, the study was conducted by analyzing four kinds of drought, including meteorological, soil moisture, hydrological, and vegetation drought were studied at the same time using occurrence, spatial-temporal evolution, severity, duration, and evolution from 1991 to 2020. The purpose of this study is to analyze and investigate various droughts that have a regional impact. The conclusions from this study are summarized as follows:

1) The evolution of spatio-temporal drought based on the drought indices analysis from the SPI index was discovered that the years with the most drought were 1992, 2004, 2012, 2016, and 2020. Droughts produced by the SPI usually started in March to May and November to December. Droughts were detected by SSI in 1992, 2004, 2016, and 2020, and SRI was similar to these indices. VCI was discovered to have a wide range of mean clearly separate areas of drought that occur with areas of each level when used in conjunction with the standardized indices referring to vegetation and moisture.

2) The relationship of four indices, including SPI, SSI, SRI, and VCI, from 1991 to 2020. SPI, SSI, and SRI are correlated similarly, but SPI and VCI indicating that both indices have a low correlation. This is due to VCI being used as an indicator of the status of vegetation variations during that drought time, which could show a slower drought than other indices when compared to SPI.

3) The study used four drought indices to investigate and analyze the spatio-temporal dynamics of drought in Thailand from 1991 to 2020. The general wetness and aridity of drought-prone locations can be easily detected. As a result, the year of dryness was 2004 and the year of wetness was 2017. The mean of each index was consistent with changes in rainfall at the time relationship, according to the results of the spatial and temporal analysis.

4) During the 30-year study period, almost the study area experienced more than 1 times the average amount of droughts. Droughts seemed to have the largest

impact between 2004 and 2016. The largest spatial extent area of the drought of four indices occurred between December 2004 and April 2016. On the other hand, the less spatial extent area of the drought among the four indices was identified in 2000, 2011, and 2017. There is a possibility that floods will occur in areas where there is no drought, but further information is needed. So, rainfall is the main factor that had a role in Thailand's drought and flooding.

In the future research should be considering correlation among both remote sensing data with the ground station data from the kinds of drought indicators that to provide more accurate data on drought in Thailand. As a result, indices obtained from satellite imagery are an alternative method that can be integrated with meteorological, soil moisture, hydrological, and vegetation data to evaluate and analyze temporal and spatial drought. The results analysis is simple and quick, and the results might well be applied to the next situation in real-time.

5.2 Discussions

The relationship between different indices such as meteorological, vegetation, soil moisture, and hydrological drought index was a different phase of factor which makes the correlation of the data difficult and diverse landscape in Thailand. For example, the northern part and the northeastern part have the highest mountain and plateau. Also, in the southern part is peninsular where was never given a good relationship on whatever was trying to matching because of the difference in the physical the landscape. The land surface model able to apply close to the total and in the summary of the result and the study area was divided for analysis into different regions of Thailand.

5.3 Data processing

1) Evaluation of drought with the indices derived from satellite imagery on the different land use and land cover in the area also occurs effect differences in drought. Therefore, for the validity of the drought assessment, the data of other factors that affect the drought occurrence should be integrated into the decision-making.

2) This study is an assessment of drought to lead to spatial management using satellite data which is a rough spatial detail or the large area. For higher-resolution data for this evaluation, satellite data or other free recorders may be used.

3) The accuracy of the drought data from the remote sensing should be assessed with other information such as field data, drought report data, community water shortages, or community environmental, socio-economic data.

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APPENDIX

APPENDIX A

The information of rain gauge stations data from the Thai Meteorology Department

No.	Latitude	Longitude	Station No.	Station Name	Data
1	19.3002	97.9727	300201	Mae Hong Son	Complete
2	18.1764	97.9307	300202	Mae Sariang, Mae Hong	Complete
3	19.9613	99.8813	303201	Chiang Rai	Complete
4	19.8727	99.7794	303301	Chiang Rai	Complete
5	19.1933	99.8838	310201	Phayao	Complete
6	19.9327	99.0453	327202	Doi Ang Khang, Chiang Mai	Not complete
7	18.8975	99.0156	327301	Mae Jo, Chiang Mai	Not complete
8	18.7713	98.9668	327501	Chiang Mai	Complete
9	18.2784	99.5066	328201	Lampang	Complete
10	17.6366	99.2448	328202	Thoen, Lampang	Not complete
11	18.3252	99.3016	328301	Lampang	Not complete
12	18.5666	99.0386	329201	Lamphun	Complete
13	18.1286	100.1623	330201	Phrae	Complete
14	18.7671	100.7635	331201	Nan	Complete
15	18.8637	100.7418	331301	Nan	Complete
16	19.1232	100.8131	331401	Tha Wang Pha, Nan	Complete
17	19.4083	100.8824	331402	Thung Chang District, Nan	Not complete
18	17.6245	100.0972	351201	Uttaradit	Complete
19	17.8651	102.7473	352201	Nong Khai	Complete
20	17.4531	101.7306	353201	Loei	Complete
21	17.4096	101.7297	353301	Loei	Complete
22	17.3785	102.8060	354201	Udon Thani	Complete
23	17.1563	104.1331	356201	Sakon Nakhon	Complete
24	17.1253	104.0566	356301	Sakon Nakhon	Complete
25	17.4121	104.7786	357201	Nakhon Phanom	Complete
26	17.2762	104.7691	357301	Nakhon Phanom	Complete
27	17.2261	102.4244	360201	Nong Bua Lam Phu	Not complete
28	17.1071	99.8003	373201	Sukhothai	Not complete
29	17.1614	99.8616	373301	Sri Samrong, Sukhothai Province	Not complete
30	16.8797	99.1403	376201	Tak	Complete
31	16.7027	98.5418	376202	Mae Sot, Tak	Complete
32	17.2439	99.0025	376203	Bhumibol Dam, Tak	Complete
33	16.7524	98.9356	376301	Doi Muser, Tak	Not complete
34	16.0255	98.8601	376401	Umphang, Tak	Complete
36	16.4347	101.1519	379201	Phitsanulok	Complete
37	16.7739	101.2453	379401	Lom Sak, Phetchabun	Complete
38	15.6572	101.1055	379402	Wichian Buri, Phetchabun	Complete
39	16.4867	99.5271	380201	Kamphaeng Phet	Complete
40	16.4622	102.7858	381201	Khon Kaen (Center)	Complete
41	16.3376	102.8230	381301	Tha Phra, Khon Kaen	Complete

The information of rain gauge stations data (cont).

No.	Latitude	Longitude	Station No.	Station Name	Data
42	16.5431	104.7252	383201	Mukdahan	Complete
43	16.3387	100.3670	386301	Phichit	Not complete
44	16.2468	103.0660	387401	Mahasarakham	Complete
45	16.3320	103.5875	388401	Kalasin	Not complete
46	15.6718	100.1302	400201	Nakhon Sawan	Complete
47	15.3497	100.5280	400301	Tak Fah, Nakhon Sawan	Complete
48	15.1578	100.1890	402301	Chainat	Complete
49	15.8071	102.0242	403201	Chaiyaphum	Complete
50	16.0534	103.6607	405201	Roi Et	Complete
51	16.0748	103.6048	405301	Roi Et	Complete
52	15.2455	104.8711	407301	Ubon Ratchathani	Complete
53	15.2408	105.0195	407501	Ubon Ratchathani (Center)	Complete
54	15.0869	104.3269	409301	Sisaket	Complete
55	15.3540	100.0096	410201	Uthai Thani	Not complete
56	14.5348	100.7229	415301	Ayutthaya	Not complete
57	14.4128	101.3844	417201	Nakhon Nayok	Not complete
58	14.1162	100.6185	419301	Pathum Thani	Not complete
59	13.5674	101.4527	423301	Chachoengsao	Complete
60	14.0114	99.9678	424301	Ratchaburi	Not complete
61	14.4750	100.0888	425201	Suphanburi	Complete
62	14.3019	99.8571	425301	U Thong, Suphanburi	Complete
63	14.7999	100.6262	426201	Lopburi	Complete
64	15.2666	101.1852	426401	Bua Chum, Lopburi	Not complete
65	13.6674	100.6031	429201	Pilot, Samut Prakan	Complete
66	13.5169	100.7591	429301	Samut Prakan	Not complete
67	13.6864	100.7653	429601	Suvarnabhumi Airport	Not complete
68	14.0509	101.3672	430201	Prachinburi	Complete
69	13.9860	101.7024	430401	Kabinburi, Prachinburi	Complete
70	14.9699	102.0803	431201	Nakhon Ratchasima	Complete
71	14.6437	101.3159	431301	Pak Chong, Nakhon Ratchasima	Complete
72	14.7396	102.1623	431401	Chokchai, Nakhon Ratchasima	Complete
73	14.8758	103.4939	432201	Surin	Complete
74	14.8926	103.4466	432301	Surin	Complete
75	15.3178	103.6767	432401	Tha Tum, Surin	Complete
76	15.2273	103.2422	436201	Buriram	Not complete
77	14.6326	102.7156	436401	Nang Rong, Buriram	Complete
78	13.4078	100.0321	438201	Samut Songkhram	Not complete
79	13.6888	102.5019	440201	Aranyaprathet, Sa Kaeo	Complete
80	13.7919	102.0300	440401	Sa Kaeo	Not complete
81	14.0224	99.5337	450201	Kanchanaburi	Complete
82	14.7445	98.6311	450401	Thong Pha Phum, Kanchanaburi	Complete
83	14.0117	99.9700	451301	Nakhon Pathom	Complete

The information of rain gauge stations data (cont).

No.	Latitude	Longitude	Station No.	Station Name	Data
84	13.7246	100.5611	455201	Bangkok	Complete
85	13.7238	100.5655	455203	Bangkok, Klong Toey Port	Not complete
86	13.6644	100.6078	455301	Bangkok Bangna	Complete
87	13.9127	100.5936	455601	Don Muang Airport Bangkok	Complete
88	13.3556	100.9800	459201	Chonburi	Complete
89	13.1626	100.8004	459202	Koh Sichang, Chonburi	Complete
90	12.9234	100.8633	459203	Pattaya, Chonburi	Complete
91	12.7003	100.9810	459204	Sattahip, Chonburi	Not complete
92	13.0780	100.8717	459205	Laem Chabang, Chonburi	Not complete
93	12.9994	100.0584	465201	Phetchaburi	Complete
94	12.6337	101.3386	478201	Rayong	Complete
95	12.7349	101.1332	478301	Huay Pong, Rayong	Complete
96	12.6097	102.1018	480201	Chanthaburi	Complete
97	12.5105	102.1677	480301	Pliw, Chanthaburi	Complete
98	11.8351	99.8082	500201	Prachuap Khiri Khan	Complete
99	12.5779	99.9518	500202	Hua Hin, Prachuap Khiri Khan	Complete
100	12.5890	99.7323	500301	Nong Phlap Sok, Prachuap	Complete
101	11.7803	102.8759	501201	Trat, Trat Province	Complete
102	10.4988	99.1863	517201	Chumphon	Complete
103	10.3307	99.0906	517301	Saweesok, Chumphon	Complete
104	9.9526	98.6346	532201	Ranong	Complete
105	9.1343	99.1499	551201	Suratthani	Complete
106	9.4387	100.0227	551203	Koh Samui, Surat Thani	Complete
107	9.1428	99.6341	551301	Surat Thani	Not complete
108	8.5702	99.2561	551401	Phrasaeng, Surat Thani	Not complete
109	8.5463	99.9374	552201	Nakhon Si Thammarat	Complete
110	8.3593	100.0573	552301	Nakhon Si Thammarat	Complete
111	8.4247	99.5044	552401	Chawang, Nakhon Si Thammarat	Not complete
112	7.6139	100.1156	560301	Phatthalung	Complete
113	8.6822	98.2530	561201	Takua Pa, Phang Nga	Complete
114	7.8824	98.3930	564201	Phuket	Complete
115	8.1027	98.3087	564202	Phuket (Center)	Complete
116	7.5427	99.0473	566201	Koh Lanta, Krabi	Complete
117	8.1017	98.9762	566202	Krabi	Not complete
118	7.5102	99.6217	567201	Trang	Complete
119	7.0156	100.4997	568301	Khor Hong, Songkhla	Complete
120	6.7873	100.4106	568401	Sadao, Songkhla	Not complete
121	7.1847	100.6024	568501	Songkhla	Complete
122	7.0361	100.4739	568502	Hat Yai, Songkhla	Complete
123	6.6538	100.0810	570201	Satun	Complete
124	6.7900	101.1449	580201	Pattani District	Complete
125	6.5155	101.2714	581301	Yala	Not complete
126	6.4269	101.8230	583201	Narathiwat	Complete

APPENDIX B

The average monthly rainfall

No.	Station No.	Month (mm)											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	300201	15	5	17	56	175	176	232	250	198	132	33	11
2	300202	8	2	23	38	158	192	207	221	176	135	26	8
3	303201	22	11	37	100	250	193	316	345	288	129	40	22
4	303301	21	14	38	88	227	178	290	327	268	116	43	19
5	310201	17	7	35	83	189	100	140	209	190	127	40	14
6	327501	14	6	21	54	175	138	157	221	227	137	46	14
7	328201	20	9	28	71	199	110	133	208	206	120	18	10
8	329201	11	3	15	62	189	132	132	205	220	117	38	8
9	330201	17	10	32	84	186	149	190	248	191	79	29	9
10	331201	18	6	33	101	190	148	213	283	208	64	13	12
11	331301	15	6	36	97	177	145	220	296	189	61	13	12
12	331401	19	7	32	98	189	190	278	333	223	73	20	17
13	351201	12	8	25	71	205	197	192	271	239	106	13	8
14	352201	12	18	46	77	247	241	310	360	271	97	20	8
15	353201	9	16	35	96	188	151	165	214	247	113	18	12
16	353301	9	21	43	107	173	157	153	211	247	121	18	8
17	354201	6	18	41	72	207	214	229	298	233	107	15	6
18	356201	7	26	58	99	237	253	351	321	243	69	14	4
19	356301	8	27	61	98	233	203	289	319	216	75	20	3
20	357201	4	18	59	111	259	365	559	538	288	86	10	3
21	357301	6	23	48	76	219	297	468	418	246	74	8	3
22	376201	13	5	25	65	175	135	119	104	245	200	26	6
23	376202	10	3	28	44	158	277	374	341	217	95	16	6
24	376203	11	3	37	58	205	146	92	123	217	191	27	9
25	376401	10	10	64	110	190	212	262	258	262	143	21	9
26	378201	8	17	27	57	157	180	183	227	279	129	33	12
27	379201	13	17	51	76	173	157	158	203	216	89	15	6
28	379401	8	15	42	56	130	138	140	183	196	95	12	7
29	379402	16	8	51	99	130	163	181	224	237	120	20	8
30	380201	6	13	37	62	187	171	168	178	268	167	23	8
31	381201	8	16	35	103	159	154	189	225	248	101	25	3
32	381301	8	13	39	92	179	137	180	198	238	114	24	5
33	383201	2	17	46	61	207	201	313	324	229	88	13	3
34	387401	9	13	42	93	194	142	208	270	253	100	17	2
35	400201	8	16	31	60	153	150	151	185	243	166	20	8
36	400301	12	16	38	73	148	144	148	190	269	159	32	6
37	402301	3	7	23	55	128	122	136	139	240	140	22	6
38	403201	12	7	45	89	145	123	140	211	266	112	14	6

The average monthly rainfall (cont).

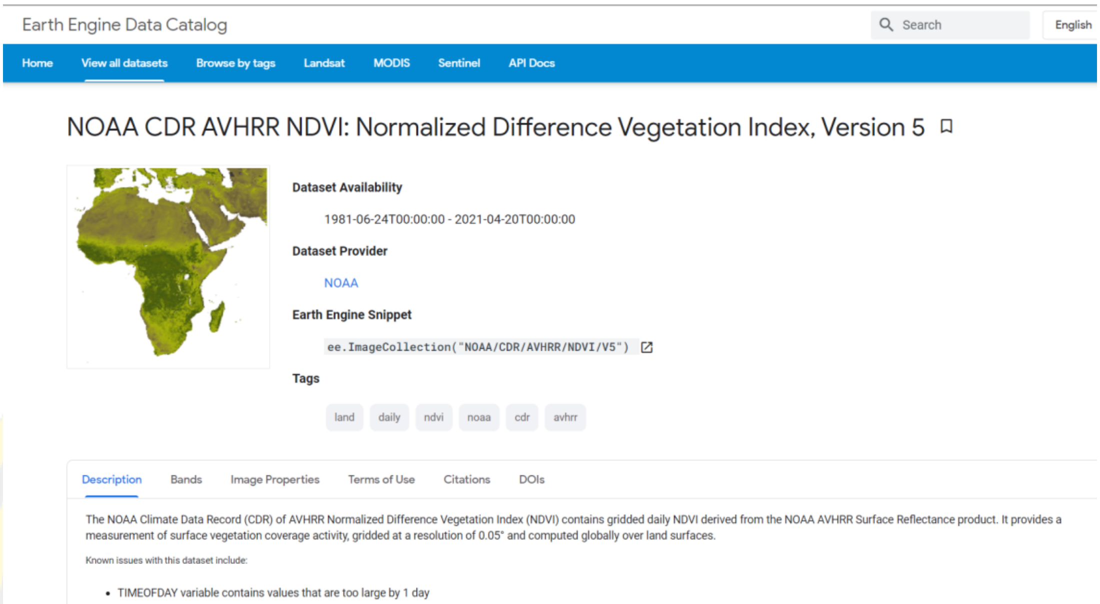
No.	Station No.	Month (mm)											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
40	405301	7	14	47	86	183	173	207	300	249	105	17	2
41	407301	2	9	26	68	206	220	285	291	305	112	19	5
42	407501	3	6	33	90	216	216	313	318	344	112	20	6
43	409301	3	8	22	74	215	184	260	268	277	125	16	3
44	423301	20	28	90	128	182	153	185	165	290	163	32	6
45	425201	6	3	29	49	118	91	109	125	195	186	43	8
46	425301	8	9	32	45	118	96	93	102	199	179	31	9
47	426201	10	11	42	79	125	122	121	147	264	133	28	9
48	429201	16	18	31	59	116	125	106	106	219	177	34	9
49	430201	10	26	43	95	182	200	269	294	353	152	23	3
50	430401	17	24	50	118	153	210	295	253	318	167	29	5
51	431201	9	12	50	78	147	140	169	176	248	145	20	3
52	431301	19	25	62	111	161	115	114	154	248	150	22	16
53	431401	12	16	36	78	141	110	120	145	202	169	25	3
54	432201	8	9	48	82	195	172	235	274	291	108	25	4
55	432301	8	7	43	76	203	186	243	270	271	112	29	2
56	432401	11	13	37	80	169	164	213	242	257	120	20	2
57	436401	6	11	38	92	170	128	170	190	258	142	35	5
58	440201	12	24	51	105	143	169	173	189	242	174	36	6
59	450201	10	24	47	69	139	113	104	94	215	187	46	6
60	450401	8	15	56	93	201	244	315	328	263	154	19	5
61	451301	5	10	37	40	127	127	89	109	213	201	44	10
62	455201	29	23	60	95	213	216	203	208	329	302	50	15
63	455301	36	19	58	103	189	206	183	210	315	240	58	13
64	455601	20	12	60	102	211	212	170	182	303	198	28	15
65	459201	22	17	59	87	151	144	166	164	253	188	45	8
66	459202	27	21	49	66	128	136	110	128	211	187	45	9
67	459203	19	25	54	75	113	135	95	97	193	206	58	11
68	465201	21	5	54	46	102	80	94	93	143	280	69	12
69	478201	32	30	69	81	193	179	167	138	261	182	37	8
70	478301	43	47	79	109	177	185	159	125	254	291	56	16
71	480201	36	31	86	134	388	496	517	413	436	280	74	15
72	480301	38	36	99	162	428	554	576	430	585	329	78	19
73	500201	51	22	87	72	129	134	183	123	143	210	134	28
74	500202	31	11	55	56	116	89	81	72	126	228	82	33
75	500301	33	8	55	55	143	114	90	90	148	253	68	22
76	501201	55	81	146	191	419	736	979	864	772	369	100	49
77	517201	107	50	120	96	190	164	197	187	172	253	252	196
78	517301	119	54	118	98	187	153	181	180	175	250	338	208

The average monthly rainfall (cont).

No.	Station No.	Month (mm)											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
79	532201	58	20	75	144	541	611	645	741	596	419	124	83
80	551201	77	18	89	78	154	136	140	122	156	193	261	166
81	551203	139	53	141	96	131	127	113	77	117	250	453	303
82	552201	308	65	169	115	156	142	129	150	172	279	656	502
83	552301	277	51	139	143	164	137	113	134	159	302	591	455
84	560301	209	55	119	117	116	101	82	98	118	245	536	463
85	561201	69	45	150	223	467	475	435	521	620	501	185	81
86	564201	61	20	92	131	243	273	229	289	345	346	176	89
87	564202	76	33	130	150	284	351	236	359	405	375	197	98
88	566201	41	24	73	117	239	304	270	299	307	295	153	94
89	567201	83	25	99	129	217	205	253	234	249	248	214	145
90	568301	139	36	86	102	186	125	100	155	161	277	484	360
91	568501	155	49	78	91	106	110	94	124	129	294	585	464
92	568502	104	29	82	130	136	122	94	126	153	241	334	252
93	570201	55	39	146	186	222	182	217	267	303	331	243	137
94	580201	124	29	60	91	146	114	136	117	136	228	404	377
95	583201	237	61	138	89	145	144	125	162	195	273	573	637
Average		38	20	59	91	190	189	214	234	253	180	97	61

APPENDIX C

Example code of Google Earth Engine.



Explore in Earth Engine: NOAA CDR AVHRR NDVI: Normalized Difference Vegetation Index, Version 5

Dataset Availability: 1981-06-24T00:00:00 - 2021-04-20T00:00:00

Dataset Provider: NOAA;

https://www.ncdc.noaa.gov/cdr/terrestrial/normalized-difference-vegetation-index

```
var dataset = ee.ImageCollection('NOAA/CDR/AVHRR/NDVI/V5')
                  .filter(ee.Filter.date('2018-05-01', '2018-06-01'));
var ndvi = dataset.select('NDVI');
var ndviVis = {
  min: -1000.0,
  max: 5000.0,
  palette: [
    'ffffff', 'ce7e45', 'fcd163', 'c6ca02', '22cc04', '99b718', '207401',
    '012e01'
  ],
};
Map.setCenter(7.71, 17.93, 2);
Map.addLayer(ndvi, ndviVis, 'NDVI');
```

Explore in Earth Engine for this study

```
var dataset = ee.FeatureCollection('USDOS/LSIB_SIMPLE/2017');
var thailandBorder = dataset.filter(ee.Filter.eq('country_na', 'Thailand'));
print(thailandBorder);
// Add thailand outline to the Map as a layer.
Map.centerObject(thailandBorder, 5.47);
Map.addLayer(thailandBorder);
// Import NOAA NDVI is generated from several NOAA's AVHRR image collection.
var NOAAdataset = ee.ImageCollection('NOAA/CDR/AVHRR/NDVI/V5');
// Define a date range of interest; here, a start date is defined and the end
// date is determined by advancing 1 year from the start date.
var start = ee.Date('1991-01-01');
var dateRange = ee.DateRange(start, start.advance(1, 'month'));
// Filter the NOAA NDVI is generated from several NOAA's AVHRR collection to include only images intersecting the desired
// date range.
var NOAAdata = NOAAdataset.filterDate(dateRange);
// Select only the 500 day NDVI data band.
var NDVIdata_avg = NOAAdata.select('NDVI');
// Scale to Kelvin and convert to Celsius, set image acquisition time.
// Chart time series of NDVI for thailand in 2015.
var ts1 = ui.Chart.image.series({
  imageCollection: NDVIdata_avg,
  region: thailandBorder,
  reducer: ee.Reducer.mean(),
  scale: 500,
  xProperty: 'system:time_start'})
  .setOptions({
     title: 'NDVI_column_number_density',
     vAxis: {title: 'Index'}});
print(ts1);
// Calculate NDVI AVHRR Sensors for thailand in 20xx.
var clippedNDVI = NDVIdata_avg.mean().clip(thailandBorder);
// Add clipped image layer to the map.
Map.addLayer(clippedNDVI, {
  min: -1.0,
  max: 1.0,
  palette: ['000000', 'f5f5f5', '119701'],
},
  'Normalized difference vegetation index, 1991-2013');
  // Export the image to your Google Drive account.
  // Select only the 500m
Export.image.toDrive({
 image: clippedNDVI,
 description: 'NDVI_Mean_2020',
 folder: 'NOAA_NDVI',
 region: thailandBorder,
 scale: 500,
 crs: 'EPSG:4326',
 maxPixels: 1e10});
```

BIOGRAPHY

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PLACE OF BIRTH	Chaiyaphum, Thailand
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EDUCATION	Bachelor Science of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand (2007 - 2011) Government High school, Satrichaiyaphum school, Chaiyaphum, Thailand. (2001 – 2007)
AWARDS OR GRANTS	2019 Awarded a scholarship to Master of Science in Geo-informatics at Burapha University (Thailand) and Wuhan University (China) from Geo-Informatics and Space Technology Development Agency (Public Organization): GISTDA