**NASA DEVELOP National Program**



Goddard Space Flight Center

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Thailand Disasters

Monitoring Risk and Extent of Drought for Enhanced Decision Making and Resource Allocation in the Kingdom of Thailand

 **Technical Report**

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# I. Abstract

Drought is a natural disaster impacting agricultural production and economic livelihoods. The Kingdom of Thailand is impacted by drought due to the variability of monsoon rains as well as other unfavorable meteorological conditions. The drought of 2015 was the worst drought to impact Thailand in over 15 years. As one of the biggest exporters of rice in the world, drought has the ability to impact the economy of Thailand by reducing agricultural yield and shrinking Thailand’s gross domestic product. The available drought monitoring system in Thailand looked at only agricultural drought. This was insufficient for analyzing accurate risk management and decision-making. Using data from various Earth-observing satellites, including Terra and Aqua (MODIS), TRMM (MI), GPM (MI), and SMOS (MIRAS), as well *in situ* data from streamflow stations, this study utilized four indices to analyze and monitor the current state of meteorological, hydrological and agricultural drought across Thailand. The Standardized Precipitation Index was used in monitoring meteorological drought, the Streamflow Drought Index was used in monitoring hydrological drought, and the Scaled Drought Condition Index and Soil Moisture Index were used in monitoring agricultural drought. All indices were based on a monthly temporal resolution for monitoring drought. The study demonstrated how a combination of various indices can offer better understanding of drought conditions, with data derived from Earth-observing satellites offering the ability to monitor drought across the entire country and in near-real time.

**Keywords**

Thailand, Drought Indices, NASA Earth Observations, Remote Sensing, NDVI, Land Surface Temperature, Precipitation, Soil Moisture Content

# II. Introduction

In recent decades, observed climate change has impacted natural and human systems across the planet, with changes in extreme weather and climatic events (IPCC, 2014). Hewitt (1997) reported that throughout the world, drought ranks first among

natural disasters in numbers of persons directly affected. Drought is a natural phenomenon resulting from deficiencies in precipitation from regional climatological norms, which are insufficient in meeting the needs of humans and the environment (Wilhite, 2005). In contrast to short-term variations in precipitation, drought is a slow-onset disaster lasting seasonally to annually. The severity of a drought depends on its duration, intensity, and spatial extent (Shaw et al., 2011). As more than half of the world’s population depends on Asian monsoon rainfall, changes in the timing, duration, and severity of precipitation can have significant effects (Buckley et al., 2006).

As one of the largest rice exporting countries in the world (USDA, 2014), Thailand farmers rely on rainfall for roughly 75% of the total 9.2 million ha of rice growing areas in the country—irrigation comprises the other 25% (Jongdee et al., 2006). Extreme climatic events like drought affect not only rainfed crops during the monsoon season but limit the availability of water for off-season irrigated crops. After the 2014 – 2015 drought in Thailand, rice exports were down by 4% in the first quarter of 2015 (Prasertsri, 2015), and the Thai cabinet allocated roughly 6.8 billion baht ($208.65 million) to alleviate drought through the installation of water pumps and mobile water tanks to the most drought affected regions (Kaewjinda et al., 2015).

In 2015, the Royal Thai Government established a four-part integrated plan for drought management. Currently, the drought monitoring system is provided by the Geo-Informatics and Space Technology Development Agency (GISTDA) to monitor agricultural drought, but there are no systems in place to monitor other types of drought that also impact the population. This project expands on that role in analyzing three types of drought as well as creating a tool to monitor agricultural drought in near-real time. The drought indices allow Thai government agencies and NGOs the ability to identify the timing and severity of drought from 2000 - present.

The objectives of this project were to: 1) Use three different drought indices to monitor meteorological, hydrological and agricultural drought in Thailand to assist in drought management and mitigation; 2) Identify extreme drought anomalies based on a climatological baseline. The indices we will examine to achieve our objectives are: the Standardized Precipitation Index (SPI) which incorporates precipitation data for monitoring meteorological drought; the Streamflow Drought Index (SDI) which incorporates *in situ* data from gauging stations and is used in monitoring hydrological drought; the Scaled Drought Condition Index (SDCI) which incorporates precipitation, land surface temperature (LST) and vegetation indices (VI); and the Soil Moisture Index (SMI) which monitors water content in the soil, and was provided as a product by Dr. John Bolten and his colleagues. The last two indices were used in monitoring agricultural drought.

The study area for this project was the Kingdom of Thailand (Figure 1). Located in the tropics from 5 - 21˚ N latitude and 97 - 106˚ E longitude, Thailand has a total area of roughly 513,000 km² (CIA, 2015). From mid-May to September the monsoon rains provide precipitation for rainfed crops, of which rice is the dominant cultivar. November through mid-March is the dry season when irrigation provides water for off-season agriculture. Most of the country has a tropical wet and dry climate, with the southern isthmus always hot and humid.

This project examined the period from 1998 - 2015 in creating indices for meteorological and hydrological drought, and the period from 2000 - 2015 in examining agricultural drought. The difference in time periods for each analysis related to data accessibility. All analysis was done on a monthly temporal resolution. The study addressed the National Aeronautics and Space Administration (NASA) Applied Science’s application area for Disasters, due to the severity of drought afflicting populations and economies in Thailand. The data analysis completed for this project contributes to improve drought monitoring, mitigation and response in Thailand. The study demonstrated how a combination of various indices can offer better understanding of drought conditions, with data derived from Earth Observing Satellites (EOS) offering the ability to monitor drought across the entire country and in near-real time.

The project partners for this study are the Royal Thai Embassy and the Asian Disaster Preparedness Center (ADPC)/SERVIR Mekong. These partners are interested in the project because they are currently only monitoring agricultural drought, and this project expanded on that role in analyzing three types of drought as well as creating a tool to monitor agricultural drought in near-real time. The drought indices allow Thai government agencies and non-governmental organizations (NGOs) the ability to identify the timing and severity of drought from 1998 - present. The methods employed allow for better allocation of resources to target the most affected areas of the country.



Figure 1. Study area map for the Kingdom of Thailand.

# III. Methodology

**Data Acquisition**

As insufficient rainfall is the leading cause of drought, data from NASA EOS were used in acquiring precipitation records to create a 17-year climatology for Thailand. Tropical Rainfall Measuring Mission – Microwave Imager (TRMM-TMI) data was collected as a Level 3 product (3B42) in HDF format from the Goddard Space Flight Center downloads portal. Data was downloaded as a RT Derived Daily Product at 0.25˚ spatial resolution. Daily data was collected from January 1, 1998 – February 28, 2015. Precipitation measurements were collected as millimeters/hour (mm/hour).

After 17 years, NASA and the Japan Aerospace Exploration Agency (JAXA) stopped TRMM’s science operations and data collection on April 8, 2015, after the spacecraft depleted its fuel reserves. In order to create a continuous climatology to monitor drought in near-real time, precipitation records for TRMM’s successor were acquired. Global Precipitation Measurement - Microwave Imager (GPM-GMI) data was collected as a Level 3 product (Integrated Multi-satellite Retrievals for GPM [IMERG]) in HDF5 format from the Goddard Space Flight Center downloads portal. Data was downloaded at 0.1˚ spatial resolution. Thirty minute data was collected from March 6, 2015 – June 15, 2015. Precipitation measurements were collected as millimeters/hour (mm/hour).

To obtain biophysical parameters for creating drought indices, products derived from NASA EOS were selected. The Terra and Aqua - Moderate Resolution Imaging Spectroradiometer (MODIS), Land Surface Temperature (LST), and Normalized Difference Vegetation Index (NDVI) data were acquired using the USGS Earth Explorer tool. For LST data, MOD11C2 and MYD11C2 products were downloaded in HDF format at 0.05˚ spatial resolution at a monthly temporal resolution. For NDVI, MOD13A3 and MYD13A3 products were downloaded in HDF format at 0.01˚ spatial resolution at a monthly temporal resolution. Both data sets were collected from February 2000 – June 2015.

The streamflow data used in this study is a time series at monthly temporal resolution from January 1998 – June 2015. *In situ* data was acquired from gauging stations from the Thailand Royal Irrigation Department (www.rid.go.th) for each region in Thailand.

The soil moisture data was obtained from Dr. John Bolten, NASA DEVELOP Science Advisor at Goddard Space Flight Center (GSFC). His soil moisture product is derived from the Palmer Model and comes in NetCDF format at 0.25˚ spatial resolution. The data set was provided already subset to the extent of Thailand. Temporal resolution is daily with data sets acquired from January 1, 2003 to May 9, 2015.

**Data Processing**

Precipitation was analyzed at a monthly scale as drought is a slow-onset phenomenon lasting from months to years. Since TRMM provided cumulative daily precipitation data and GPM provided rate of precipitation per hour in 30 minute increments, their data needed to be processed into cumulative monthly precipitation to correspond with the monthly LST and NDVI products. It was determined a monthly temporal resolution was appropriate in identifying historic drought anomalies and monitoring drought in near-real time. Preprocessing of both GPM and TRMM data was done using matrix laboratory software (MATLAB), summing the 30 minute and daily precipitation records to a monthly temporal resolution.

As TRMM’s spatial resolution is 0.25° and GPM’s spatial resolution is 0.1°, the latter resolution was chosen for analysis as GPM will be the main source of precipitation data until the termination of GPM’s mission. TRMM data was resampled from 0.25° to 0.1° using the methodology based on area interpolation and done using MATLAB.

SDI is the hydrological drought index based on streamflow data which is point locations of each basin or sub-basin. The study for Thailand disasters selected records based on the completeness of available data and considered only the main streams and rivers throughout the country. Records were then interpolated to raster file format to create a continuous hydrological data set of stream runoff using ArcGIS software and resampled to match the 0.1˚ spatial resolution for all processed data sets.

For MODIS data, five tiles for the M\*D13A3 products were downloaded for each date and the images mosaicked together using the MODIS Reprojection tool (MRT) in ArcGIS. The MRT was also used to reproject both the LST data and the vegetation data to WGS 1984. ArcGIS was used to resample the MODIS products to 0.1˚ spatial resolution to match the resolution of the precipitation data. ArcGIS was also used to subset both LST and NDVI data sets to the same spatial extent as the precipitation data.

**Data Analysis**

1. SPI (meteorological drought)

The standardized precipitation index (SPI) is an indicator of the amount of precipitation in a study area for a certain period of time (1, 3, 6, or 12 months) when compared with its historical record (McKee, 1993). Therefore it shows the statistics of rainfall in a study area, specifically the *Z* – score of the cumulative rainfall probability. The interpretation of the SPI values is shown in Table 1.

|  |  |
| --- | --- |
| SPI | Interpretation |
| 2.0 | extreme wet condition |
| 1.5 to 1.99 | severe wet condition |
| 1.0 to 1.49 | moderate wet condition |
| 0.5 to 0.99 | mild wet condition |
| -0.49 to 0.49 | optimum rainfall |
| -0.5 to -0.99 | mild drought condition |
| -1.0 to -1.49 | moderate drought condition |
| -1.5 to -1.99 | severe drought condition |
| ≤ -2.0 | extreme drought condition |

Table 1. Interpretation of SPI index. Values ≤ -0.5 indicate drought conditions.

In this work, the period of time for drought analysis is 1 month. Thus, the monthly precipitation data is analyzed by the statistical methods to determine the *Z* – score of the cumulative rainfall probability, or SPI, for each month and area. First, the monthly precipitation data in a month in an area (*X*) from 1998 to present are gathered and are subsequently fitted into the Gamma function (*g*(*X*)) in which the rainfall is statistically converted into the probability

Where *β* and *α* are a scale parameter and a shape parameter, respectively. Nevertheless, the Gamma function is undefined for zero precipitation (*X*=0). Therefore, the probability of zero-precipitation (*g*(*0*)) is manually calculated from the ratio of the number of zero-precipitation in a time series (*m*) to the number of total precipitation observation (*n*)

Then, the Accumulative Probability Function (*H*(*X*)) can be determined from

Finally, the inverse normal of *H*(*X*) with standardization of mean 0 and standard deviation of 1.0 would give the Z-score or, in another words, SPI.

2) SDI (hydrological drought)

The Streamflow Drought Index (SDI) is used for investigating hydrological drought occurrence. It has an advantage of simplicity and effectiveness by exclusively using streamflow as the key variable for assessing drought (Nalbantis, 2008). Due to monsoon rains dividing the country into two distinct seasons (wet and dry), the Thailand Royal Irrigation Department defines the hydrological year starting from April and ending in March. In this study, the temporal resolution for SDI analysis is set for one month.

The steps to obtain SDI value and its drought state can be defined as follows:

1. The monthly streamflow volume ()and the cumulative streamflow volume (*Vi,k*) can be obtained from

Where *i* is the year; is total number of years or sample size; *j* is the month according to the hydrological year (*j*=1 for April and *j*=12 for March); and *k* is the study period. The *Vi,k* is cumulative streamflow volume for the *i*-th hydrological year and *k*-th reference period.

1. In general, for some data sets, streamflow may not follow a normal distribution. Thus, normality testing based on skewness is applied to measure the asymmetry of the probability distribution of the random variable (streamflow,) about its mean. Skewness coefficients of cumulative streamflow volumes for all reference periods can be estimated by

Skewness coefficient =

The test of Harris, Loftis and Montgomery (1987) was applied which gave critical upper limits of the absolute value of the skewness coefficient as shown in appendices Table 3.

1. For a normally distributed data set, the Streamflow Drought Index (SDI) can be calculated by cumulative streamflow volume

Where and are respectively the mean and the standard deviation of cumulative streamflow volumes of reference period *k,* which are estimated over a long period of time.

1. In case streamflows exhibit skewness at 0.05 statistical significance, the initial streamflow data can then be transformed using the two-parameter log-normal distribution to remove its skewness (Nalbantis.I and Tsakiris. G,2009). Then the SDI index is defined as

Where

are the natural logarithms of monthly or cumulative streamflow with mean and standard deviation as these statistics are estimated over a long period of time.

The states of hydrological drought are classified into five states which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought) as shown in the following Table 2.

|  |  |  |
| --- | --- | --- |
| SDI | State | Description |
| ≥ 0.0 | 0 | Non-drought |
| -1.0 to -0.01 | 1 | Mild drought |
| -1.5 to -1.01 | 2 | Moderate drought |
| -2.0 to -1.51 | 3 | Severe drought |
| < -2.0 | 4 | Extreme drought |

Table 2. Different states for SDI showing drought conditions. SDI values less than 0 indicate progressively worsening drought, with State conditions increasing in turn.

3. SDCI (agricultural drought)

For agricultural drought the Scaled Drought Condition Index (SDCI) was used (Rhee et al, 2010). The SDCI combines LST, NDVI and precipitation (*X*) to monitor the extent of drought.

Each component of the index was calculated as follows:

Scaled LST =

Scaled precipitation =

Scaled NDVI =

Finally, the components were weighted and summed together.

SDCI = 0.25(scaled LST) + 0.5(scaled precipitation) + 0.25(scaled NDVI)

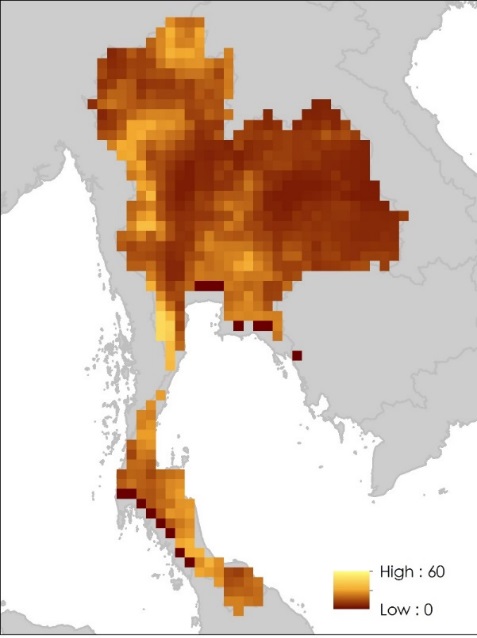
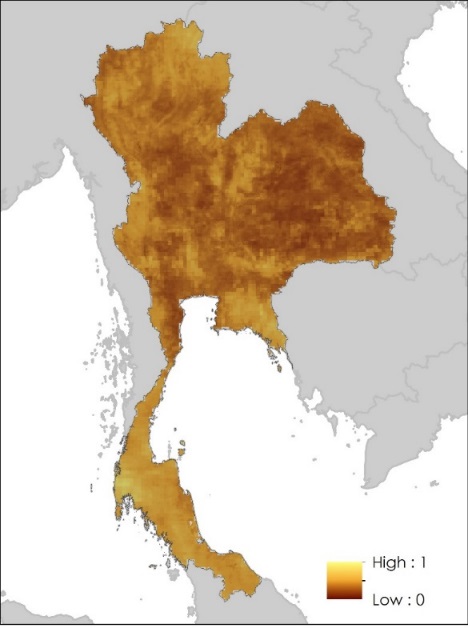
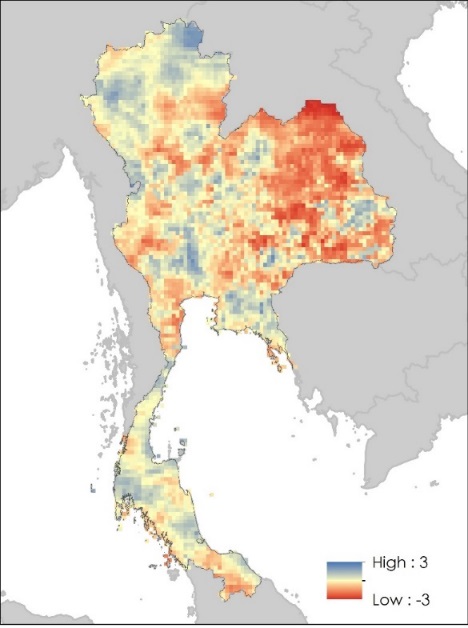
The resulting index contains values ranging from 0 to 1 with 0 indicating dry conditions and 1 indicating wet conditions.

# IV. Results & Discussion

SPI, SDCI and the Soil Moisture Index (SMI) were used to monitor the spatial extent of drought in a monthly temporal resolution. SDI was presented as a time series and provided the effect of drought based on streamflow on the major streams and rivers in water catchment basins in Thailand. SDI was used to monitor 26 locations of drought using a monthly temporal resolution.

1. Standardized Precipitation Index (SPI)

SPI was analyzed based on monthly precipitation data from TRMM and GPM from 1988 to May 2015. 209 SPI maps were created on a monthly scale by stretching the minimum and maximum values from -3 to 3. SPI values in red indicate more severe drought areas, whereas values in blue represent wetter conditions. A time series was also created and analyzed in determining drought anomalies from the climatological baseline. An example of a SPI map is shown in Figure 2 below.



SMI

SDCI

SPI

Figure 2. Maps showing SPI, SDCI and Soil Moisture Index (SMI) in Thailand for April 2015. SPI values < 0 indicate drought conditions; SDCI values < 0.5 indicate drought conditions; SMI indicates the percent of water content in the soil.

2. Scaled Drought Condition Index (SDCI)

The SDCI was used to monitor the effect of agricultural drought by utilizing LST and NDVI from MODIS-derived products as well as precipitation data acquired from TRMM and GPM. Maps were created for SDCI to monitor the spatial extent of agricultural drought across the country from January 2000 to May 2015. A time series was also created and analyzed in determining drought anomalies from the climatological baseline. An example of a SDCI map is shown in Figure 2. Darker colors correspond with lower values. Values < 0.5 represent drought in that region.

3. Soil Moisture Index (SMI)

The SMI was obtained as a soil moisture product from Dr. John Bolten at Goddard Space Flight Center. This product was derived by processing SMOS satellite imagery using the Palmer model. It was used to validate the other indices in this study.

4. Streamflow Drought Index (SDI)

The SDI was used to monitor the effect of hydrological drought. Monthly streamflow data from 26 *in situ* streamflow stations was used to calculate the SDI, resulting in a monthly time series from April 1998 to March 2014. The time series was analyzed in determining drought anomalies based on this baseline. An example of one location for the SDI is show in Figure 3. Negative SDI values indicate drought conditions, with greater negative values indicating more extreme drought. Positive SDI values represent normal to wet conditions.

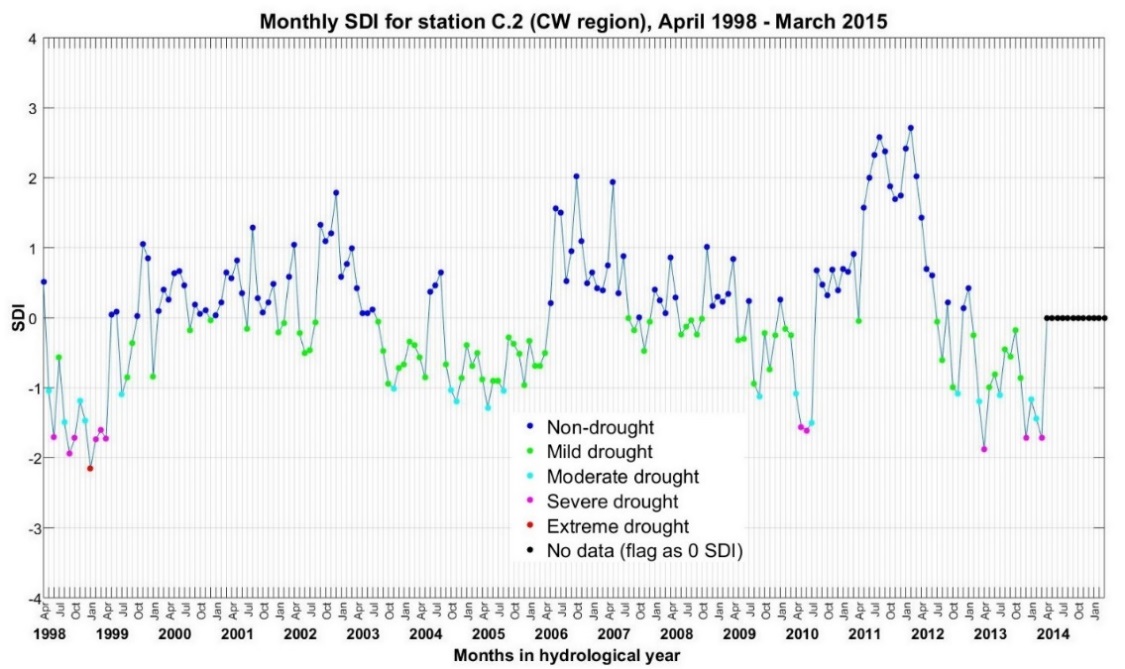


Figure 3. SDI time series plotted from April 1998 – March 2015 at station C.2, central region of Thailand.

**Analysis of Results**

Four indices were utilized to monitor drought by two methods: first being spatial extent and second as a time series. Index maps were analyzed at a monthly scale so we can see the spatial extent of drought in Thailand. Then, time series plots at any region were analyzed to compare all indices. This approach allowed us to derive anomalies and identify drought. In February 2005, all indices show extreme drought in the central region of Thailand. The index map (Figure 4) also substantiates the extreme drought conditions which correspond with the historical drought data in Appendices, Table 4.

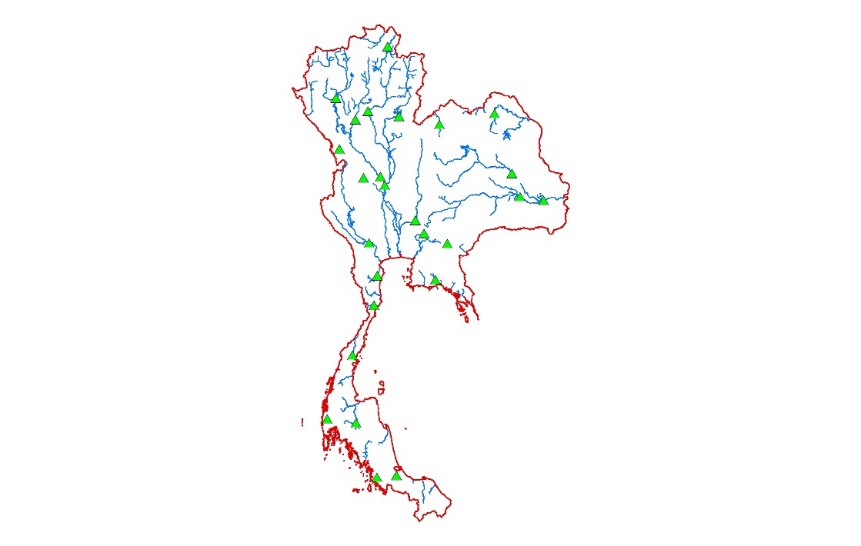
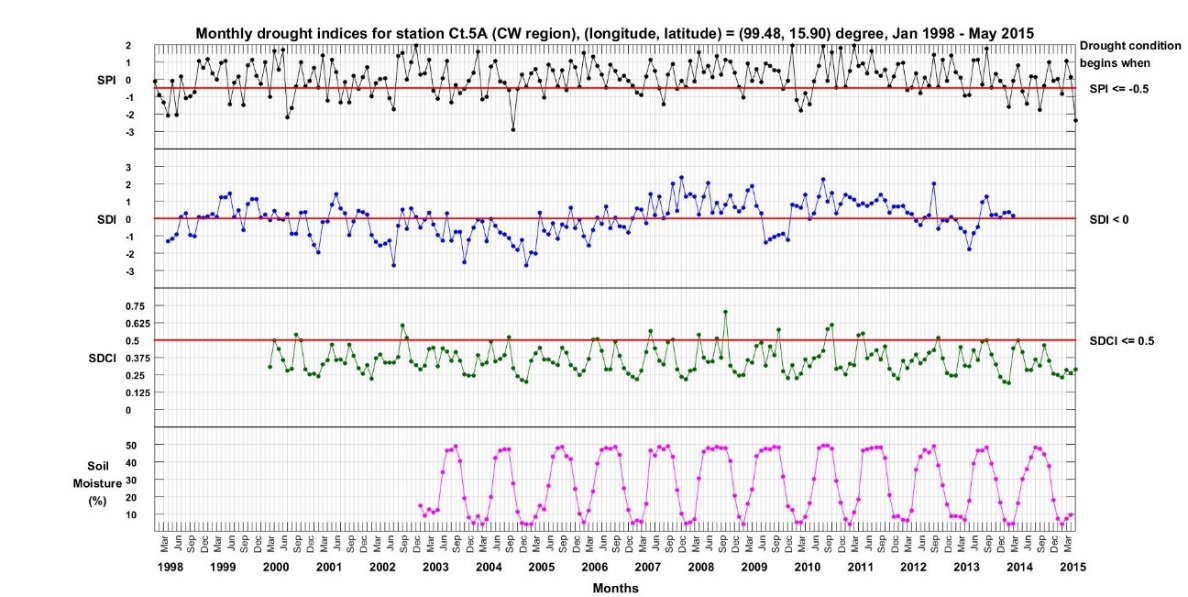
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Figure 4. Time series plot of drought severity indices (SPI, SDI, SDCI and % Soil Moisture) for a location in central Thailand. Drought onset is represented by a horizontal red line.

# V. Conclusions

In this project, a drought monitoring system was developed based on meteorological, hydrological, and agricultural drought to improve upon the current system in Thailand. SPI is an indicator of meteorological drought based on precipitation amounts in the study area. SDI provided the effect of hydrological drought based on the streamflow from major streams and rivers in Thailand. SDCI and SMI were used to monitor agricultural drought by observing the effect of drought due to bioclimatic conditions. SDCI incorporates three factors: LST, NDVI, and precipitation. SMI measures the water content in the soil.

This drought monitoring system used EOS as well as *in situ* data allowing end users to access and characterize regional drought in Thailand. This leads to better decision making processes that are necessary in mitigating the impacts of regional drought.

Future work will be creating a near-real time drought monitoring tool using EOS that will aid in mitigating risk and improve resource allocation in the country. For SPI and SDI, future work will be to calculate the temporal resolution of 3, 6, 9 and 12 months in order to identify seasonal drought and its duration. Further future work will be in calculating the lag correlation for the datasets by taking monthly averages and then analyzing 1, 2, 3 and 4 month lag correlations to demonstrate the relationship between all drought indices.

# VI. Acknowledgments

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# VIII. Content Innovation

Inline Supplementary Material (figures, tables, computer code)

Database Linking Tool

Data Profile

Executable Papers

Interactive Map Viewer

# IV. Appendices

Table 3. Value of the skewness coefficient at 5% and 1% significance levels obtained from Harris, J., Loftis, J. C. and Montgomery, R. H. (1987). [Values in parenthesis are from Snedecor and Cochran (1967)]

|  |  |  |
| --- | --- | --- |
| **Sample size,n** | **α = .05** | **α = .01** |
| 9 | 0.953 | 1.420 |
| 10 | 0.950 | 1.395 |
| 11 | 0.927 | 1.358 |
| 12 | 0.915 | 1.331 |
| 13 | 0.886 | 1.306 |
| 14 | 0.861 | 1.291 |
| 15 | 0.854 | 1.280 |
| 16 | 0.833 | 1.246 |
| 17 | 0.817 | 1.220 |
| 18 | 0.798 | 1.197 |
| 19 | 0.769 | 1.161 |
| 20 | 0.777 | 1.146 |
| 21 | 0.753 | 1.116 |
| 22 | 0.742 | 1.099 |
| 23 | 0.732 | 1.087 |
| 24 | 0.710 | 1.074 |
| 25 | 0.712 (0.711) | 1.060 (1.061) |
| 26 | 0.689 | 1.013 |
| 27 | 0.689 | 1.016 |
| 28 | 0.674 | 1.006 |
| 29 | 0.669 | 0.992 |
| 30 | 0.651(0.662) | 0.972 (0.986) |

Table 4. Historical Drought Situation in Thailand (1998-2013)

