

# Exploration of Spatio-Temporal Drought Patterns using Satellite-Derived Indices for Crop Management in Northeastern Thailand

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## Abstract:

Drought monitoring is normally based on climatic data which often lack the full spatial coverage and immediate data availability, requiring long time for analysis. Rapid access to satellite data offers an alternative for identifying drought patterns which are manifestation of meteorological and hydrological droughts. The objective is therefore to explore drought patterns using vegetation indices as related to drought conditions. The study area, Northeast Thailand, covers an area of about 170,000 sqkm and is characterized by gently undulating topography with diverse crop and forest types. The Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Drought Index (NDDI) of the Terra-MODIS acquired in 2001-2008 were used to identify the surface state in relation to the corresponding rainfall data. Establishment of a relationship between the rainfall derived data and the indices was performed to identify a spatio-temporal pattern of drought. With the relationship established, the spatio-temporal drought patterns could be predicted from the satellite-derived data. The NDVI, NDWI and NDDI indices provide information on drought condition and is found to be more effective compared to the use of the conventional method. The information obtained can be used in decision making for land being planted to crops.

## 1. Introduction

The dynamic nature of drought causes difficulties in planning, monitoring, predicting and providing assistance to drought-stricken areas. Analysis of drought may assimilate information on rainfall, stored soil moisture, or water supply, normally they do not have full coverage for the entire areas. Alternatively drought may be calculated at one location where the input data are collected and available. Satellite observations are a source of timely continuous geo-referenced information. In addition, drought may affect people and agriculture at local scales or have impacts on economics, society and environments as well. Although the effects or losses are substantial, they are difficult to quantify.

Northeast Thailand contains one-third of the total population and land area of the kingdom. Over 70% of the population is engaged in agriculture which is dominated by rain-fed production. At the present time, less than 6% of the cultivated land in the northeast is irrigated, leaving the majority of farmers operating in rain-fed conditions (Rigg, 1985) In addition, water shortage for domestic consumption is usually identified as the principal constraint for the people during the dry season. Lack of water or drought in the region has a profound impact that can be listed as economic, social and environmental. The information obtained can address this issue with rapid access, based on satellite derived indices. The drought assistance can be rapidly executed in terms of spatial and temporal aspects.

No universal definition of drought is identified. Drought can be defined as period of abnormally dry weather, which results in a change in vegetation (Heim, 2002). Soil moisture and vegetation growth are the most direct and important indicators of drought events. A number of drought indicators are widely accepted, each of the indices has recognized drawbacks and advantages. Some selected drought indicators are shown in table1. A promising MODIS data offers effective opportunities instead of collecting huge

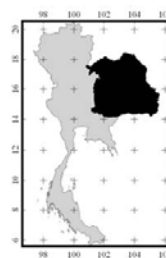
volume or lacking the full coverage of climatic data. This study thus aims to explore spatio-temporal drought patterns with satellite-derived indicators over the Northeast Thailand.

**Table 1.** Drought Indicators

Drought Indices	Source and reference
(1) Normalized Difference Vegetation Index (NDVI)	Lawrence&Ripple, 1998. Chen et al., 2005 Volcani et al., 2005. Gu et al., 2007. Shakya&Yamaguchi, 2007. Bayarjargal et al., 2006. Cheng et al., 2008
(2) Normalized Difference Water Index (NDWI)	Gao ,1996.Chen et al., 2005. Gu et al., 2007. Cheng et al., 2008
(3) Enhanced Vegetation Index (EVI)	Huete et al., 2002. Cheng et al., 2008
(4) The difference of index (dINDEX) & The difference of NDVI	Volcani et al., 2005
(5) Simple Ratio (SR) & Modified SR	Lawrence&Ripple, 1998. Sims&Gamon, 2002
(6) The Normalized Difference Index (NDindex) & The Modified of Normalized Difference Index (mNDindex)	Sims&Gamon, 2002
(7) Normalized Difference Drought Index (NDDI)	Gu et al., 2007
(8) Vegetation Condition Index (VCI)	Kogan, 2000. Bayarjargal et al., 2006
(9) Temperature Condition Index (TCI)	Kogan, 2000. Bayarjargal et al., 2006
(10) Vegetation and Temperature Index (VT)	Kogan, 2000. Bayarjargal et al., 2006
(11) Vegetation Health Index (VT)	Bayarjargal et al., 2006
(12) Land Surface Temperature (LST)	Bayarjargal et al., 2006. Shakya & Yamaguchi, 2007
(13) Vegetation Temperature Condition Index (VTCI) & Vegetation Water Temperature Condition Index (VWTCI)	Shakya&Yamaguchi, 2007
(14) Soil-Adjusted Vegetation Index (SAVI)	Huete et al., 1997. Lawrence&Ripple, 1998
(15) Modified Soil-Adjusted Vegetation Index (MSAVI)	Lawrence&Ripple, 1998
(16) Optimized Soil-Adjusted Vegetation Index (OSAVI)	Lawrence&Ripple, 1998
(17) Transformed Soil-Adjusted Vegetation Index (TSAVI)	Lawrence&Ripple, 1998
(18) Perpendicular Drought Index (PDI)	Ghulam et al., 2007
(19) Modified Perpendicular Drought Index (MPDI)	Ghulam et al., 2007

## 2. The study Area

The study area encompassed most of North-East Thailand, with an approximate area of 170,000 km<sup>2</sup>, between 14° 18' N to 18° 15' N and 102° 22' E 104° 50' E (Fig. 1). Most of the area is dominated by rice paddy fields, cassava, sugarcane, rubber tree and rangelands with isolated patches of remnant forest. The dense forest mainly *Dipterocarp* sp and *Evergreen* sp covers extensively over the mountain areas, National parks and wildlife sanctuaries. Geologically, the most extensive areas are formed by a thick sequence of Mesozoic rock, the Korat group ranging in age from upper Triassic to Tertiary. The region is bound by the prominent topography or low hill on the west and the south. The flat to gently undulating alluvial plains are formed in the north and the south of the region and is divided by the Phu Phan range into 2 basins, Sakon Nakhon in the North and Korat basin in the south. These two basins are underlain by the Maha Sarakram geologic Formation which consists of sandstone and siltstone with interbedded rock salt. Mean annual rainfall ranges from 1100 m.m. in the southwest to 1800 m.m. in the Northeast with overall average of 1200 m.m. The soils are inherently low in fertility and have sandy textures with low water holding capacities. The region is frequently subjected to drought due to dry periods within the wet season.



**Figure 1.** North-East Thailand

### 3. Methodology

#### 3.1 Data sources

Rainfall data over 70 stations in NE Thailand of 8 years (2001-2008) collected by the Meteorological Department and the Royal Irrigation Department were used in this study.

Multi-temporal Terra-MODIS data of the 16 day composite images at 250m resolution during the period of 2001-2008 available from <http://daac.ornl.gov/> were used.

#### 3.2 Rainfall analysis and image processing

Mean annual rainfall, mean 16-days rainfall and their standard deviations for 8 year-records were analyzed. The cumulative rainfalls summed over the preceding months and its slope gradient for each year were performed. Inverse Distance Weighted (IDW) was applied to spatially interpolate the mean annual rainfall data from the stations for 8 years of the study period. We created the spatial standard deviation (SD) of mean annual rainfall maps from this interpolation. The multi temporal MODIS data (2001-2008) were digitally analyzed as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

Where  $\rho_{NIR}$  and  $\rho_{Red}$  are the reflectance values at  $0.857 \mu\text{m}$  and  $0.645 \mu\text{m}$ , respectively

$$NDWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$$

Where  $\rho_{NIR}$  and  $\rho_{SWIR}$  are the reflectance values at  $0.857 \mu\text{m}$  and  $1.65 \mu\text{m}$ , respectively

$$NDDI = \frac{NDVI - NDWI}{NDVI + NDWI}$$

In addition, analysis of change detection was digitally performed, based on the change in NDVI and NDWI values of pairs of images for different dates. To assess the change we applied the method as described by volcani et al (2005) in which the no change is determined by the thresholds of the mean d NDVI to 1 step standard deviation (-1SD to +1SD = no change). The higher step of SD from the mean d NDVI or d NDWI determined the greater magnitude of the change. The d NDVI and dNDWI is defined as  $d\text{ NDVI} = \text{NDVI}_1 - \text{NDVI}_2$ ,  $d\text{ NDWI} = \text{NDWI}_1 - \text{NDWI}_2$  where  $\text{NDVI}_1$  and  $\text{NDVI}_2$  are the NDVI images derived from date1 and date2 respectively and  $\text{NDWI}_1$  and  $\text{NDWI}_2$  are the NDWI images generated from date1 and date 2 as well.

### 4. Results and Discussion

#### 4.1 Temporal Variability

To better understand the variability of NDVI, NDWI and NDDI values, the cumulative rainfall for the period of 2001-2008 are described. The means of cumulative rainfall for 2001-2008 with its slope gradient provided the onset and the end of rainfall. The period of May to October contributes over 90% of rain with its slope gradient over 7.9 and peak in August and September. The NDVI, NDWI and NDDI values over the entire Northeast period were performed in relation to the cumulative rainfall. The cumulative rainfalls were summed over the preceding 15 days for each year, corresponding the image data. The high NDVI and NDWI values are strongly correlated with the greenness of the area in contrary to the NDDI value. the more pronounced increase of NDDI value occurs during the dry period. Distinctions in the timing of the NDVI, NDWI and NDDI values response to rainfall were evident over the Northeast. The relationships between the indices and the cumulative rainfall were presented in Fig 2.

The onset of greenness increase with increasing NDVI and NDWI values or decreasing NDDI values which occur in May. The satellite derived indices measured green up were found to lag behind the cumulative amount of rainfall, indicating the delay in vegetation development. During May to October or wet season, the indices response to rainfall were remarkably identified and reached maximum at the end of October. In the beginning of November when the areas are dried out, the NDVI and NDWI values decrease with decreasing slope gradient of cumulative rainfall while the rapid increase of

NDDI values during the dry months of the years, providing that NDDI may be a more sensitive index for drought identification. In the dry period, the NDWI values is more sensitive to water content than that of the NDVI and the NDVI-NDWI difference is higher than that of the wet season. Eventhough the NDDI value is more sensitive than the difference between NDVI and NDWI, suggesting the application of the NDDI for drought monitoring. Some selected NDVI and NDWI images in the dry and wet seasons over the entire study area are illustrated in Fig 3.

#### 4.2 Spatial Variability of Rainfall

Anomalies of spatial rainfall patterns over the entire Northeast for the period 2001-2008 are presented in Fig 4 in which the difference in spatial rainfall are shown by the step of SD. A broad pattern of increasing rainfall from southwest to northeast is evident for the entire area study. The relative drought areas are located in the southwest parts of the region with high variability in mean rainfall values. In the northernmost parts of the region, rains occur with virtually equal frequency throughout the rainy season. The analysis reveals three drought-prone areas which its magnitudes can be derived from the SD steps, the more minus step the higher degree of drought.

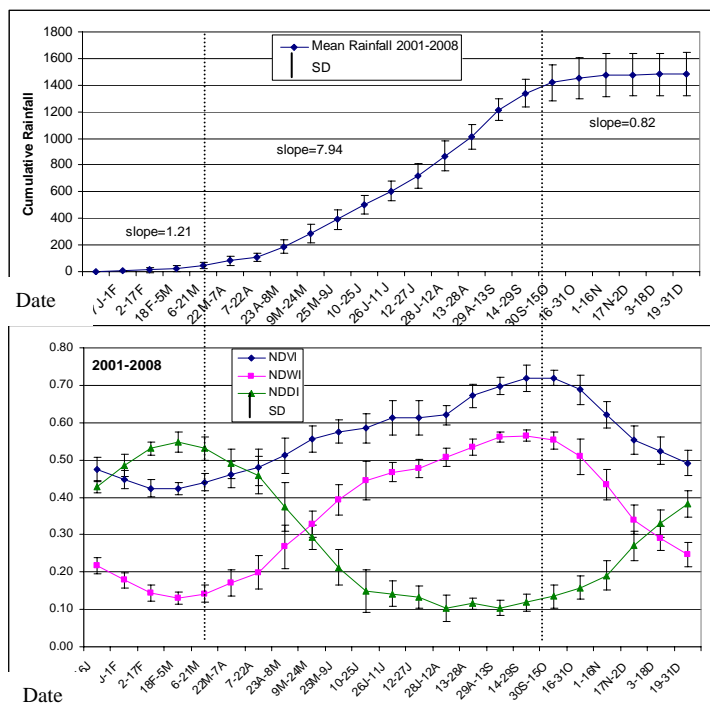
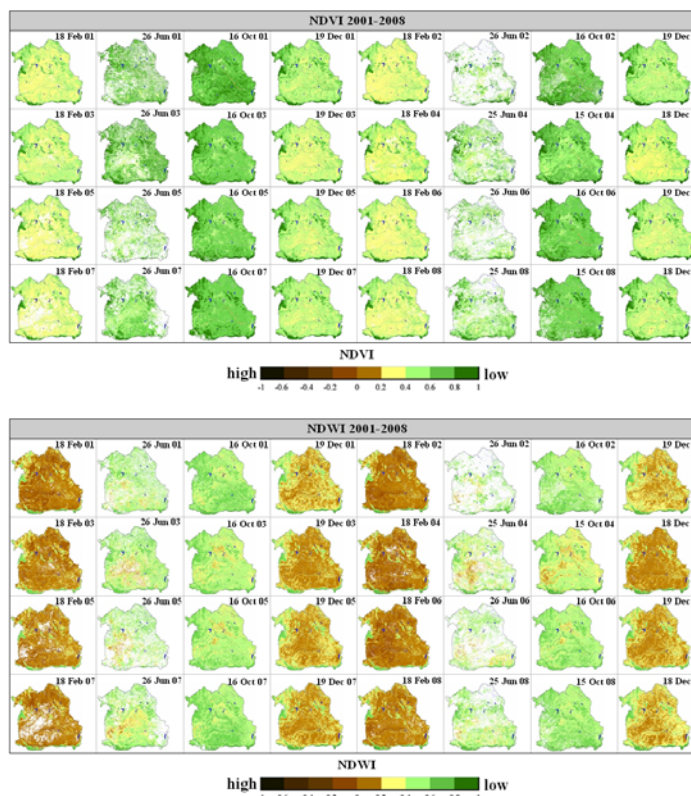


Fig.2 Relationships between 8 years-mean cumulative rainfall and satellite-derived indices



### 4.3 NDDI images

As discussed earlier NDDI is more sensitive indicator for drought severity, to illustrate the relationship between drought conditions and NDDI, NDDI maps over the Northeast are presented in Fig 5. Spatial variability in NDDI for the wet and dry seasons is evident more distinction in the timing response to rainfall than the difference between NDVI and NDWI.

### 4.4 Change Detection of NDVI/NDWI images

The change detection of NDVI and NDWI images was applied for evaluating the magnitude of drought severity as a reason that the NDVI is substantially sensitive to vegetation cover but the NDWI is sensitive to both vegetation and water content. The change in image indices between different dates provide the degree of severity. Some selected NDVI and NDWI images differencing and their associated histograms of the changes are provided in Fig 6. As we set dNDVI or dNDWI is zero if no change, the severity of the change can be derived from the SD steps, the greater step the higher changes. The pairs of set images used for the change detection analysis provide the direction of changes. The negative SD indicates the greater NDVI or NDWI value of the second image in contrary to the positive SD.

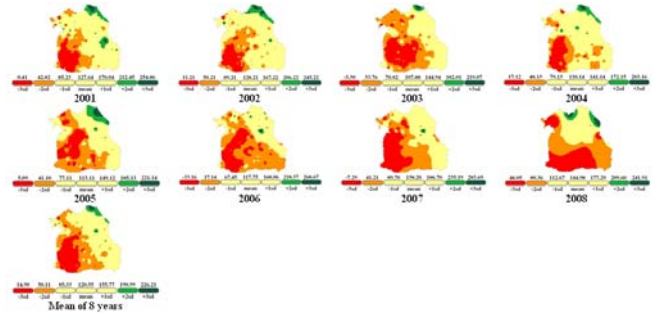


Fig 4 Deviation of Spatial rainfall pattern\_NE Thailand

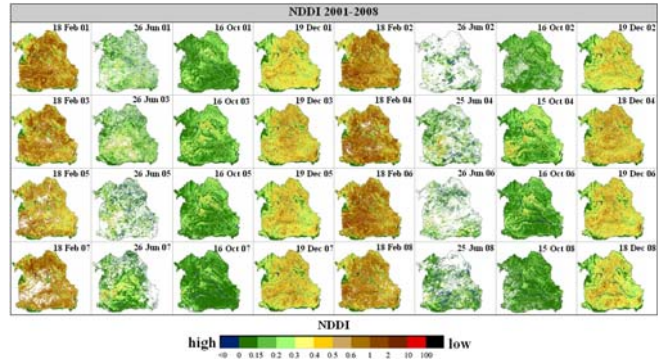


Fig5 Spatial NDDI over the Northeast

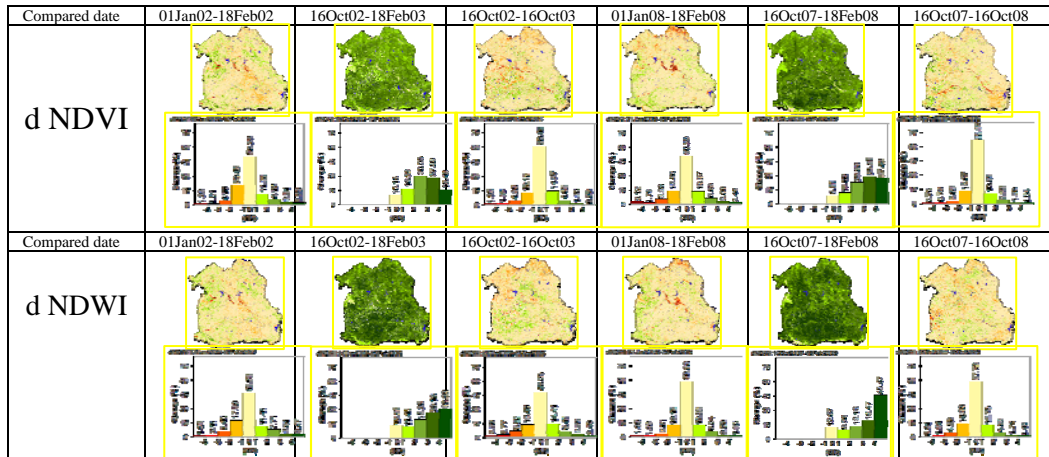


Fig 6 NDVI / NDWI images differencing and their associated histograms of the changes

Satellite derived data can address the issue on water shortage with rapid access. The drought assistance can be rapidly executed. Spatio-temporal variability of drought can be used for cropping schedule, crop types to be grown, supplemented water supply, selection of drought-tolerant crops and etc. From the finding the southwest of the region is drought-stricken areas suggesting the priority of irrigation should be provided for this region. The magnitude of drought as defined by the indices offers the opportunities in the selection of alternatives for changes in the traditional cropping system. Water management in relation to land types could be suggested to optimize the land use particularly in the drought prone area.

## 5. Conclusions

In conclusion cumulative rainfall has a significant impact on vegetation development to which the satellite derived-indices are great correlated. The NDDI value is more sensitive to the severity of drought than the difference between NDVI and NDWI. Changes in phenological state of different vegetation covers identify the spatio-temporal pattern of drought. The changes represent the  $\Delta$  NDVI and  $\Delta$  NDWI values of multi-date images covering over diverse vegetation types. With availability and rapid access of satellite data as well as difficulty in gathering the continuous spatial coverage of climatic data, the satellite derived indices can be used to monitor the drought condition in the vast extent.

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