A STUDY OF THE DROUGHT IMPACT ON VEGETATION AND ITS SPATIAL VARIATION IN TAIWAN

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Abstract: Drought has profound influences on plant growth as well as ecosystem structure and function. Many studies have predicted that drought will be more frequent in the future due to global change. This will cause major change in ecosystem and possibly change the carbon budget from carbon sinks to carbon sources. Such changes may in turn aggravate global climate change. The rainfall pattern has been undergoing major changes in Taiwan. Both floods and droughts become more prominent and frequent. Because of the complicate interaction between topography and monsoons, the changes in rainfall patterns diverge considerably in different time and space. Although drought tends to change carbon budget in ecosystem, few studies have examined the impact of drought on vegetation growth in Taiwan.
Therefore, this study aims to examine the effects of drought events on vegetation growth in different regions of Taiwan. Muti-years MODIS satellite data are used to calculate the normalized difference vegetation index (NDVI) after dry seasons as well as to evaluate drought-induced vegetation changes.
The results show that during dry seasons the rainfalls were very diverse in different region of Taiwan. We also found several significant drought events occurring from 2001 to 2010. The estimated correlation between NDVI values and rainfall is 0.5 in Spearman Rank Correlation (moderate correlation). This research helps to understand the influences of drought events on ecosystem in Taiwan and also to evaluate the effects of drought under global change on vegetation growth in Taiwan.

1.INTRODUCTION

Water is an important environmental factor affecting plants growth and their geographical distributions. Variation in precipitation pattern would lead to the change in river runoff and the availability of water resource. There has been an increasing interest in climate change issues, and many researches showed that the precipitation pattern has changed in recent years (Huang et al., 2003). IPCC (2007) concluded that the average weather conditions are going to change and the probability of extreme conditions is increasing.
Drought is not a simple physical phenomenon, but instead an interaction between natural water availability and human demands for water supply. Generally speaking, there are three types of drought conditions: (1) Meteorological drought, occurring when the rainfall is below average precipitation for a long period of time; (2) Agricultural drought, occurring when there is insufficient rainfall in crop zone to keep average crop production; and (3) Hydrologic drought, occurring when the availability of water reserved sources such as aquifers, lakes, and reservoirs falls below the statistical average. Since climate changes and the extreme rainfall pattern cause the increasing frequency of draughts, it is important to investigate the water-shortage effect on plant growth. This study focus on the meteorological drought because it has great impacts on agriculture, water supply, forest ecosystems, biodiversity, natural habitats, as well as many social-economic sectors (Wilhite, 2000; Heim, 2002; IPCC, 2007).
This study uses the data of Taiwan to examine the water shortage effect. Remote sensing and geographic information system (GIS) techniques were applied. Based on the MODIS images after the drought events during 2001 to 2010, the normalized difference vegetation index (NDVI) was calculated to monitor the vegetation changes. In order to detect the spatial diversity in Taiwan, 5 geographical districts were divided respectively to watershed systems.

2. METHODS

2.1. Study Area

Taiwan is our study area and is an island located in the Pacific Ocean. Its total land area is about 36,000 square kilometers. With the Tropic of Cancer passing through the center of the island, Taiwan has tropical, sub-tropical, and temperate climates along with very diverse seasonal patterns. The highest average temperature is about 36 degrees Celsius, which often occurs in the months of July and August, while the lowest average temperature is about 10 degrees Celsius which often occurs in January. The mean annual rainfall is over 2,500mm/year in Taiwan. Comparing geographically, the northern region has more rainfall than the others, and the upland area receives more rainfall than the west lowland area. The island receives abundant rainfall brought by May-Yu frontal edge and Typhoons which mostly take place from May to October, classified as wet season .The period from November to the next April is classified as dry season when the drought event can occur.

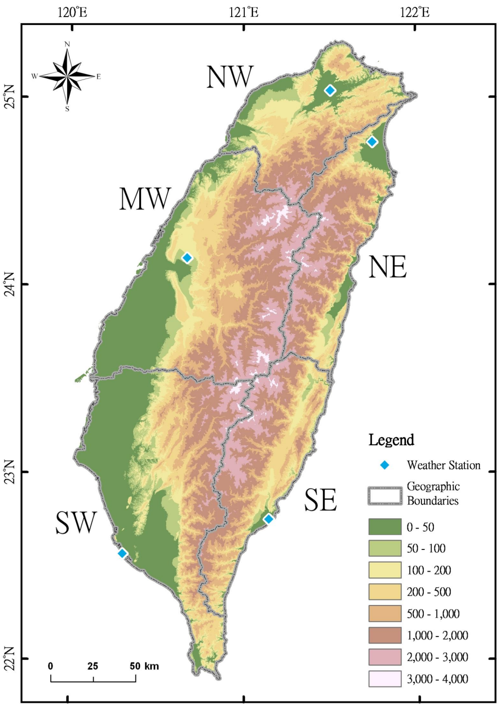


Fig.1: Study area

2.2. Research Data

2.2.1. Meteorological Data

Meteorological data including daily rainfall and temperature recorded in weather stations from 2000/11/01 to 2010/04/30 were used in this study. The drought event in this study is defined by the relative comparison of low rainfalls in the past 10 years to examine the drought effect on vegetation.

2.2.2. Spatial Data

The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km and is able to record the entire surface of the earth every one to two days. For different purposes, its detectors contain 36 spectral bands with measurement between 0.405 and 14.385 µm. It provides data at three spatial resolutions (250m, 500m, and 1,000m). The MODIS data used in this research were free downloaded from LP DAAC (Land Processes Distributed Active Archive Center; https://lpdaac.usgs.gov/get_data/).

2.3. Methods

2.3.1. Meteorological Data Processing

The weather stations of Taipei, Taichung, Kaohsiung, Yi-Lan, and Taitung were adopted to represent the 5 districts of weather condition in Taiwan (i.e., North-Western, Middle-Western, South-Western, North-Eastern, and South-Eastern). The total rainfall and raining days in dry seasons were calculated to analyze the rainfall pattern and to detect the drought event in each region.

2.3.2. Vegetation Data

MOD13Q1(Terra MODIS vegetation index) was the estimate of the surface reflectance of the red and near infrared channels with the corrections for molecular scattering, ozone absorption, aerosol optical thickness, and adjusted to nadir in the framework of BRDF model, which serves as the inputs to the NDVI equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{\mathrm{Re}d}}{\rho_{NIR} + \rho_{\mathrm{Re}d}}$$

where

ρ_{NIR}: Reflectance of the near infrared channel (841-876nm)

ρ_{Red}: Reflectance of the red channel (620-670nm).

MOD13Q1 is derived within a 16-day interval by maximum value compositing technique (MVC). Both the composite day and pixel reliability are included in the data product. MVC characterizes the highest NDVI observed in the data period. Since the residual cloud and longer optical path length tend to lower NDVI, MVC can composite the least atmospheric-contaminated and most near-nadir observations within the compositing cycle.

2.3.3 Correlation Coefficient

Because the sample size is relatively small, the Spearman rank correlation test was applied in this study to evaluate the correlation between the rainfall and NDVI. It is a nonparametric statistic method which measures the relationship between different rankings within the same set of items. The estimate represents the degree of similarity between two rankings.

$$r_s = 1 - \frac{6\sum d_i}{n(n^2 - 1)}$$

where

n: sample size

d_i: squared difference between two rankings

3.RESULTS

The rainfall patterns were different by regions according to the meteorological data analysis. That is, the average rainfall from November to next April was 1,047 mm in East-North region but only 132 mm in the South -Western. The phenomenon was caused by North-Eastern monsoon in winter and meanwhile brings large rainfall variation in the region (Fig 2). According to the 10-year data, the driest period occurs since 2001/11 to 2002/04, the relative droughts were observed in every region including the North-Eastern. The rainfall in this period is even less than half of the average rainfall in every region (except for East-South) where shorter rainy days are also shown during then (Table1).

Table 1: Total rainfall and rainy days in the dry season from November to next April

	Taipei North-Western		Taichung Middle Western		Kaohsiung South -Western		Yi-lan North-Eastern		Taitung South --Eastern	
	Rainfall (mm)	Rainy (days)	Rainfall (mm)	Rainy (days)	Rainfall (mm)	Rainy (days)	Rainfall (mm)	Rainy (days)	Rainfall (mm)	Rainy (days)
2000/11~2001/04	1045.9	25	421.1	15	104.9	3	2226.6	44	314.1	9
2001/11~2002/04	335.9	12	72.1	1	52.5	1	462.6	11	157.1	2
2002/11~2003/04	466.2	15	305.3	11	183	8	539.7	14	234.2	10
2003/11~2004/04	631.7	23	315.1	11	142.7	3	756.7	24	286.2	5
2004/11~2005/04	899.2	23	497	19	222.9	4	1351.1	34	403.8	7
2005/11~2006/04	660.8	21	387.4	13	153.5	5	1166.4	37	289.1	11
2006/11~2007/04	924.3	28	450.7	15	85	2	920.7	32	134.3	4
2007/11~2008/04	716.2	27	158.2	7	132	5	1373.8	36	531.6	8
2008/11~2009/04	577.2	19	512.3	11	175.3	8	814.3	26	313.6	10
2009/11~2010/04	634.3	18	367	10	70.5	2	856	26	189	4
average	689.17	21.1	348.62	11.3	132.23	4.1	1046.79	28.4	285.3	7

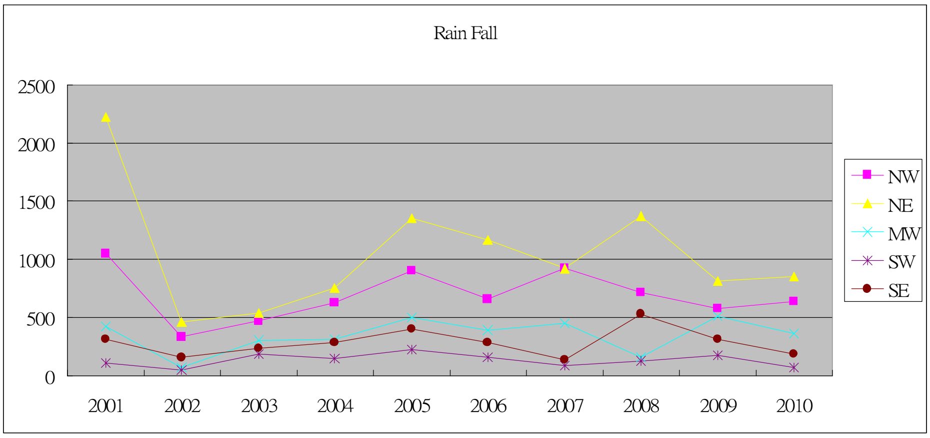


Fig 2. The dry season rainfall patterns in different regions from 2001 to 2010.

The NDVI after the dry season (near the end of April) were shown in Fig 3 and Fig 4. The data of 2006 was excluded in the following analysis because the image quality is too bad to result a reasonable NDVI value. The high correlation between rainfall and NDVI can be observed in the North-Western but there is no correlation in North-Eastern. The correlation between rainy days and NDVI is highest in the Middle-Western, and is still no correlation in the North-Eastern. The overall correlation is 0.5 (moderate correlation) in Taiwan, but can increase to 0.633 if the North-Eastern region was excluded in the calculation (shown in Table 2).

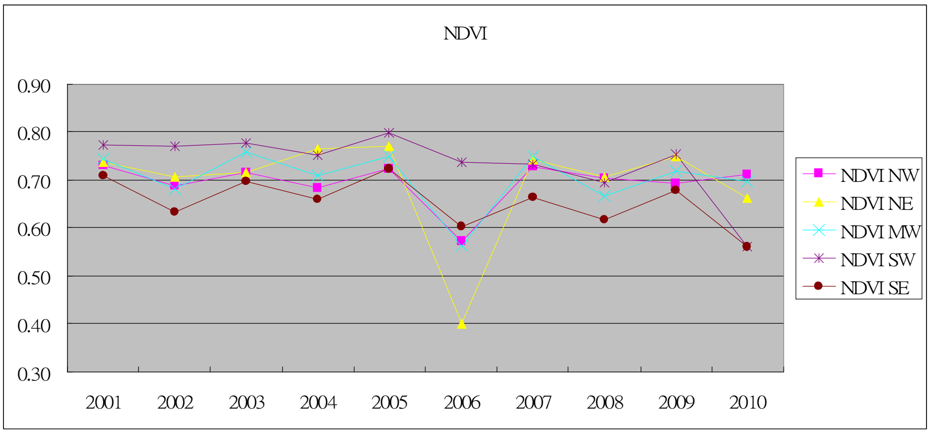
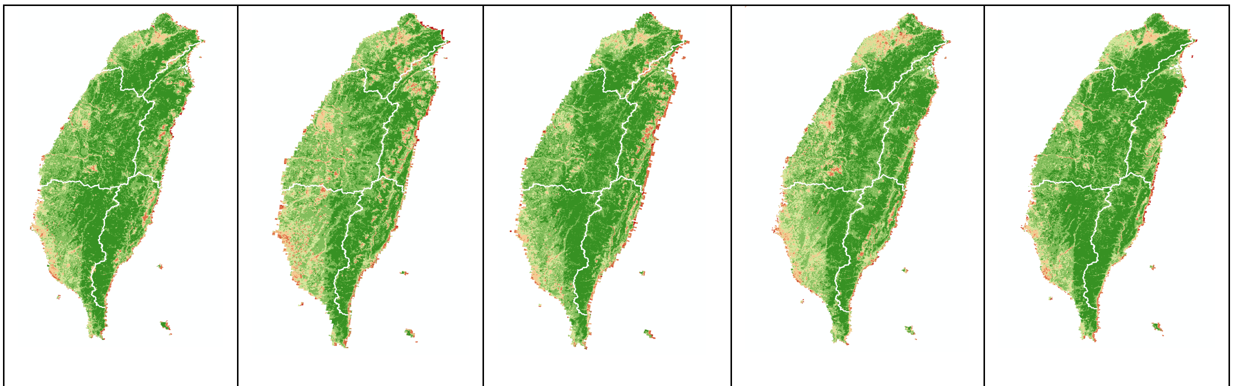
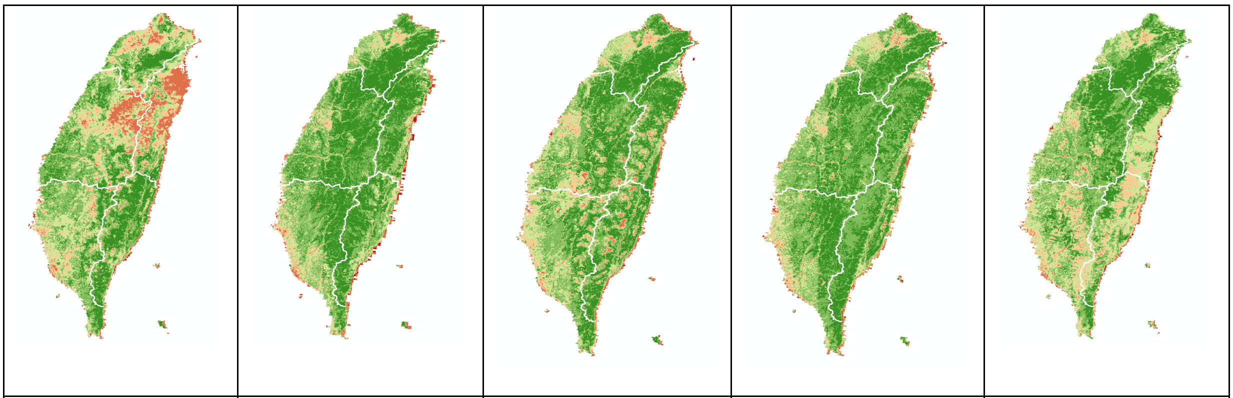


Fig 3. The NDVIs near the end of April in different regions.



2001	2002	2003	2004	2005



2006	2007	2008	2009	2010

Fig 4. The MODIS NDVI images from 2001 to 2010.

Table 2. The rank correlation between NDVI and rainfall pattern

		2001	2002	2003	2004	2005	2006*	2007	2008	2009	2010	NDVI Ave.	Rank Corr.
Taipei	NDVI	0.73	0.69	0.72	0.68	0.72	0.57	0.73	0.70	0.69	0.71	0.709	
	NDVI rank	1	8	4	9	3	-	2	6	7	5	-	
	rainfall rank	1	9	8	6	3	-	2	4	7	5	-	0.750
	rainy days rank	3	9	8	4	4	-	1	2	6	7	-	0.425
I-Lan	NDVI	0.74	0.71	0.72	0.77	0.77	0.40	0.74	0.71	0.75	0.66	0.729	
	NDVI rank	5	7	6	2	1	-	4	8	3	9	-	
	rainfall rank	1	9	8	7	3	-	4	2	6	5	-	0.050
	rainy days rank	3	9	8	4	4	-	1	2	6	7	-	0.092
Taichung	NDVI	0.74	0.68	0.76	0.71	0.75	0.56	0.75	0.67	0.72	0.70	0.720	
	NDVI rank	4	8	1	6	2	-	3	9	5	7	-	
	rainfall rank	4	9	7	6	2	-	3	8	1	5	-	0.517
	rainy days rank	2	9	4	4	1	-	2	8	4	7	-	0.817
Kaohsiung	NDVI	0.77	0.77	0.78	0.75	0.80	0.74	0.73	0.70	0.75	0.56	0.735	
	NDVI rank	3	4	2	6	1	-	7	8	5	9	-	
	rainfall rank	6	9	2	4	1	-	7	5	3	8	-	0.567
	rainy days rank	5	9	1	5	4	-	7	3	1	7	-	0.292
Taitung	NDVI	0.71	0.63	0.70	0.66	0.72	0.60	0.66	0.62	0.68	0.56	0.661	
	NDVI rank	2	7	3	6	1	-	5	8	4	9	-	
	rainfall rank	3	8	6	5	2	-	9	1	4	7	-	0.317
	rainy days rank	3	9	1	6	5	-	7	4	1	7	-	0.500
Overall with/ without East-North													0.500 / 0.633

*The NDVI of 2006 were exclude in the NDVI average and correlation analysis

4. CONCLUSIONS & RECOMMENDATIONS

With climate changes and extreme rainfall pattern causing the increasing frequency of draughts, it is important to investigate the water-shortage effect on plant growth. The results in this study show that the dry season rainfalls in Taiwan were different by regions and the correlation between rainfall and NDVI can be observed. Avoiding the typhoon rainfall effect, we analyzed the drought influence on vegetation during dry season. The NDVI is detected to have significant correlations with the rainfall, which may due to the water-shortage effect on plants. There still have more meteorological and environmental factors to be examined in future study in order to discover other factors affecting the vegetation. For example, further research can conduct an examination on the effects of drought in different severity (defined by the number of non-rainy days) and on the timing of the occurrence of drought affecting NDVI. The relationship between drought effect and environment factors such as elevation, slope, and aspect can also be explored in the future.

However, single weather station was used to represent the regional precipitation characteristics in this study may cause the biases in results. The spatial interpolation formula such as Kriging analysis can be used in further study to improve the regional representation of the rainfall data.

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