

Application of Remote Sensing Technology for Drought Monitoring in Mahasarakham Province, Thailand

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Abstract

Drought, a natural phenomenon, has been found often in Mahasarakham province. It has impact on vegetation in the area. Due to the reason, the objective of the study is to develop a methodology to detect drought in the area using vegetation spectrum in different periods of the satellite passing over the area in Mahasarakham province, approximately 5,291.6830 sq.km. The Normalized Vegetation Index (NDVI) obtained from the Modis data has been used in order to detect the vegetation condition in the study area. In addition, the Standardized Vegetation Index (SVI) was used to examine the area with the NDVI difference from the average value of NDVI in the same period. This can reflect the drought through the vegetation index. However, the study has discovered that in the year 2010, the drought in the area was the most severe. The second and the third most severe droughts occurred in 2007 and 2012 respectively. The study has deployed the analyzing technique and the formation of drought according to spatial and time factors. Different satellite images obtained from the Modis data revealed the formation and type of droughts effectively. This will be useful for the preparation of the drought mitigation in the area for concern agencies.

1. Introduction

A drought was natural water deficiency from delayed rain and unseasonable rainfall. That affected on life style and worldwide economic system, also Thailand where emphasized about it (Gomasathit et al., 2015). The drought damaged economic system, society, and environment. The climate change created worldwide higher temperature. Since the last 100 year (1901 – 2000) the average temperature of the earth has increased for 0.6 degree Celsius; more 5 – 10 percent of rainfalls on central and northern hemispheres. But the rain has decreased for 3 percent in southern hemisphere (Gitay et al., 2002). For Thailand, the drought was not new but repeated problems especially for northern east, the main cause was rainfall. Lacking of rain has appeared every year particularly in winter to summer (Thai Meteorological Department, 2013 and Wattanakij and Mongkolsawat, 2008). A dry spell affected to vegetation, therefore the vegetation variation could also indicate drought (Marshall and Zhou, 2004).

The remote sensing was a new, effective, and up-to-date technology which could be applied in different situations (Laosuwan et al., 2011, Laosuwan and Rotjanakusol, 2013, Laosuwan and

Uttaruk, 2013, Laosuwan et al., 2013 and Laosuwan and Uttaruk, 2014) especially for disaster monitoring such as drought, inundation, and soil erosion (Laosuwan and Rotjanakusol, 2013). The applying of remote sensing on abnormal climate around the arid zone was one method of vegetation variance (Bayarjargal et al., 2006, Benedetti, and Rossini, 1993, Kogan, 1997 and Laosuwan and Gomasathit, 2014). The MODIS data was used on vegetation change (Laosuwan et al., 2013). That data could show repeated continuously record and nearly real time. It could be applied on creating index multi-temporal images which followed some changing processes up on the earth. When the satellite's data was analyzed via image processing by mathematic equation, the clarity data has shown.

The famous equations were NVDI which required RED wave and Near Infrared (NIR) differences (Gibson and Power, 2000, Pettorelli et al., 2005, Sternberg et al., 2010 and Tucker et al., 2005). That index represented vegetation change in any time of any area on the earth (Kriegler et al., 1969 and Fensholt and Proud, 2012). The purpose of this study was to develop the drought monitoring in Mahasarakham province in northeast Thailand.

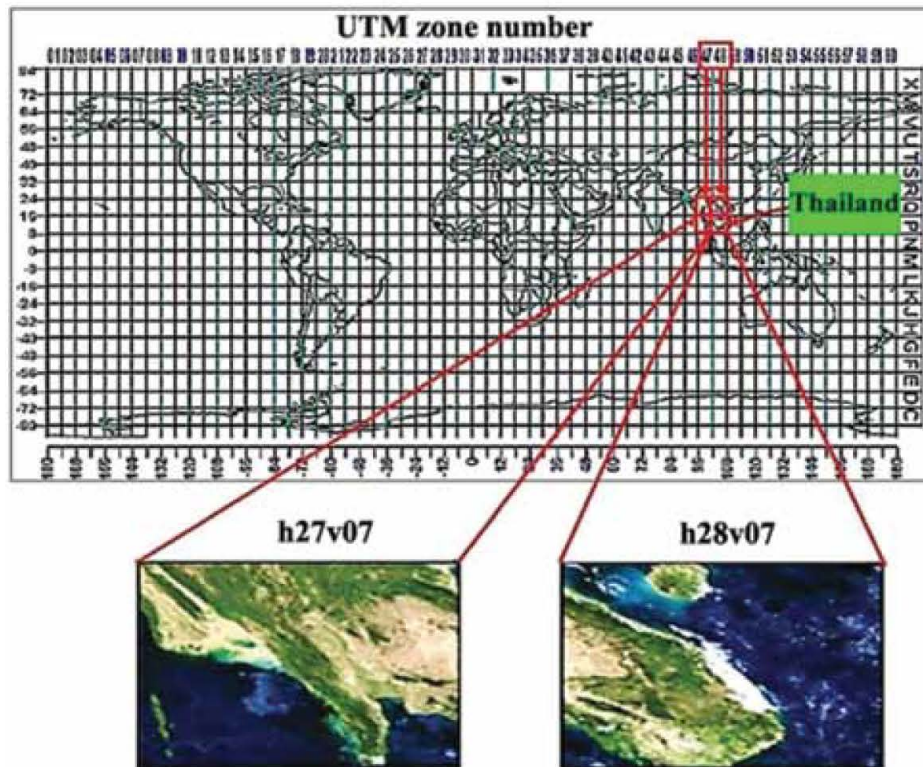


Figure 1: MODIS satellite's data (h27v07 and h28v07)

2. Data Usage

The MODIS data was used in this study. It was designed for tracking and monitoring environmental and natural resources. The spatial data was 250 – 1000 meters, 36-band recording, and could monitor all area in the world by 2 days. Therefore, the MODIS data was appropriate for spatial change monitoring. The MOD13Q1 product was used for NDVI. The MODIS data in 2007, 2010, and 2012 were gathered. The MODIS data around in northeast Thailand were distinguished into 2 sections; h27v07 and h28v07 (Figure 1), then mosaic image was used to merge those images. The radiometric correction was required by using WGS 84/UTM Zone 48N, then subset image for the specific area; Mahasarakham province.

3. Methodology

3.1 NDVI

It was different calculation between electromagnetic reflection of RED wave and NIR wave (Kriegler, 1969, Peters et al., 2002, Singh et al., 2003, Wattanakij and Mongkolsawat, 2008 and Fensholt and Proud, 2012) as shown in equation 1.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Equation 1

The values of NDVI were between -1 to +1. The water area was shown as negative value in NDVI. The land area with less vegetation was shown as nearly 0 value in NDVI. The green area was shown as +1. From those abilities, NDVI was a tool for analyze and forecast changes of vegetation which was affected from surrounding environment. (Benedetti and Rossini, 1993, Peters et al., 2002, Singh et al., 2003 and Wang et al., 2003)

3.2 SVI

For SVI calculation, the NDVI data in each image at any ranges of time were required. The Z-score calculation was used for NDVI deviation in the required month; how was that deviation different from other deviation in the same month in other years. The positive values represented higher value than standard, but negative values represented lower value than standard (Peters et al., 2002 and Wattanakij and Mongkolsawat, 2008). The standard score could be calculated as equation 2.

$$Z_{ijk} = \frac{NDVI_{ijk} - \overline{NDVI}_{ij}}{\sigma_{ij}}$$

Equation 2

Where;

Z_{ijk} = the z-value for pixel i during week j for year k

$NDVI_{ijk}$ = the weekly NDVI value for pixel i during week j for year k

\overline{NDVI}_{ij} = the mean NDVI for pixel i during week j

over n years and

σ_{ij} = the standard deviation of pixel i during week j over n years

The Z_{ijk} was assumption for the standard normal distribution; the average value was 0 and the standard deviation was 1, to experiment all points in the images on each season in 2007, 2010, and 2012. The probability of SVI from NDVI's standard scores reflected vegetation states which were likely to occur as shown in equation 3.

$$SVI = \frac{(Z_{ijk} - Z_{ijMIN})}{Z_{ijMAX} - Z_{ijMIN}} \quad \text{Equation 3}$$

Where;

Z_{ijk} = z-value for pixel i during week j for year k;

Z_{ijMAX} = maximum of z-value for pixel i during week j and

Z_{ijMIN} = minimum of z-value for pixel i during week j

The probabilities in the images were shown as SVI index. It was the probability of the present vegetation by using vegetation state from the pass. The SVI values were more than zero but less than one ($0 < SVI < 1$); 0 was the lowest standard score of SVI from 2007's, 2010's, and 2012's images. This study has distinguished the droughts from SVI values into 5 levels. Each SVI value was between 0-1 (Wang et al., 2003 and Wattanakij and Mongkolsawat, 2008), the vegetation levels have shown in Table 1.

Table1: The vegetation levels

Drought level of SVI	Percentage of SVI	Vegetation density
1.00 – 0.95	96.0% - 100%	very high
0.95 – 0.75	76.0% - 95.0%	high
0.75 – 0.25	26.0% - 75.0%	moderate
0.25 – 0.05	6.0% - 25.0%	low
0.05 – 0.00	0% - 5.0%	very low

3.3 SVI Analysis for Drought Monitoring

The SVI calculation was done by using monthly SVI data in 2007, 2010, and 2012 for the standard scores, then the average and standard deviation in each images needed to be clarified. The SVI calculation required the standard scores of each month and year, then analyzed for monthly probability in each point of images; SVI in each image. The monthly SVI map creating of 2007, 2010, and 2012 were done by arranging SVI values into levels.

4. Result

4.1 NDVI Calculation

The downloaded of MODIS data from <http://glovis.usgs.gov/> was NDVI information which could identify the differences vegetation density. From the monthly data in 2007 could be concluded that, the lowest, highest, average, and standard deviation of NDVI (Table 2) represented the vegetation density in the range of -1 to 1. The average represented density and drought of vegetation in each period of time and season. The highest average was 0.3926 in October; rainy season, and the lowest average was 0.1977 in February; end of winter. From the monthly data in 2010 could be concluded that, the lowest, highest, average, and standard deviation of NDVI (Table 3) represented the vegetation conditions in the range of -1 to 1. The average represented density and drought of vegetation in each period of time and season. The highest average was 0.5619 in May; early rainy season, and the lowest average was 0.2113 in April; end of summer.

Table 2: The lowest, highest, average and standard deviation of NDVI in 2007

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2007	-0.1987	0.7228	0.2114	0.1825
18/02/2007	-0.2000	0.7437	0.1977	0.1702
02/02/2007	-0.2000	0.6650	0.2005	0.1726
06/03/2007	-0.0571	0.9323	0.2549	0.2274
07/04/2007	-0.1990	0.8698	0.2587	0.2297
09/05/2007	-0.1933	0.9704	0.2643	0.2347
12/07/2007	-0.1711	0.8881	0.3171	0.2733
13/08/2007	-0.1202	0.9762	0.3264	0.2853
30/09/2007	-0.1917	0.9963	0.3531	0.3181
16/10/2007	-0.1996	0.8667	0.3926	0.3181
01/11/2007	-0.2000	0.8493	0.3582	0.3094
17/11/2007	-0.2000	0.8110	0.2601	0.2265
19/12/2007	-0.1986	0.7743	0.2436	0.2125

Table 3: The lowest, highest, average and standard deviation of NDVI in 2010

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2010	-0.1992	0.8426	0.2393	0.2091
18/02/2010	-0.1951	0.8674	0.2599	0.2319
06/03/2010	-0.1924	0.8134	0.2374	0.2118
07/04/2010	-0.1888	0.8441	0.2113	0.1903
09/05/2010	-0.0080	0.9283	0.2621	0.2316
25/05/2010	-0.2000	0.9995	0.5619	0.1789
10/06/2010	-0.1348	0.9351	0.2628	0.2353
12/07/2010	0.0000	0.9650	0.2858	0.2498
13/08/2010	-0.1986	0.9993	0.3102	0.2774
30/09/2010	-0.1782	0.9953	0.3508	0.3134
16/10/2010	-0.1986	0.8647	0.3807	0.3295
01/11/2010	-0.2000	0.8592	0.3114	0.2754
17/11/2010	-0.1994	0.8327	0.2832	0.2462
19/12/2010	-0.1997	0.7937	0.2476	0.2184

Table 4: The lowest, highest, average and standard deviation of NDVI in 2012

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2012	-0.1992	0.8426	0.2349	0.2103
18/02/2012	-0.1949	0.8490	0.2465	0.2202
02/02/2012	-0.1997	0.8593	0.2477	0.2194
05/03/2012	-0.1990	0.9986	0.2939	0.2590
06/04/2012	-0.1992	0.8787	0.2745	0.2437
08/05/2012	0.0000	0.9868	0.2941	0.2587
24/05/2012	0.0000	0.8863	0.2309	0.2077
09/06/2012	-0.0956	0.8264	0.2445	0.2149
11/07/2012	-0.1184	0.9930	0.3045	0.2614
12/08/2012	-0.1202	0.9762	0.3303	0.2846
29/09/2012	-0.2000	0.9995	0.7333	0.1720
15/10/2012	-0.1990	0.8486	0.3688	0.3171
31/10/2012	-0.1984	0.8282	0.3317	0.2827
16/11/2012	-0.1944	0.9980	0.2693	0.2365
18/12/2012	-0.1995	0.7831	0.2541	0.2193

From the monthly data in 2012 could be concluded that, the lowest, highest, average, and standard deviation of NDVI (Table 4) represented the vegetation density in the range of -1 to 1. The average represented density and drought of vegetation in each period of time and season. The highest average was 0.7333 in September; rainy

season, and the lowest average was 0.2349 in May; early rainy season.

4.2 The Results of SVI

The drought monitoring by using reflection of the vegetation probability in many periods of time was the Standard Vegetation Index. The differences of SVI in each point and period of the images in each year were calculated. The results were; In 2007, the lowest, highest, average, and standard deviation of SVI (Table 5) represented the vegetation density in the range of 0 to 1.

Table 5: The lowest, highest, average and standard deviation of SVI in 2007

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2007	0	1	0.4450	0.1981
18/02/2007	0	1	0.4188	0.1808
02/02/2007	0	1	0.4630	0.1995
06/03/2007	0	1	0.3153	0.2298
07/04/2007	0	1	0.4283	0.2149
09/05/2007	0	1	0.3940	0.2017
25/05/2007	0	1	0.2661	0.2024
10/06/2007	0	1	0.4608	0.2326
12/07/2007	0	1	0.4073	0.2582
13/08/2007	0	1	0.4594	0.2602
30/09/2007	0	1	0.5554	0.2678
01/11/2007	0	1	0.4560	0.2949
17/11/2007	0	1	0.4560	0.2240
19/12/2007	0	1	0.4546	0.2184

Table 6: The lowest, highest, average and standard deviation of SVI in 2010

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2010	0	1	0.4209	0.2016
18/02/2010	0	1	0.4282	0.2183
02/02/2010	0	1	0.4398	0.2179
06/03/2010	0	1	0.4398	0.2179
07/04/2010	0	1	0.3873	0.1842
25/05/2010	0	1	0.2171	0.2156
12/07/2010	0	1	0.2962	0.2589
13/08/2010	0	1	0.4228	0.2323
30/09/2010	0	1	0.4562	0.2670
16/10/2010	0	1	0.5448	0.3098
01/11/2010	0	1	0.4829	0.2599
17/11/2010	0	1	0.4676	0.2386
19/12/2010	0	1	0.4503	0.2199

Table 7: The lowest, highest, average and standard deviation of SVI in 2012

Day/Month/Year	Minimum	Maximum	Average	Standard Deviation
17/01/2012	0	1	0.4167	0.2018
02/02/2012	0	1	0.4225	0.2072
05/03/2012	0	1	0.4116	0.2167
06/04/2012	0	1	0.4395	0.2261
08/05/2012	0	1	0.2989	0.2623
24/05/2012	0	1	0.2605	0.2344
09/06/2012	0	1	0.3689	0.2332
11/07/2012	0	1	0.3806	0.2353
12/08/2012	0	1	0.4109	0.2597
29/09/2012	0	1	0.5148	0.2886
15/10/2012	0	1	0.5142	0.3028
31/10/2012	0	1	0.5164	0.2755
16/11/2012	0	1	0.3889	0.1985
18/12/2012	0	1	0.4616	0.2233

The average represented density and drought of vegetation in each period of time and season. The highest average was 0.5554 in September; rainy season, and the lowest average was 0.2661 in May; early rainy season. The SVI variances in each season and period depended on the averages, SVI standard deviation, and the lowest and highest of standard scores. In 2010, the lowest, highest, average, and standard deviation of SVI (Table 6) represented the vegetation density in the range of 0 to 1. The average represented density and drought of vegetation in each period of time and season. The highest average was 0.5448 in October; rainy season, and the lowest average was 0.2171 in May; early rainy season. The SVI variances in each season and period depended on the averages, SVI standard deviation, and the lowest and highest of standard scores.

In 2012, the lowest, highest, average, and standard deviation of SVI (Table 7) represented the vegetation density in the range of 0 to 1. The average represented density and drought of vegetation in each period of time and season. The highest average was 0.5164 in October; rainy season and the lowest average was 0.2605 in May. The SVI variances in each season and period depended on the averages, SVI standard deviation, and the lowest and highest of standard scores. Therefore, the three-year SVI averages could be concluded in Figure 1.

The graphs represented the SVI variances in each period and season which were depended on vegetation density and rainfall. In summer the results were low in January to May. The lowest result was in May 2010, then had increased to the highest in October 2007; rainy season. It had started to go down again in winter; November to February.

4.3 The Results of Drought Classification from Spatial SVI

The results of SVI analysis in 2007, 2010, and 2012 then showed in every 16-day results of 3 seasons; summer (February 17 to May 15), rainy season (May 17 – October 16), and winter (October 17 to February 16) which were classified by the vegetation density in each month (Figure 2). The percentages vegetation density results by the area of studied have shown in Figure 3. From the classification, SVI drought monitoring, monthly SVI variances in periods of time by rainfall found that, the 0.00 – 0.25 SVI were classified to be low and very low class. In May 2012, there was 2.453 percent of the area of studied. The 0.25 – 0.75 SVI were classified to be moderate class.

The most distribution was in June 2007; 99.395 percent of the area of studied. The SVI comparison in various time in a year showed the different changes of vegetation. The spatial SVI reflected the obvious unusual vegetation differences of each area in 2007, 2010, and 2013; as shown in Figures 4-6. The SVI classification in figure 4 found that, the lowest density of vegetation in Mahasarakham was in early February. The distribution of vegetation was high in May; end of summer. In summer, November had the high distribution of vegetation, then it was slowly down until February 2008. The SVI classification in figure 5 found that, the distribution of vegetation was high in February. It had started to the lowest in May; rainy season. The lowest density was in May because it was early rainy season. The distribution of vegetation was high in August and reached to the highest in October. In winter, November had the high distribution of vegetation, then it turned to the lowest in January 2011.

The SVI classification in figure 6 found that, the distribution of vegetation in summer 2012 of Mahasarakham was high in April. It was started to low in May. In rainy season, the lowest density of vegetation was in May, then it was started to get high and reached the highest in October. In winter, the density distribution was high in October, then it was started to down in November. Those could well reflect the clearly spatial and chronological droughts.

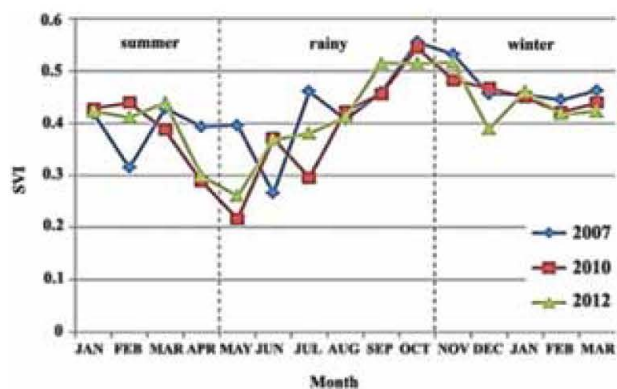


Figure 2: Three-year SVI averages

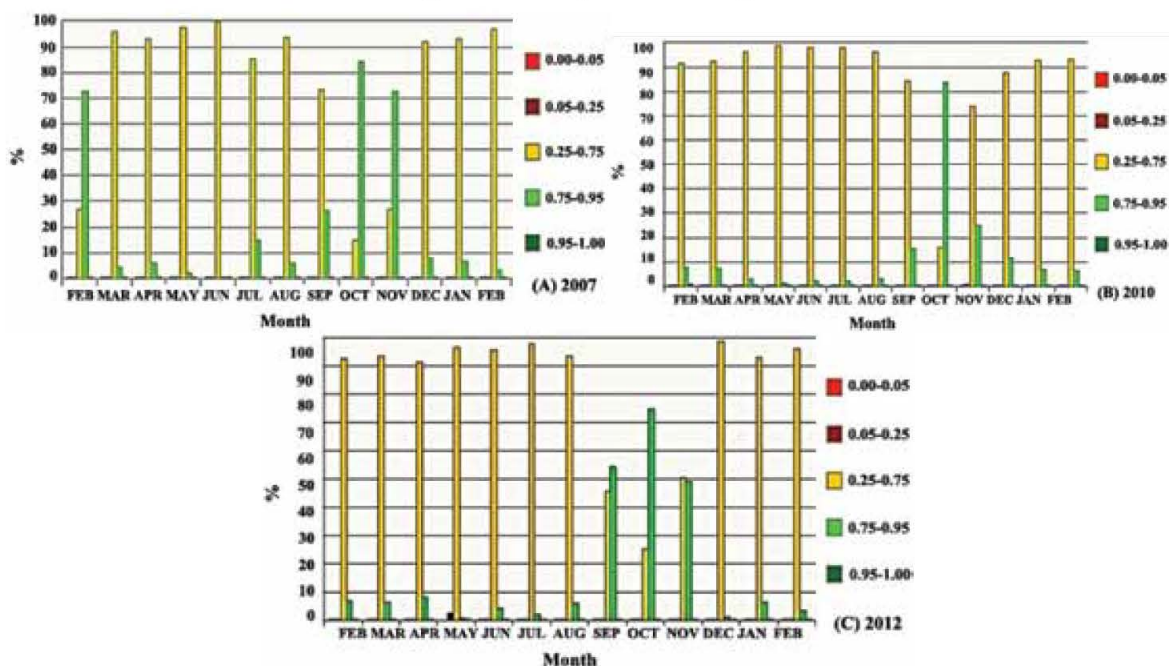


Figure 3: The percentages vegetation density (A) 2007, (B) 2010, (C) 2012

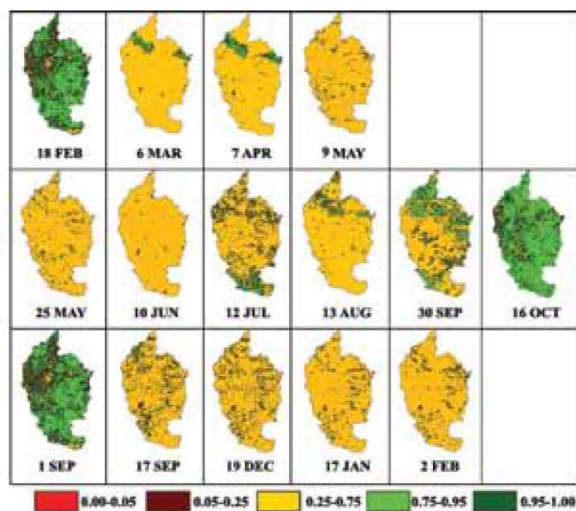


Figure 4: The spatial SVI reflected in 2007

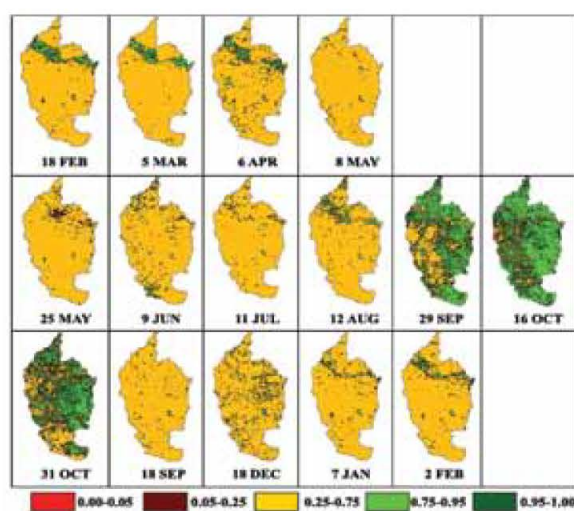


Figure 5: The spatial SVI reflected in 2010

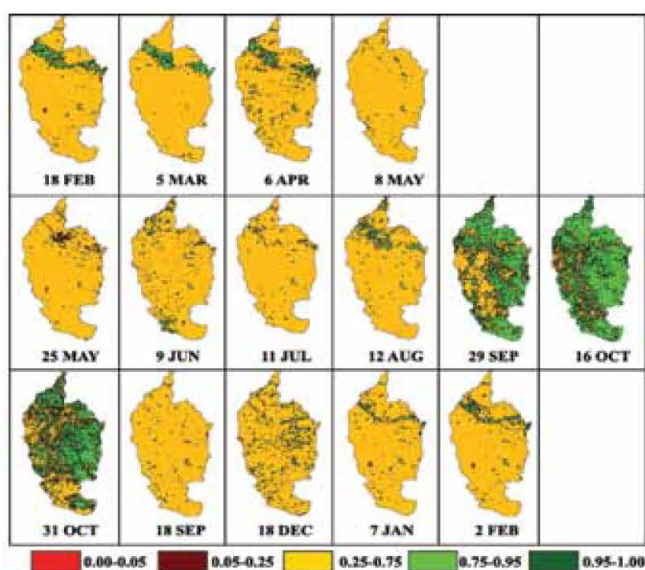


Figure 6: The spatial SVI reflected in 2012

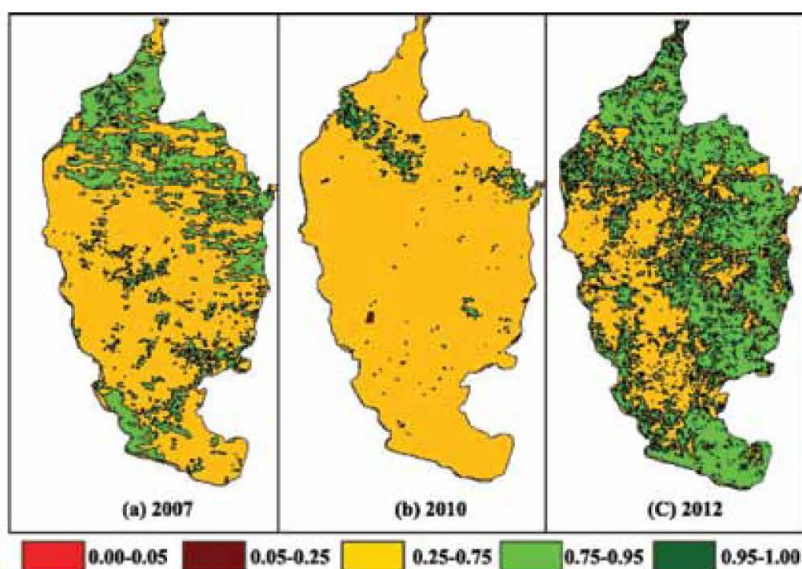


Figure 7: Annually spatial overlaying of Mahasarakham in 2007, 2010, and 2012

4.4 The Annual Results of the Spatial SVI Classification by the Level of Drought

From the study of annually spatial overlaying of Mahasarakham in 2007, 2010, and 2012 as shown in Figure 7. The chorological and spatial drought reflections were clearer than then monthly reflection. The SVI variances depended on the rainfall which was the drought determination. That factor reflected the vegetation states; comparable. The lower index than standard average meant drought. The nearly 0 values of SVI index reflected severe drought. The nearly 1 vales of SVI index reflected high moisture.

5. Conclusion

The study of SVI variances in summer, rainy season, and winter in 2007, 2010, and 2012 by showing 16-day results; comparable, have shown that, the lower average of SVI meant drought, and the nearly 0 values meant severe drought. The higher SVI index than the average meant moisture, and the nearly 1 value meant high moisture. The SVI analysis in five periods of time had found the density of vegetation as;

Period 1 (0.00 – 0.05) in 2007, 2010, and 2012 had the drought variances as 0.0066, 0.0178, and 0.0205.

Period 2 (0.05 – 0.25) in 2007, 2010, and 2012 had the drought variances as 0.0652, 0.1695, and 0.1136

Period 3 (0.24 – 0.75) in 2007, 2010, and 2012 had the drought variances as 73.5349, 96.4499, and 46.5068.

Period 4 (0.75 – 0.95) in 2007, 2010, and 2012 had the drought variances as 26.3167, 3.1526, and 53.3546.

Period 5 (0.95 – 1.00) in 2007, 2010, and 2012 had the drought variances as 0.0768, 0.2104, and 0.0047.

From the average of SVI analysis found that, in 2010 there were the most droughts for 0.1789 percent or 0.9419 sq.km, droughts were 0.1695 percent or 8.9694 sq.km, and medium droughts were 96.4499 percent or 5,103.8829 sq.km; the total was 96.637 percent. Those well reflected drought in Mahasarakham. The SVI variances in each season and period of time depended on the average standard deviation of SVI, the lowest, and the highest values of standard scores.

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References

- Bayarjargal, Y., Karnieli, A., Bayasgalan, M., Khudulmur, S., Gandush, C. and Tucker, C. J., 2006, A Comparative Study of NOAA-AVHRR Derived Drought Indices using Change Vector Analysis," *Remote Sens. Environ.*, Vol. 105, 9-22.
- Benedetti, R. and Rossini, P., 1993, On the use of NDVI Profiles as a Tool For Agricultural Statistics: the Case Study of Wheat Yield Estimate and Forecast in Emilia Romagna. *Remote Sens Environ.*, Vol. 45, No. 3, 311-326.
- Fensholt, R. and Proud, S. R., 2012, Evaluation of Earth Observation Based Global Long Term Vegetation Trends - Comparing GIMMS and MODIS Global NDVI Time Series. *Remote Sens. Environ.*, Vol. 119, 131-147.
- Gibson, P. J. and Power, C. H., 2000, *Introductory Remote Sensing Digital Image Processing and Applications*, Routledge, London, UK. 249.
- Gitay, H., Suárez, A., Watson, R. T. and Dokken, D. J., Eds., 2002, *Climate Change and Biodiversity*, IPCC Technical Paper V, IPCC, Geneva, 85.
- Gomasathit, T., Laosuwan, T., Sangpradit, S. and Rotjanakusol, T., 2015, Assessment of Drought

Risk Area in Thung Kula Rong Hai using Geographic Information System and Analytical Hierarchy Process. *International Journal of Geoinformatics*, 11 (2), 21-27.

- Kogan, F. N., 1997, Global Drought Watch from Space, *Bull. Am. Meteorol. Soc.*, Vol. 78, No. 4, 621-36.
- Kriegler, F. J., Malila, W. A., Nalepka, R. F. and Richardson, W., 1969, Preprocessing Transformations and their Effects on Multispectral Recognition. In: *Proc. The Sixth International Symposium on Remote Sensing of Environment, 13-16 October*, Ann Arbor, MI, USA, 97-131, 1969.
- Laosuwan, T., Chunpang, P. and Sukkasena, S., 2011, Development of Robotic Aerial Remote Sensing System for Field Educational Purposes. *International Journal of Geoinformatics*, Vol. 7, No. 4, 21-27.
- Laosuwan, T. and Rotjanakusol, T., 2013, The Observation and Monitoring of Water Situation by using Remote Sensing Technology and GIS. *J. Sci. Technol. MSU.*, Vol. 32, No. 2, 246 -256.
- Laosuwan, T., and Uttaruk, P., 2013, Review of Methods and Potential Role of Remote Sensing for Forest Carbon Stock Measurement: A Pilot Project for REDD+, Thailand. *International Journal of Geoinformatics*. Vol. 9, No. 1, 39-48.
- Laosuwan, T., Pattanasethanon, S. and Sangiamvibool, W., 2013, Automated Cloud Detection of Satellite Imagery using Spatial Modeler Language and ERDAS Macro Language, *IETE Tech. Rev.*, Vol. 30, No. 3, 183-190.
- Laosuwan, T. and Uttaruk, P., 2014, Estimating Tree Biomass via Remote Sensing, MSAVI 2, and Fractional Cover Model. *IETE Tech. Rev.*, Vol. 31, No. 5, 362-68.
- Laosuwan, T., and Gomasathit, T., 2014, Using Satellite Data and Image Processing Techniques for Cloud Analysis in Meteorology," 10th Mahasarakham University Conference, *J. Sci. Technol. MSU.*, 227-237.
- Marshall, G. and Zhou, X., 2004, Drought Detection in Semi-Arid Regions using Remote Sensing of Vegetation Indices and Drought Indices. In: *Proc. IEEE 2004 International Geoscience and Remote Sensing Symposium (IGARSS'04)*, 20-24 September, Anchorage, Alaska, Vol. 3, 1555-1558.
- Peters, J. A., Walter-Shea, E. A., Ji, L., Andres, V., Michael, H. and Svoboda, M. D., 2002, Drought Monitoring with NDVI-Based Standardized Vegetation Index, *Photogramm. Eng. Remote Sens.*, Vol. 68, No. 1, 71-75.
- Pettorelli, N., Vik, J., Mysterud, A., Gaillard, J. M., Tucker, C. J. and Stenseth, N. C., 2005, Using

- the Satellite-Derived NDVI to Assess Ecological Responses to Environmental change, *Trends Ecol. Evol.*, Vol. 20, No. 9, 503–510.
- Singh, R. P., Roy, S. and Kogan, F., 2003, Vegetation and Temperature Condition Indices from NOAA AVHRR Data for Drought Monitoring Over India, *Int. J. Remote Sens.*, Vol. 24, No. 22, 4393–4402.
- Sternberg, T., Tsolmon, R., Middleton, N. and Thomas, D., 2010, Tracking Desertification on the Mongolian Steppe through NDVI and Field-Survey Data, *Int. J. Digit. Earth*, Vol. 4, No. 1, 50–64.
- Thai Meteorological Department, 2013, The Expectation of the Weather during the Rainy Season of 2013. Available from: <http://www.tmd.go.th> [Last accessed on 2013 June 10].
- Tucker, C. J., Pinzon, J. E., Brown, M. E., Slayback, D. A., Pak, E. W., Mahoney, R., Vermote, E. F. and Saleous, N. E., 2005. An extended AVHRR 8-KM NDVI Dataset Compatible with MODIS and SPOT Vegetation NDVI Data, *Int. J. Remote Sens.*, Vol. 26, No. 20, 4485–4498.
- Wang, J., Rich, P. M., Price, K. P., 2003, Temporal Responses of NDVI to Precipitation and Temperature in the Central Great Plains, USA, *Int. J. Remote Sens.*, Vol. 24, No. 11, 2345–1364.
- Wattanakit, N. and Mongkolsawat, C., 2008, Drought Detection in Northeast Thailand using Standardized Vegetation Index of Multi-Temporal Satellite Data, In: Proc. 4th Environment Naresuan Conference, Naresuan University, Thailand, 206–215.