Correlation Analysis of MODIS Vegetation Indices and Meteorological Drought Indices for Spring Drought Monitoring

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ABSTRACT: Diverse researches using vegetation index have been carried out to monitor spring droughts that have frequently occurred since 2000. The strength of the drought monitoring using vegetation index lies in that it can reflect characteristics of satellite images: large area coverage, cyclicity, and promptness. However, vegetation index involve uncertainly caused by diverse factors that affect vegetation stress. In this study, multi-temporal vegetation index is compared with the most representative meteorological drought indices like PSDI, SPI. Based on the results from analyses, usability of vegetation index as a tool of drought analysis is proposed.

Key Word: Drought Index, NDVI, SPI, PDSI

1. INTRODUCTION

Droughts can be indirectly analyzed by using changes in vegetation index values produced by satellite images. The method has been used in Korea to monitor droughts that have frequently occurred since 2000 (Shin, 2003; Shin, 2006; Park et al, 2006). In mid-1990s, drought monitoring using vegetation index began to be applied to the Great Plains of the United States. The method was introduced to Korea after 2001 when nation-wide spring drought occurred. The strength of the vegetation index-based drought monitoring is that the monitoring method enables efficient spatio-temporal grasp of changes in drought events. Thanks to the development of low resolution satellite images such as MODIS(Moderate-Resolution Imaging Spectroradiometer) images, which are characterized by outstanding temporal resolution, the use of the method is expected to increase.

However, drought analysis that uses vegetation index considers only meteorological factor as a factor that affects vitality of vegetation. Because of the existence of other indirect and direct factors that cause vegetation stress, many uncertainties are involved in such method of analysis. To secure objectivity of drought analysis that uses vegetation index and to establish a drought monitoring system that uses the drought analysis method, it is therefore necessary to compare the method with most representative drought analysis tools that are used for drought management. In the case of the Great Plains of the United States, a research comparing NOAA AVHRR NDVI(Normalized Difference Vegetation Index) and SPI(Standardized Precipitation Index) drought index was carried out. Highest correlation was found in three-month SPI in grassland and six-month SPI in farmland (Lei and Albert, 2003).

In this study, PDSI(Palmer Drought Severity Index), SPI which a meteorological drought index that quantifies drought and that is used as a basic index for drought monitoring and MODIS NDVI are compared to propose correlation among them and to secure objectivity of drought analysis that uses vegetation index. Moreover, an analysis that considers land cover and geographical location was carried out to propose effective drought monitoring method that uses vegetation index.

2. METHODOLOGY AND DATA

To analyze the correlation between vegetation index and meteorological drought index, data from observation points involving the two indices were compared. Data for the month of April, when droughts are most frequent, from 2000 to 2007 were selected. To establish vegetation index, monthly data of 1 km resolution MODIS NDVI products in the South Korea were collected and converted. To calculate drought indices in each location, 53 observation points, for which long-term rainfall data are available, were selected to compute PDSI and SPI of each location and to produce a spatial distribution map.

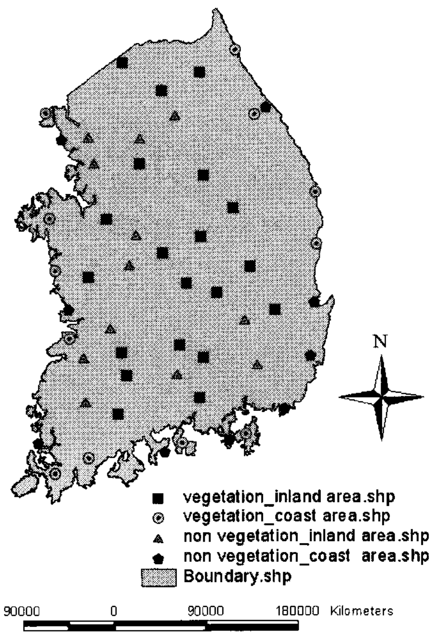
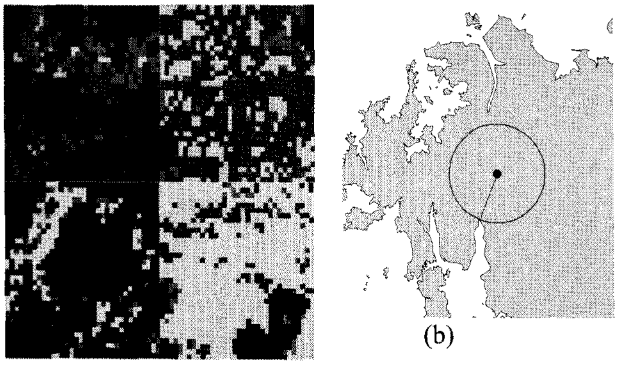


Figure 1. 53 observation points

In this study, observation points were categorized into four classes in consideration of the land cover and seawater that affect vegetation. As shown in Figure 2 (a) and Table 1, land cover rate of each cell where an observation point is included was calculated; observation points with more than 50% land cover rate were separated from those with less than 50% rate. As shown in Figure 2 (b), the distance between observation points and the coast was computed; observation points within 10 km radius from the coast were treated separately as they can be influenced by seawater that affects evapotranspiration. As a result, four categories of observation points for analyses emerged: 20 "vegetation cover/inland" points, 12 "vegetation cover/coastal" points, 12 "non-vegetation cover/inland" points, 9 "non-vegetation cover/coastal" points.



(a) (b)

Figure 2. Land cover in each of observation points (examples) (a) Computation of distance from the coast (b)

Table 1. Categorization of observation points by land cover

No.	station	water	urban	bare Soil	wetland	grass	forest	paddy	non-Vegetation	Vegetation	inland	Vegetation_in land
101	Chuncheon	0.0%	25.4%	10.9%	0.0%	0.0%	2.3%	61.3%	36.3%	63.7%	O	O
105	Gangneung	0.0%	85.3%	6.4%	0.0%	1.6%	0.2%	6.6%	91.7%	8.3%		
108	Seoul	0.0%	49.9%	6.1%	0.2%	26.1%	17.6%	0.0%	56.1%	43.9%	O	
112	Incheon	0.9%	86.4%	4.7%	0.1%	5.8%	2.1%	0.0%	92.0%	8.0%		
119	Suwon	15.4%	28.8%	14.6%	0.0%	4.0%	9.4%	27.8%	58.8%	41.2%	O	
129	Seosan	0.0%	1.1%	6.9%	0.0%	5.6%	16.3%	70.0%	8.0%	92.0%		
130	Uljin	21.9%	3.9%	7.0%	0.0%	11.5%	45.7%	10.0%	32.8%	67.2%		
135	Choopoong-ryung	0.2%	6.8%	1.5%	0.0%	14.5%	26.0%	51.1%	8.5%	91.5%	O	O
138	Pohang	57.9%	28.2%	3.4%	0.8%	10.6%	1.2%	0.0%	87.5%	12.5%		
140	Gunsan	67.7%	14.2%	4.0%	7.3%	5.2%	1.6%	0.0%	85.9%	14.1%		
143	Daegu	0.0%	98.4%	1.4%	0.0%	0.1%	0.1%	0.0%	99.8%	0.2%	O	
152	Ulsan	0.0%	86.9%	3.6%	0.0%	6.7%	0.0%	2.8%	90.5%	9.5%		
156	Kwangju	0.0%	78.0%	8.3%	0.0%	4.3%	9.3%	0.0%	86.3%	13.7%	O	
159	Busan	11.3%	72.1%	4.4%	0.2%	6.6%	5.5%	0.0%	87.7%	12.3%		
162	Tongyeong	45.3%	17.3%	1.1%	0.5%	12.3%	22.3%	1.3%	63.7%	36.3%		
165	Mokpo	0.0%	34.6%	16.9%	1.2%	7.6%	21.5%	18.2%	51.5%	48.5%		
168	Yeosu	17.0%	63.8%	9.4%	0.0%	1.6%	4.6%	3.5%	90.3%	9.7%		
201	Ganghwa	0.0%	8.4%	7.6%	0.0%	8.2%	14.0%	61.7%	16.1%	83.9%		
202	Yangpyung	4.1%	42.6%	7.8%	0.0%	0.3%	1.9%	43.3%	54.5%	45.5%	O	
212	Hongcheon	1.4%	54.7%	8.2%	0.0%	0.5%	6.9%	28.3%	64.3%	35.7%	O	
221	Jecheon	0.0%	0.3%	3.5%	0.0%	17.5%	19.9%	58.8%	3.8%	96.2%	O	O
235	Boryeong	0.0%	11.0%	7.6%	0.0%	11.6%	12.5%	57.3%	18.6%	81.4%		
245	Jeongeup	0.0%	74.9%	5.4%	0.1%	11.3%	6.7%	1.7%	80.2%	19.8%	O	
256	Suncheon	14.4%	17.9%	5.0%	0.0%	5.9%	18.9%	37.6%	37.4%	62.6%	O	O
260	Jangheung	0.0%	5.9%	0.4%	0.0%	1.2%	10.5%	82.0%	8.3%	91.7%		
261	Haenam	0.0%	4.1%	0.4%	0.2%	0.6%	1.3%	93.2%	4.5%	95.5%		
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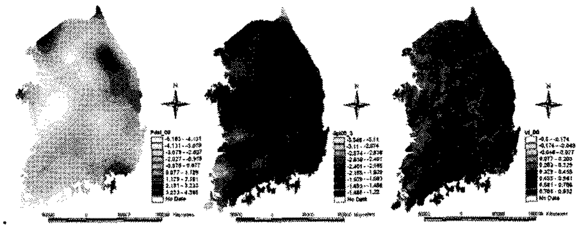
3. CORRELATION ANALYSIS OF DI AND VI

3.1 Creation of correlation coefficient map for vegetation index and drought index

As shown in Figure 3, monthly PDSI; one-month, three-month, and six-month SPI; and NDVI were used to analyze the relationship between vegetation index and drought index. Each of drought indices and NDVI were grid data with identical cell interval. ArcView grid computation was carried out to compute correlation coefficient of each of grid data. Table 2 shows correlation coefficients between NDVI in Aprils of the years from 2000 to 2007 and each of drought indices. No correlation was found between vegetation index and drought index of the same period. This can be explained by two factors. First, each NDVI just reflects current vitality of vegetation, whereas PDSI and SPI show current value that calculated result with past multi-temporal data. Second, drought index, which was generated by interpolation of point data, included qualitative spatial unbalance.



(a) PDSI (b) SPI 3-month (c) NDVI

Figure 3. PDSI, SPI 3-month, NDVI (2000/4)

Table 2. Correlation coefficient between vegetation index and drought index by year

April	NDVI & PDSI	NDVI & SPI 1	NDVI & SPI 3	NDVI & SPI 6
2000	-0.08	-0.05	0.14	-0.1
2001	0.03	-0.00	-0.1	-0.07
2002	0.11	-0.09	-0.05	0.08
2003	-0.07	-0.13	-0.13	-0.14
2004	0.07	0.14	0.06	0.13
2005	-0.01	-0.08	-0.05	-0.03
2006	-0.08	-0.03	-0.00	0.08
2007	0.10	0.07	0.02	-0.01

To find out the relationship between changes in inter-temporal drought indices and changes in vegetation indices, correlation between drought index and vegetation index for each of the cells during the eight years was calculated as shown in Table 3. The results were presented in a correlation map shown in Figure 3.

Table 3. Correlation coefficient of multi-temporal vegetation index and drought index

NDVI								SPI 6 month								R
2000	2001	2002	2003	2004	2005	2006	2007	2000	2001	2002	2003	2004	2005	2006	2007	
0.255	0.276	0.289	0.301	0.298	0.286	0.291	0.319	-2.344	-1.013	-0.082	1.065	-0.504	-0.918	-0.465	-0.461	0.720
0.252	0.271	0.289	0.416	0.305	0.306	0.312	0.320	-2.340	-1.001	-0.078	1.069	-0.496	-0.910	-0.468	-0.451	0.873
0.294	0.328	0.355	0.549	0.398	0.385	0.387	0.410	-2.335	-0.988	-0.074	1.074	-0.488	-0.901	-0.472	-0.442	0.878
0.352	0.394	0.442	0.563	0.441	0.431	0.447	0.441	-2.330	-0.974	-0.070	1.078	-0.479	-0.891	-0.476	-0.432	0.953
0.268	0.289	0.313	0.384	0.315	0.305	0.301	0.308	-2.325	-0.959	-0.066	1.083	-0.471	-0.882	-0.481	-0.422	0.927
0.219	0.240	0.263	0.294	0.270	0.259	0.246	0.276	-2.320	-0.942	-0.061	1.087	-0.463	-0.872	-0.487	-0.412	0.904
0.211	0.214	0.230	0.233	0.232	0.228	0.202	0.267	-2.314	-0.925	-0.056	1.092	-0.455	-0.861	-0.492	-0.402	0.374
0.264	0.281	0.334	0.402	0.306	0.319	0.289	0.317	-2.308	-0.907	-0.051	1.097	-0.447	-0.851	-0.498	-0.393	0.897
0.449	0.495	0.621	0.708	0.554	0.490	0.498	0.473	-2.302	-0.888	-0.046	1.101	-0.439	-0.841	-0.505	-0.383	0.852
0.492	0.577	0.727	0.819	0.649	0.735	0.535	0.511	-2.296	-0.867	-0.041	1.106	-0.431	-0.831	-0.512	-0.374	0.712
0.498	0.565	0.738	0.824	0.662	0.747	0.563	0.523	-2.289	-0.846	-0.036	1.110	-0.424	-0.822	-0.519	-0.365	0.723
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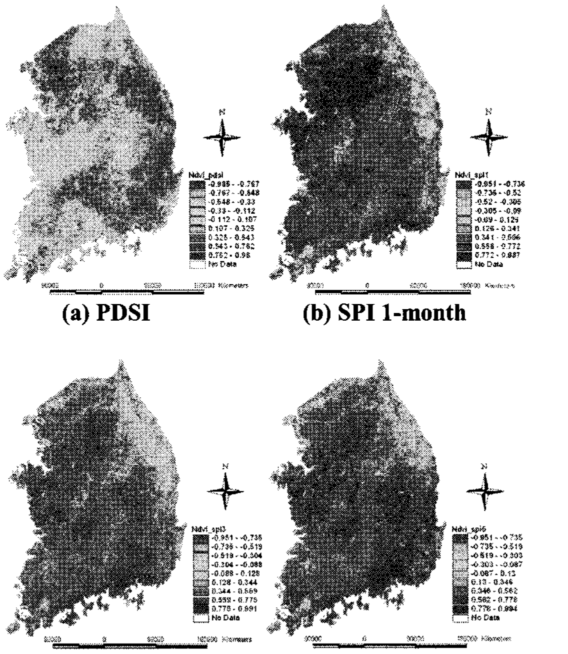

(a) PDSI (b) SPI 1-month

(c) SPI 3-month (d) SPI 6-month

Figure 3. Correlation coefficient map of vegetation index and drought index by pixel (2000~2007)

Table 4. Mean of correlation coefficient map

2000~2007	NDVI & PDSI	NDVI & SPI 1	NDVI & SPI 3	NDVI & SPI 6
mean of correlation coefficient	0.187	0.468	0.503	0.519

The correlation map of inter-temporal drought index and NDVI, which were calculated for each of the pixels, can illustrate not only local correlation but also can identify NDVI that are highly correlated with a drought index. Table 4 shows the average for each of correlation coefficients. In the case of NDVI and PDSI, correlation was not high whereas local correlation was found between NDVI and SPI. The highest correlation was found between six-month SPI and NDVI.

3.1 Correlation computation for each point and comparison of coefficient of determination

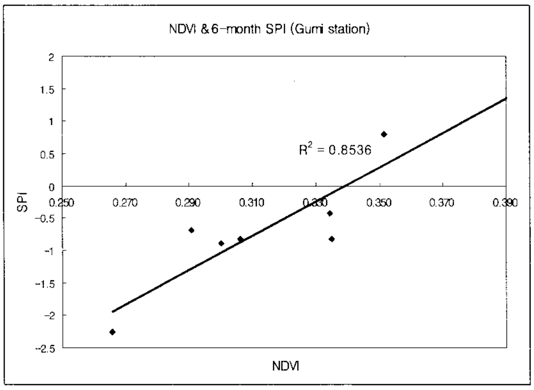

Figure 4. Correlation analysis of vegetation index and drought index by point (Gumi point)

Correlation shown in Figure 3 and Table 4 stems from the comparison between drought index interpolated by observation point and cell-unit calculation of NDVI. In this study, Cell-unit analysis for 53 observation points was carried out for more accurate comparison of NDVI and drought index. As was proposed in the methodology section of this paper, 53 observation points were classified in accordance with their geographical location and land cover rate; as shown in Figure 4, correlation was calculated for each of observation point pixels. Then, coefficient of determination, which shows the fitness of the regression, was computed to evaluate the usability of vegetation index. Moreover, monthly SPI was produced for more accurate identification of water shortage periods that are reflected by vegetation index.

Table 5. Comparison of coefficient of determination (r^2) of vegetation index and drought index (vegetation & inland area)

vegetation-inland area		PDSI	SPI 1	SPI 2	SPI 3	SPI 4	SPI 5	SPI 6
Gumi	NDVI	0.13	0.49	0.70	0.83	0.75	0.80	0.85
Chuncheon	NDVI	0.46	0.57	0.57	0.75	0.75	0.68	0.87
Hapcheon	NDVI	0.32	0.58	0.84	0.61	0.59	0.66	0.45
Geochang	NDVI	0.24	0.63	0.76	0.58	0.51	0.58	0.49
Mungyeong	NDVI	0.01	0.59	0.60	0.75	0.79	0.75	0.82
Yeongju	NDVI	0	0.29	0.37	0.62	0.49	0.60	0.74
Jecheon	NDVI	0.01	0.43	0.49	0.71	0.70	0.80	0.68
Choopoong-ryung	NDVI	0.2	0.55	0.66	0.83	0.67	0.71	0.80
Suncheon	NDVI	0.03	0.56	0.58	0.64	0.48	0.47	0.41

Table 6. Comparison of coefficient of determination (r^2) of vegetation index and drought index (vegetation & coast area)

vegetation-coast area		PDSI	SPI 1	SPI 2	SPI 3	SPI 4	SPI 5	SPI 6
Seosan	NDVI	0.15	0.46	0.53	0.65	0.55	0.46	0.76
Uljin	NDVI	0.69	0.38	0.42	0.38	0.14	0.16	0.89
Geoje	NDVI	0.3	0.31	0.29	0.50	0.61	0.65	0.77
Boryeong	NDVI	0.02	0.32	0.45	0.55	0.25	0.22	0.35
Haenam	NDVI	0.14	0.53	0.57	0.69	0.70	0.60	0.62
Ganghwa	NDVI	0.06	0.60	0.62	0.55	0.55	0.53	0.29
Jangheung	NDVI	0.19	0.35	0.31	0.48	0.40	0.38	0.51
Namhae	NDVI	0.03	0.33	0.32	0.42	0.46	0.45	0.49
Yeongdeok	NDVI	0.01	0.22	0.12	0.03	0.11	0.12	0.48

Table 7. Comparison of coefficient of determination (r^2) of vegetation index and drought index (non vegetation & inland area)

non vegetation-inland area		PDSI	SPI 1	SPI 2	SPI 3	SPI 4	SPI 5	SPI 6
Yangpyung	NDVI	0.04	0.51	0.54	0.70	0.61	0.59	0.71
Jeongeup	NDVI	0	0.55	0.57	0.43	0.55	0.56	0.45
Miryang	NDVI	0.09	0.62	0.53	0.69	0.72	0.70	0.72
Seoul	NDVI	0.08	0.52	0.53	0.47	0.55	0.40	0.28
Suwon	NDVI	0.09	0.62	0.52	0.55	0.46	0.37	0.51
Daegu	NDVI	0	0.22	0.19	0.34	0.29	0.31	0.43
Kwangju	NDVI	0.07	0.20	0.22	0.16	0.21	0.22	0.15
Hongcheon	NDVI	0.21	0.18	0.13	0.24	0.21	0.14	0.30
Sancheong	NDVI	0.18	0.13	0.31	0.26	0.42	0.52	0.44

Table 8. Comparison of coefficient of determination (r^2) of vegetation index and drought index (non vegetation & coast area)

non vegetation-coast area		PDSI	SPI 1	SPI 2	SPI 3	SPI 4	SPI 5	SPI 6
Ulsan	NDVI	0	0.14	0.17	0.49	0.55	0.52	0.87
Yeosu	NDVI	0.01	0.50	0.55	0.78	0.76	0.78	0.81
Mokpo	NDVI	0.18	0.40	0.42	0.46	0.55	0.45	0.39
Tongyeong	NDVI	0.24	0.13	0.13	0.15	0.14	0.15	0.10
Pohang	NDVI	0	0.24	0.09	0.11	0.00	0.00	0.38
Incheon	NDVI	0.01	0.28	0.41	0.45	0.45	0.42	0.21
Busan	NDVI	0.23	0.16	0.12	0.19	0.10	0.08	0.12
Gangneum	NDVI	0.04	0.24	0.14	0.05	0.02	0.04	0.17
Gunsan	NDVI	0.06	0.19	0.17	0.05	0.00	0.00	0.01

4. RESULT

Tables 5-8 show coefficient of determination between PDSI, monthly SPI drought index, and NDVI for each location. Correlation analysis for 20 "vegetation cover/inland" points, 12 "vegetation cover/coastal" points, 12 "non-vegetation cover/inland" points, 9 "non-vegetation cover/coastal" points was carried out and top-nine points were presented. Shaded parts show highest values among correlation analysis results. Analysis by points did not reveal correlation between PDSI and NDVI. Correlation between three-month and six-month SPI drought index and NDVI was relatively high. Correlation between vegetation index and drought index was highest in inland vegetation cover. Correlation was lowest in non-vegetation cover/coastal region. For each of the classes, points with more than 0.6 of coefficient of determination were selected. Highest correlation was found at points with more than 95% level in the case of vegetation cover/inland points, more than 58% level for vegetation cover/coastal points, more than 50% level for non-vegetation/inland points, and more than 44% level for non-vegetation cover/coastal points. In addition, highest correlation was found between six-month SPI and vegetation index.

5. CONCLUSION

NDVI has been continuously studied and used to detect spring droughts, which has regularly occurred in the South Korea, and to evaluate the intensity of the droughts. To secure objectivity of NDVI-based drought analysis, correlation between PDSI, SPI representative drought index, and NDVI analyzed in this study. This study showed that NDVI is correlated with SPI drought index and that the finding can be applied to offset weaknesses of existing drought index. Moreover, it was shown that PDSI, which is based on water budget analysis, is not correlated with vegetation index, unlike SPI, which is computed by cumulative rainfall. Based on the finding that NDVI is most highly correlated with six-month SPI, drought analysis based on vegetation index could be most effectively used for droughts that last from winter to spring. It is expected that the usability of NDVI will be maximized in inland areas with vegetation cover.

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