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Investigation of Vegetation Dynamics of Mongolia Using Time Series of NDVI in Response to Temperature and Precipitation

Dugarsuren Narangarav and Chinsu Lin*

*Department of Forestry, National Chiayi University, 300 University Rd., Chiayi, Chiayi 60004, Taiwan, e-mail: ndugarsuren@yahoo.com, *corresponding author: e-mail: chinsu@mail.ncyu.edu.tw*

Abstract

Climate is one of the most important factors affecting the condition of vegetation. Plants are highly sensitive to climate change and display the most sensitive response to the effect of the climate change and environment, most particularly seen in the annual and seasonal alternations of vegetation productivity. Through the analysis of remotely sensed images, it is proved that vegetation indices can give significant information regarding vegetation. The main purpose of this study was to estimate the influences of precipitation and temperature on spatio-temporal pattern of vegetation dynamics in Mongolia using MODIS sensor derived NDVI images over the course of 10 years. The correlation coefficient showed that mean growing season NDVI was correlated with both climatic factors, but more significantly correlated with precipitation (r^2=0.92, p=0.000) than temperature (r^2=0.55, p=0.013). Growing season precipitation slightly decreased with an annual average decrement of 0.2 mm (r^2=0.06). Meanwhile, the growing season mean temperature slightly increased over 10 years, with an annual average increment of 0.01°C per year (r^2=0.003) from 2000 to 2009. However, the relationship between NDVI and climatic factors, and their change trends have been varied spatially and temporally.

Key words: Normalized Difference Vegetation Index, precipitation, temperature, correlation analysis, Mongolia

Introduction

Climatic condition is one of the most important factors affecting the structure and dynamics of vegetation. Plants are highly sensitive to climate change and display the most sensitive response to the effect of the climate change and environment, which particularly seen in the annual and seasonal alternations of vegetation productivity (Wang *et al*., 1999). Through the analysis of remotely sensed images, it is proved that vegetation indexes can give the more significant information regarding vegetation. The Normalized Difference Vegetation Index (NDVI) is a widely used one among vegetation indices, and it is the perfect indicator of coverage, growth, biomass as well as photosynthesis of the vegetation (Keeling *et al*., 1996; Piao *et al*., 2003). NDVI is defined by following formula:

$$NDVI = \frac{P_{nir} - P_{red}}{P_{nir} + P_{red}} \qquad (1)$$

where, P_{nir} refers to reflection rate of the near infrared waveband and P_{red} refers to the reflection rate of red waveband.

Although the correction to remove the effects of atmosphere has already been carried out on NDVI images (Vermote & Vermeulen, 1999), but some noise was still observed in the datasets due to minor cloud cover, water, snow or shadow. In order to eliminate further these noises, the Maximum Value Composite was used in data preprocessing. Regression or correlation technique is the common empirical approaches used to quantify the relationships between two and more variables (Zimmerman, 1986). For the two variables, x and y, the correlation coefficients calculated as:

$$r_{xy} = \frac{\sum_{i=1}^{n} \overline{x_i - (y)}}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \times \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \qquad (2)$$

where, n is the number of samples; x_i represents the value of x for the sample i; y_i

represents the value of y for the sample i; x is the mean for all x_i; y is the mean for all y_i.

The spatial and temporal resolution of NDVI image derived from MODIS sensor; in combination with climatic data make it possible to monitor vegetation activity at the different spatial and temporal changes as regression and correlation techniques. The main purpose of this research is to estimate influences of precipitation and temperature on the spatial and temporal pattern of vegetation dynamics within Mongolia from NDVI images derived from MODIS sensor over the course of 10 years.

Material and Methods

Study area

Mongolia is one of the largest landlocked countries in the world, extending between the latitudes of 41º35'- 52º09'N and longitudes of 87º44' - 119º56'E, and covering 1,564 square kilometers. The average altitude is 1580 m a.s. l. The main climatic characteristics of Mongolia are sunny days (an average of 260), long and cold winters, dry and hot summers, low precipitation, and high temperature fluctuation. The temporal and spatial distributions of temperature and precipitation in Mongolia are variable from north to south direction. The mean air temperature in the warmest month is 15-20^{o}C in the north, and 20-25^{o}C in the south of Mongolia. The summer continues over 3 months in the Gobi desert and steppe zones. The total annual precipitation in mountainous regions averages about 400 mm, in the steppe 150-250 mm, and in the desert-steppe less than 100 mm. There is very little precipitation at the beginning of the growing season. About 85 to 90 percent of the precipitation falls during the three summer months (June to August). This pattern has considerable effects on the growth of several spring plants (Shiirevdamba, 1998).

Table 1. Selected meteorological stations corresponding with land cover types

№	Station name	Latitude (°)	Longitude (°)	Altitude (m)	Landscape types
1	Sukhbaatar	50.25	106.21	null	Forest
2	Inget Tolgoi	49.27	103.59	800	Forest
3	Khutag-Undur	49.23	102.42	933	Forest
4	Baruun-Urt	46.68	113.28	981	Grassland
5	Undurkhaan	47.32	110.67	1033	Grassland
6	Hujirt	46.90	102.77	1662	Grassland
7	Sainshand	44.90	110.12	938	Desert-steppe
8	Mandalgovi	45.75	106.27	1393	Desert-steppe
9	Ehiin gol	43.15	99.00	974	Desert
10	Dalanzadgad	43.58	104.42	1465	Desert

Ten meteorological stations distributed over different land cover types have been selected for analyze of this study. Table 1 demonstrated that selected meteorological stations and their corresponding land cover types.

Forest-steppe: This belt comprises the convergence of high mountain, taiga and steppe plants, including *Poa, Koeleria* and their "cushion" communities. This belt is dominated by *Rhodicoccum, Carex, Koberisia,* Larches *Larix sibirica* and Birch species and the plants of steppe meadows and river banks. This zone has unique, rare vegetation including *Adonis mongolica* and *Saussurea involucrata* plant species.

Steppe (grassland): This zone is divided into 3 subzones: meadow steppe, typical steppe and dry steppe. The steppe zone occupies a far greater area than another zones, covering 25.9% of Mongolia. Of which 4.3 % is meadow steppe, 10.1% is typical steppe, 14.3 % dry steppe and 5.5% mountain steppe. The Mongolian steppe has some species of *Caragana* and *Artemisia frigida as xerophytes shrubs*.

Desert-steppe: This zone has dry steppe plants, including *Artemisa frigida* and *Caragana*. At the same time, it also includes the plant species of transitional zones which are influenced by the Central Asian desert vegetation cover.The climate is dry and arid, annual precipitation 100-

200 mm, soil cover is thin and *Caragana bungei* exist as relict plant species.

Desert: This zone is divided into three sub-zones: semi desert steppe, typical desert and extreme (arid) desert. *Allium polyrrhizum, Stipa gobica* and some semi-dwarf shrubs grow throughout these sub-zones, especially along the boundaries of the steppe zone. The vegetation cover of the desert steppe is dominated by semi-dwarf and dwarf shrubs. The climate is an extreme continental climate with annual precipitation of 50-100 mm. Vegetation is dominated by rare and endemic plant species including: *Populus diversifolia, Incarvillea potaninii, Ammopiptantus mongolicus* and *Halimodendron halodendron.*

Data source

The multi-temporal NDVI images used in this research were acquired from the NASA Terra (AM-1) satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. MOD13Q1 vegetation index products with 250 m spatial resolution and 16 day temporal resolution have been downloaded from the EOS NASA Land Processes Distributed Active Archive Center website: http://lpdaac.usgs.gov/datapool/datapool.asp. Monthly mean air temperatures and precipitation data at the 10 meteorological stations distributed over different vegetation cover have been selected for relation analysis from January 2000 to December 2009. Locations and distribution of the stations are given in Fig. 1. The land cover (LC) map extracted from previous research, included 12 land cover types, which have been utilized for this study. For the convenience of discussion of vegetation spatial variation, the image has been integrated into four broad classes: forest, grassland, desert-steppe and desert (Fig. 1).

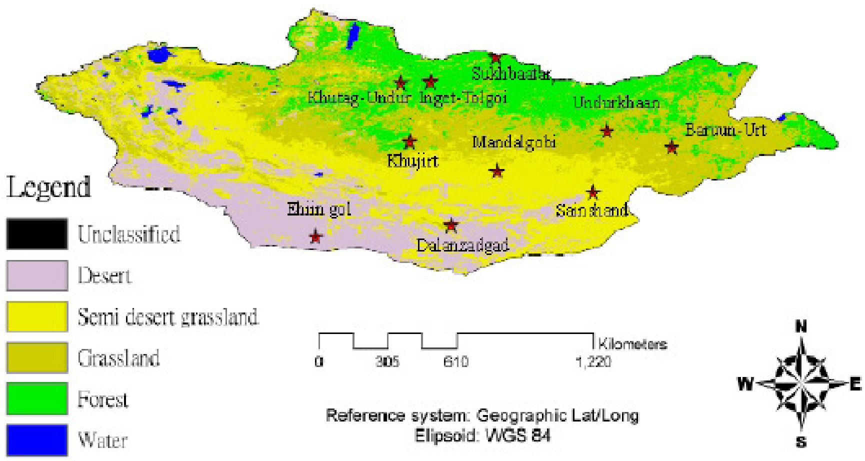

Figure 1. Land cover map with selected meteorological stations.

Methodology

Prior to analysis, the MODIS derived NDVI images were geometrically corrected using ENVI 4.5 image processing software to the Geographical (Lat/Lon) WGS84 system with the nearest neighbor assignment. Mosaic and subset operations were then carried out on the geo-corrected images to obtain MODIS NDVI time serial images which completely cover the whole Mongolia. Further NDVI image and climatic data have been organized into a suitable historical database, implemented in order to grant their spatial temporal integration such as monthly, annual (growing season) and inter annual NDVI time series. Maximum Value Composite method was used to obtain the monthly value of NDVI images. Growth season and inter annual average NDVI images were generated by averaging the monthly NDVI images at all selected stations, and in each station as well as in each growing season during 10 years. Mean NDVI composites for each period were calculated based on the pixel by pixel grid model using Formula 3:

$$\text{NDVI mean} = \text{mean}\,(NDVI_{i1}, NDVI_{i2} \ldots\ldots NDVI_{ij}) \quad (3)$$

where, i is 1, 2,…, n (period), j is number of years.

The NDVI values at the 10 selected meteorological stations were extracted from stacked NDVI images according to the corresponding coordinate of stations' location as shown in Fig. 1. Furthermore, time series analysis and correlation analysis were employed to judge the trend of vegetation cover change, its significance and relation to climate factors (temperature and precipitation).

Minitab 15 statistical software was used for the correlation analysis in this research.

Results and Discussion

Annual variation of NDVI

By averaging the monthly NDVI, temperature and precipitation data during the last 10 years, the inter-annual mean dynamic of temperature, precipitation and NDVI at the selected stations were worked out as shown in Fig. 2. The temporal pattern of NDVI coincided with the seasonality of climatic variables. A remarkable increase of NDVI was found in May, and continued steeply through June to the end of July. After showing the annual maximal values in July or August, NDVI dropped continuously until October to reach the same levels of those found in April. From October to the next April, variation of NDVI was mainly caused by snowfall.

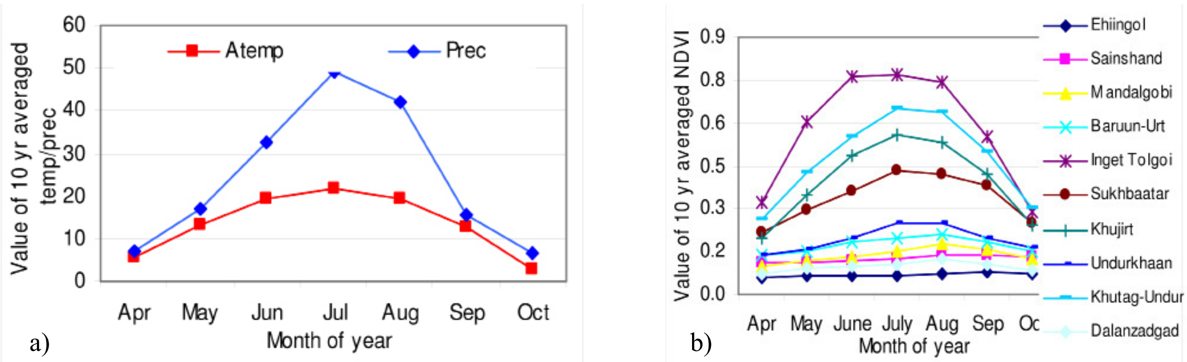

Figure 2. Ten years averaged growing season dynamics. a - air temperature and precipitation; b - NDVI at each selected station.

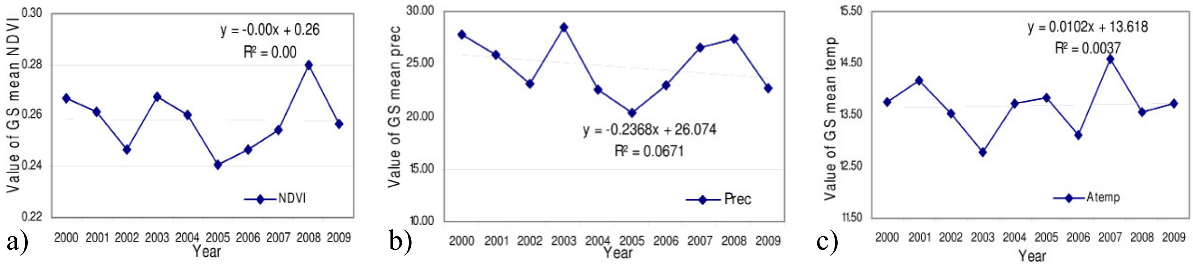

Figure 3. Inter-annual change trend in (a) growing season mean NDVI, (b) growing season mean precipitation (mm), and (c) growing season mean temperature (°C) of selected stations from 2000 to 2009.

Trends and inter-annual variations in mean growing season NDVI

The figure 3 illustrates the change trend in mean growing season NDVI, growing season mean precipitation, and growing season mean temperature of all selected stations during 2000-2009. In general, the variations of NDVI, averaged over all stations in last 10 years were not changed (r^2=0.00) (Fig. 3a). While the growing season precipitation was slightly decreased with an annual average decrease of 0.2 mm (r^2=0.06), and growing season mean temperature was very slightly increased over 10 years, with an average increase of 0.01°C per year (r^2=0.003) (Fig. 3b-c).

The figures given in Appendix 1 showed the variations in mean growing season NDVI, growing season precipitation and temperature from 2000 to 2009 at each selected station. Mean growing season NDVI for all these stations slightly increased (ranging from r^2=0.01 to r^2=0.58). The Sukhbaatar (App.1(1)), Inget Tolgoi (App.1(2)) and Khutag-Undur (App.1(3)) stations are located in forest area. Inget Tolgoi and Khutag-Undur stations exhibited the most significant increasing trend of NDVI, with an average annual increment of 0.0326 and 0.0138 (r^2=0.58 and r^2=0.52), respectively. Precipitation has not been changed at Inget Tolgoi station, but decreased at Sukhbaatar station during these 10 years. Meanwhile, at Khutag-Undur station the precipitation was increased with mean annual increment of 0.4854 (r^2=0.05). The Baruun-Urt (App.1(4)), Undurkhaan (App.1(5)), Khujirt (App.1(6)) stations are situated in grassland area. Their mean growing season NDVI were increased, with mean annual increment of 0.0019, 0.0032 and 0.0028 (r^2=0.024, 0.043 and 0.016), respectively. In Sainshand (App.1(7)) station, located in desert-steppe the mean growing season NDVI and precipitation were decreased, with average annual decrement of 0.002 and 0.34 (r^2=0.122 and 0.038), respectively. While mean temperature was slightly increased with annual increase of 0.042 (r^2=0.05). In contrast, the Mandalgobi station (App.1(8)) in desert-steppe, interannual variation of growing season NDVI and temperature were increased slightly with annual average change of 0.002 and 0.048 (r^2=0.05 and 0.06), individually. The precipitation of the Mandalgobi station has been decreased, with an annual average decrement of 0.86 (r^2=0.2). Both Ehiingol (App.1(9)) and Dalanzadgad (App.1(10)) stations in desert area, the NDVI, temperature and precipitation are showed a similar trend over the study period. Mean growing season NDVI and temperature were weakly increased, but precipitation was decreased slightly. Annual increments of NDVI were 0.0013 and 0.002 (r^2=0.1 and 0.05), respectively. As for temperature, mean annual increment for both stations were 0.036 (r^2=0.05) and 0.016 (r^2=0.11), respectively. At the same time, the precipitation was slightly decreased by 0.026 (r^2=0.0002) in Ehiingol and 0.34 (r^2=0.033) in Dalanzadgad stations in desert area during 10 years of period. Slightly increasing trend of NDVI at the some stations over the last decades has might been effected by the net carbon productivity changes due to recent global warming which accelerates carbon loss through soil heterotrophic respiration. This result is consistent with the results of several other studies (e.g. Raich *et al.*, 2002; Piao *et al.*, 2006).

Interannual change rate of seasonal NDVI

The figure 4 allows us to see quantitative results of inter-annual change rate (percent) of NDVI, and climatic variables averaged over 10 stations during the 10-year study period. Decreased precipitation from that of previous year was being corresponded with decrease of

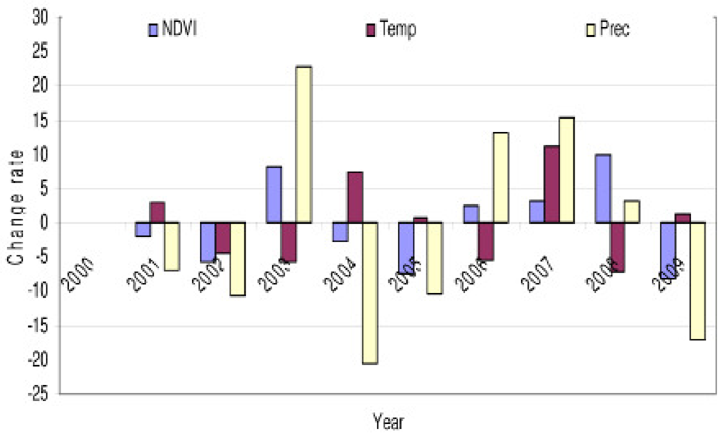

Figure 4. Quantitative result of inter-annual change rate of NDVI and climatic variables averaged over studied stations in 10 years.

growing season NDVI in 2001, 2002, 2004, 2005 and 2009. In contrast, increased NDVI in 2003, 2006, 2007, 2008 was associated with increased precipitation in these years. The temperature increases were noted in 2001, 2004, 2005, 2007 and 2009, but decrease in 2002, 2003, 2006 and 2008. Generally, NDVI and precipitation are co-varied over the study stations. Change of precipitation regulates the change of growing season NDVI in a certain year in the same direction, both positive and negative deviations. The same result has been observed as considering change trend at each selected stations (App. 1).

Correlation between mean growing season NDVI and climate variables

In considering the relationship between mean growing season NDVI with climatic variable for the whole study area, the correlation coefficient showed that mean growing season NDVI was significantly correlated with both climatic variables, however, more higher correlation was found with precipitation (r^2=0.92, p=0.000) than with temperature (r^2=0.55, p=0.013) over the study period.

As shown in Table 2, the high correlation coefficients were generally associated with precipitation rather than temperature at most of stations. However the correlations between mean growing season NDVI and climatic variables were differentiated at the stations located in different land cover types. For two stations located in forested area, Inget Tolgoi and Khutag-Undur, the growing season NDVI was more strongly correlated with temperature (r^2=0.97, p=0.000 and r^2=0.84, p=0.003) than with precipitation (r^2=0.73, p=0.01 and r^2=0.76, p=0.01), respectively. Forest area mainly appears under conditions of sufficient precipitation and low temperature compared to other vegetation type, in which temperature probably is the decisive factor for vegetation growth. In contrast, at Sukhbaatar station (in a forest area) the growing season NDVI was more significantly correlated with precipitation (r^2=0.85, p=0.003) than with temperature (r^2=0.79, p=0.007). In case of Baruun-Urt and Undurkhaan stations, which situated in the grassland steppe, the growing season NDVI was more closely associated with precipitation (r^2=0.82, p=0.006 and r^2=0.73, p=0.014) than temperature (r^2=0.78, p=0.008 and r^2=0.71, p=0.017), respectively. The Khujirt station (in grassland) showed a contrasting result that the NDVI had more close correlation with temperature (r^2=0.91, p=0.000) rather than with precipitation (r^2=0.78, p=0.008).

Table. 2. Correlations between NDVI and climatic variables in selected stations

	Station name	NDVI vs Temp.		NDVI vs Prec.		Vegetation type
		r^2	p	r^2	p	
1	Sukhbaatar	0.79	0.007	0.85	0.003	Forest
2	Inget Tolgoi	0.97	0	0.73	0.014	Forest
3	Khutag-Undur	0.84	0.003	0.76	0.01	Forest
4	Baruun-Urt	0.78	0.008	0.81	0.006	Grassland
5	Undurkhaan	0.71	0.017	0.73	0.014	Grassland
6	Khujirt	0.91	0	0.78	0.008	Grassland
7	Sainshand	0.03	0.6	0.22	0.2	Desert-steppe
8	Mandalgobi	0.5	0.07	0.46	0.09	Desert-steppe
9	Ehiingol	0	0.98	0.16	0.3	Desert
10	Dalanzadgad	0.02	0.065	0.71	0.016	Desert

One of the observations that should be noted is that the correlation coefficients were generally very low at the stations in semi desert grassland and desert due to the sparse vegetation cover in these areas.

Conclusion

Through the analysis, the following conclusions are brought forward. Firstly the different natural zones contribute to a difference of correlation between NDVI and climatic variables. There are strong correlations of NDVI with precipitation, and moderate correlations with temperature during the study period. The temporal variation of mean NDVI spatial pattern in most stations was most strongly influenced by variation of mean precipitation during the growing season in Mongolia. Secondly, the mean growing season NDVI and temperature were slightly increased, but precipitation was slightly decreased in most of selected stations distributed over the study area. However, these trends were not significant during the 10-years of study period.

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