Spatial and Temporal Patterns of NDVI Response to Precipitation and Temperature in Mongolian Steppe

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Abstract: Understanding of recent trends of the vegetation cover changes, and its relationship with the climate change will be helpful in more accurate prediction of the vegetation cover changes. The accurate prediction of vegetation cover is helpful in reduction of loss and damages to the economy of the country. Rainfall is one of the limiting factors of animal productivity and socio-economic development of Mongolia. In this study we analyzed temporal patterns of NDVI in relation to precipitation and/or air temperature in steppe zone of Mongolia. NDVI from the SPOT VEGETATION data, at a spatial resolution of 1 km and 10 day intervals, were used to investigate the vegetation variations in Mongolia during the period from 2003 to 2009. Then, GIS and remote sensing techniques were used to examine the relationship between precipitation/temperature and the NDVI in Mongolia, and the seasonal change of NDVI is taken as a tool for drought monitoring. The results indicated that the NDVI values changed in relation to different amount of precipitation and maximally responds to the variation of precipitation with a lag of about 10 days and 20 days during vegetation period.

Key Words: Mongolia, NDVI, Precipitation, Remote sensing, Steppe

1. Introduction

Nomadic livestock husbandry is a traditional sector of Mongolia and plays an important role in Mongolian economy. Livestock husbandry is very sensitive and vulnerable to weather and climate and therefore greatly depends on pasture condition.

Intensity and frequency of natural disasters, including droughts and dzuds (a Mongolian term for an extreme weather conditions in which large numbers of animals die due to starvation) are increasing significantly during the last few years because of climate change.

These phenomena cause significant economic damages and losses. Recent studies shows that changes in climate of Mongolia manifest significantly in winter season (Natsagdorj *et al.,* 2001).

According to climate change studies conducted in Mongolia, during the period between 1940 and 2005, the annual average temperature in Mongolia has increased by about 1.9°C and winter temperature changes were even greater in the mountainous areas (2.0 - 3.7°C) (Batima *et al.,* 2005).

The annual precipitation has been decreased from the 1940's to about the mid-1980's, and is on increase in following years. Only in Gobi desert area the precipitation is not increasing. Annual mean precipitation has been decreasing in central Mongolia, but has been increasing in both the eastern and western regions of country (Batima *et al.,* 2005).

Dynamic changes in the Mongolian pasture and its correlation with weather and climate conditions were studied using meteorological and agro-meteorological regular observation data (Dagvadorj, 1996), various maps and digital data of NOAA/AVHRR satellite (Erdenetuya, 2004).

However, spatial and temporal patterns of NDVI (Normalized Difference Vegetation Index) in response to precipitation and air temperature in Mongolian Steppe still aren't well interpreted.

In this study we examined the spatiotemporal patterns of NDVI distribution and its response to precipitation or air temperature in Mongolian steppe using remote sensing technology.

Since pastures in the mountain steppe zone are most populated and overgrazed, we have selected locations with different conditions of usage and protection. Hustai National Park and Chinggis Khaan International airport are area under protection and have not been used by livestock, while the Altanbulag site is presents common pastures in Central Mongolia.

The main objective of this study is to find out the response of NDVI values to different amount of precipitation dropped during in summer time in conditions of mountain steppe of Mongolia.

2. Materials and Methods

2.1. Site description

To study the NDVI response to precipitation and temperature, three sites were selected.

The selection of that site was based on the level of land use. To find out the changes in NDVI values, it is important to know the influence of livestock and wild animals that graze on steppe pastures. For this reason, the selected sites include a site with full protection from livestock and wild ungulates grazing (control area), a site where only wild animals are grazing (protected area) and a site where both domestic and wild animals utilizing the pastures. As the control area we chose the fenced part Chinggis Khaan (106°45'59" E, 47°50'35''N) International airport (Ulaanbaatar city). This control area has an area of 2 × 4 km and has been fenced since 1986 year to keep out livestock and human.

To exclude influence of the livestock grazing on vegetation cover we selected protected area, named the Hustai National Park, (105°55'23" E, 47°40'48" N) that was established in 1993. Third site was chosen in the area that of border National Park, but used by herders for the livestock grazing. The site is located in the south part of Altanbulag soum (106°24'32"E, 47°41'46"N), Tuv province of Mongolia, Altanbulag soum has 566,866 hectares area, livestock population is 104,500 heads. In this area the livestock grazes during all seasons.

2.2. Data and methods

Meteorological variables (ten-days precipitation and air temperature data sets) from June 2003 to August 2009 were obtained from 3 meteorological stations (**Table 1**).

NDVI data came from 2 satellite image sources namely SPOT VEGETATION (VGT) and NOAA/AVHRR. NDVI data included a 10-day composite SPOT VEGETATION data set (with 1 km resolution) from June of 2003 to August of 2009, which were downloaded from the internet database (http://free.vgt.vito.be/home.php).

NOAA/AVHRR NDVI data (with 8 km resolution and 15 day intervals) were processed by in the GIMMS group at NASA (http://iridl.ldeo.columbia.edu/SOURCES/.UMD/.GLCF/.GIMMS/.NDVIg/.global/.ndvi).

The mathematical combinations of the 0.55-0.68 μm and 0.725-1.10 μm wavelength data provide important information on pasture vegetation condition (Tucker, 1979). This parameter is called "Normalized Difference Vegetation Index" (NDVI), which is derived from the visible red (RED) and near-infrared (NIR) spectral bands (defined by Equation 1):

$$NDVI = (NIR - RED) / (NIR + RED) \qquad (1)$$

The NDVI was calculated from SPOT VGT data by using the combinations of bands 2 (0.61-0.68 μm) and 3 (0.78-0.89 μm)

Then, a yearly NDVI anomaly during the warming season (June to August) was calculated as follows (defined by Equation 2):

$$NDVI\sigma = \{((NDVI\alpha)/(NDVI\mu)-1)100\} \qquad (2)$$

where NDVIσ(Anyamba and Turker, 2005) are the respective (June to August) percent anomalies, NDVIα are individual seasonal (June to August) means, and NDVIμ is the long term (June to August) mean. The individual seasonal NDVI is 3 month mean value for year. The long term NDVI is annual mean index.

The Hovmöller diagram method is the 2D method to examine the pattern in different meteorological data by longitude and latitude over huge territories was used to study the NOAA/AVHRR NDVI spatial patterns during 2003-2006 (Hovmöller, 1949).

3. Results and Discussion

3.1. Trends in spatial variations of NDVI.

Spatial patterns of NDVI calculated from NOAA/AVHRR during 2003-2006 are presented in **Figure 1**. We also have analyzed the NDVI change. The results show that highest NDVI was registered in control area. The annual average of NDVI in control area was 0.5. Those values in other two sites were 0.4-0.5 respectively. The NDVI spatial distribution was irregular. NDVI higher values ranging 0.5-0.6 were

Table 1. Selected meteorological stations.

	Station	Buyant-uhaa	Hustai	Altanbulag
1	Longitude	106°45' 59" E	105°55'23" E	106°24'32"E
2	Latitude	47°50' 35"N	47°40'48" N	47°41'46"N
3	Altitude (m)	1272	1100-1840	1260
4	Precipitation(mm)	248.8	270	131.1
5	Temperature (^{0}C)	-1.6	0.2	-1.1

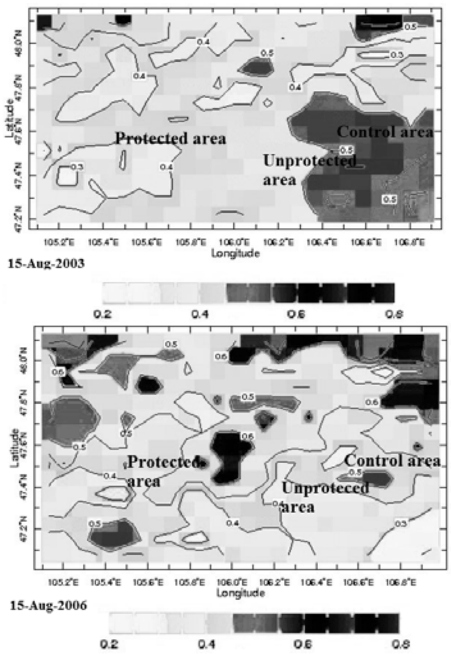

Fig.1. Spatial distributions of the trends in NDVI.

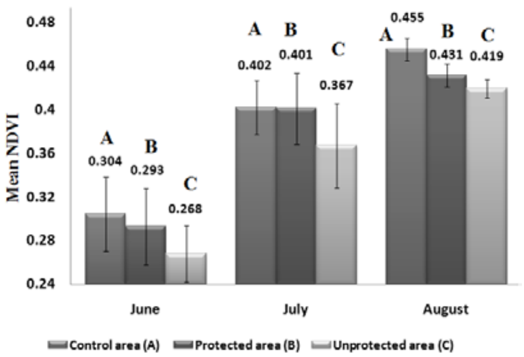

Fig.2. NDVI value between June-August, 2003-2009

distributed over the north-west and middle part of the protected and unprotected sites. Lower values of 0.2 - 0.3 dominate in north-east part and south. Spatially, only during 2003, the NDVI was homogenous over study area. During most years the NDVI values were sporadic and might be depended on surface roughness, exposition and the soil moisture.

3.2. Seasonal pattern of NDVI.

Figure 2 shows the seasonal dynamics of NDVI in the study area during 2003-2009. SPOT VGT satellite data for ten days shows NDVI value increase from June to August.

The seasonal increase in NDVI was the same for all three sites, with highest values registered during three months in control area. The NDVI values were lowest in the Altanbulag site.

3.3. Spatial distribution of NDVI

We have analyzed the distribution and long terms vegetation dynamics. The seasonal mean NDVI (Spot VGT) was highest during 2004, 2006, 2008, and lowest in 2005, 2007. The first decrease in mean NDVI registered in 2004 and lowest was in 2005. As it was mentioned above, despite very low precipitation uncharacteristically high NDVI values registered in 2006 (**Fig. 3**).

3.4. Relationship between NDVI and precipitation

The 10 and 20 days time lag of NDVI response to precipitation was observed in conditions of Hustai National Park. Also, the time lag was different in 2003 and 2007, 10 days and 20 days, respectively in protected area.

3.5. Changes in mean NDVI and precipitation in study area during 2003-2009

In general, NDVI pattern follows that of precipitation, with 10 to 20 days time lag, although that trend was not seen in 2006 (**Fig. 4**a), when despite low amount of monthly precipitation (60.5 mm) high NDVI (0.44) was registered.

In that year (2006), we found that the increase of NDVI was response to a relative high amount of precipitation (Altanbulag soum 26.1 mm, Buyant-uhaa 35mm, Hustai 40.3 mm) dropped during third ten days of July (2006). This is showing that even in condition of dry, low precipitation summer season, one moment high rain could sharply change NDVI. So far, the NDVI values might be depending to the time and amount of precipitation in conditions of mountain steppe of Mongolia.

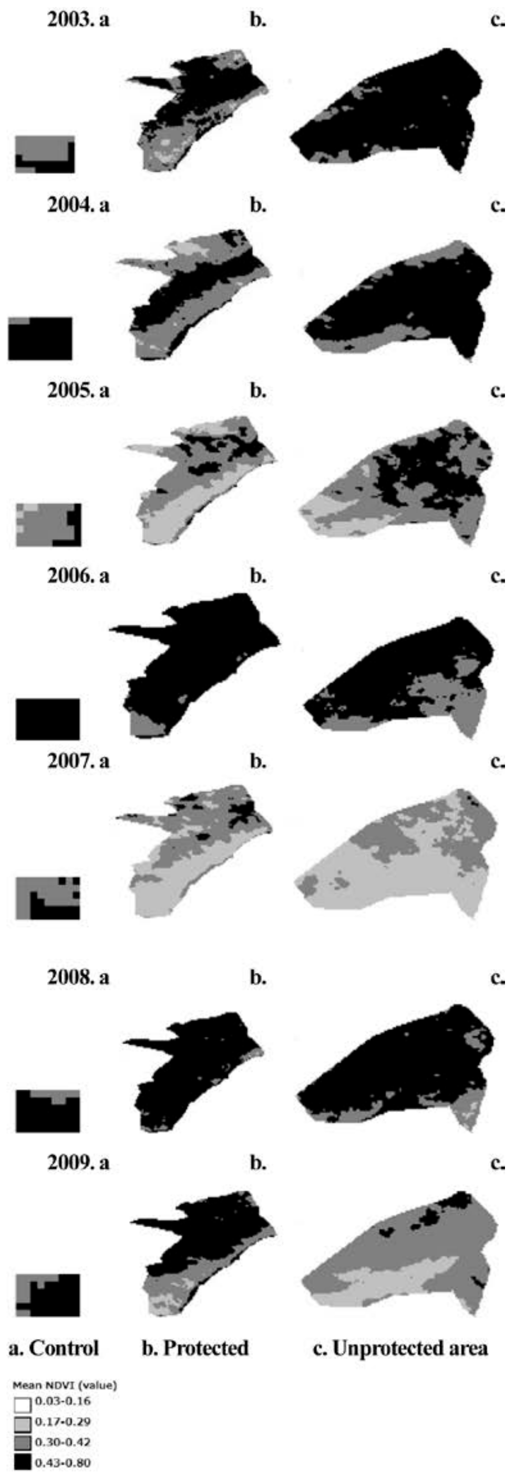

Fig. 3. Spatial and temporal distribution of NDVI in study area during August.

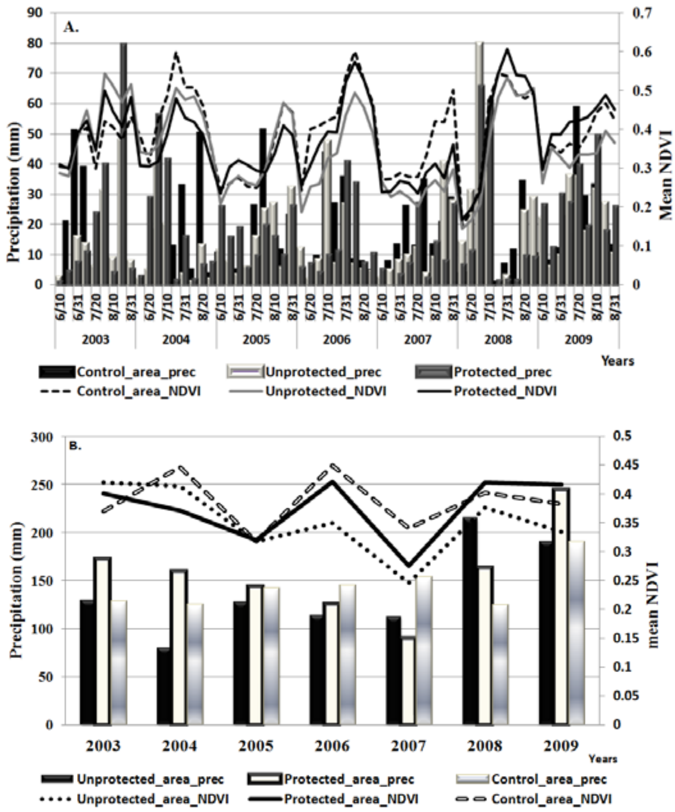

Fig. 4. Changes in mean NDVI and precipitation in study area during 2003-2009.

Table 2. Correlation matrix (Principal component analysis, Xlstat).

Variables	Temp (°C)	Prec(mm)	mean NDVI
Temp (°C)	1	-0.8	0.15
Precipitation(mm)	-0.8	1	0.46
mean NDVI	0.15	0.46	1

3.6. Relationship between NDVI, temperature and precipitation in study area during 2003-2009

Table 2 shows distribution of the maximum correlation between precipitation and NDVI. Negative correlations are recognized with respect to the summer air temperature in study area.

3.7. NDVI anomaly index

Examination of this time series (2003-2009) reveals that 2005 and 2007 were marked by low values below average NDVI and characterized by a significant large-scale drought. On the other hand, 2006 and 2008, were marked by a very wet trend with regional high values above average NDVI. The drought occurred every two years in protected area and unprotected area. At control area had been changed to wet and drought.

The NDVI has been used to monitor the response of vegetation cover to climate factors in Mongolia (Erdentuya 2004; Iwasaki, 2006), in the USA (Wang *et al*., 2003), in Africa (Anymba *et al*., 2005; Davenport *et al*., 1993). Erdenetuya (2004) used NOAA/AVHRR; Iwasaki (2006) used SPOT VGT, Wang *et al*. (2003) used NOAA/AVHRR, Anyamba *et al*. (2005) used Landsat, SPOT, MODIS, and Davenport *et al*. (1993) used NOAA/AVHRR, respectively. Iwasaki (2006) found, 10 to 30 days time lag in NDVI after rain in steppe zone of Mongolia. Anyamba and Turker (2005) and Wang *et al*. (2001) observed strong relationship between precipitation and NDVI in Africa.

In our study, we found the same pattern in conditions of mountain steppe zone of Mongolia. The results of our study shows that NDVI depends on the time and amount of precipitation.

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