Landscape dynamics assessment of dry climatic zones on the Baikal-Gobi transect from NDVI time series and field investigations data

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Abstract. Starting in the eighties of the 20th century, the scientists of the Baikal Institute of Nature Management (BINM SB RAS) have been conducting field observations of the Transbaikalia geosystems transformation due to the change of climate and nature management. An utmost importance is placed on the study of a negative response of the land geosystems. This is shown through their deterioration, degradation, and desertification in particular. Through the years of research (1985-2015) in dry areas of the north of Central Asia, the scientists of the BINM SB RAS established a network of key sites for contact monitoring of the status and dynamics of the geosystems and the negative natural-anthropogenic processes along the Baikal-Gobi meridional transect (51-44° N, 105-107° E). The monitoring of the status and dynamics of the vegetation cover of some key sites is conducted by processing and analysis of multitemporal and multispectral Landsat and MODIS Terra imagery. An automatic analysis of the time variation of NDVI and a comparison with the progress of the index in the previous seasons are performed. The landscape indication of the key sites is made on the basis of satellite imagery and complete geobotanical descriptions. Landscape profiles and facies maps with natural boundaries are created.

1. Introduction

According to the United Nations Convention to Combat Desertification (UNCCD), land degradation in arid, semi-arid, and dry sub-humid areas – also referred to as drylands – may result from various factors, including climatic variations and human activities [1, 2].

It includes diverse processes, ranging from changes in plant species composition to soil erosion, and reduces the land's productive potential [3-5]. Land degradation may diminish the land's resilience, making it more vulnerable and reducing its capacity to recover from disturbances. Furthermore, land degradation can have negative effects on other resources, such as water, soil, flora, and fauna [6, 7].

Causes of land degradation can be natural or man-made. Natural causes include periodic stress from extreme and persistent climatic events, aridity, and droughts. Man-made causes include unsustainable human land use – for example, overgrazing, deforestation, and over-cultivation – as well as indirect socio-economic drivers, such as unstable food market prices and political instability or changes [8-10].

Land degradation and desertification processes are widespread in Russia and Mongolia. Over 85% of the Mongolian territory is located in dry climate zones: dry sub-humid, semiarid, arid, and extra-
The vegetation is the first experience the impact of desertification [11], and that’s why investigation of its changes have a particular importance.

Our research deals with vegetation dynamics of dry climatic zones of Mongolia from field investigations and NDVI (Normalized Difference Vegetation Index - a standardized index, showing the presence and condition of vegetation) time series analysis. The tasks of this study included: 1) field geobotanical studies on testing ranges and classification of vegetation; 2) analysis of the dynamics of the NDVI vegetation index according to satellite data; 3) analysis of the spatial structure of phytocenosis. A number of model monitoring polygons and key sites of contact monitoring has been established in different latitudinal zones according to the longitudinal transect (105-107° E, 51-44° N). These polygons include a wide range of territories with dry climate conditions. This work revealed the main factors, agents, and trends of development for desertification processes in different climate zones.

Two model polygons were considered in Central Mongolia: 1) the Kharaa River downstream basin and the Orkhon River right feeder; 2) the central part of Dundgovi aimag (Mid-Gobi). The first polygon is situated in a semiarid climate zone with grassland and bunchgrass steppes. The second is located in an arid climate zone; from botanical and geographical points of view, its main feature is the prevalence of desertified steppes.

2. Materials and methods
Remote sensing methods, especially satellites, have provided opportunities to organize immediate vegetation monitoring.

Of particular importance in the establishment of a system of remote sensing monitoring is the possibility of organizing completely automated satellite data processing. Over the last years, such technologies were actively being established and developed in the Russian Space Research Institute, Russian Academy of Sciences (IKI RAS). They allowed the creation and actualization of the archive of constant satellite observations on the territory of Russia and adjoining states for the period from 2000 until the present. The basis of automatized technologies established by the IKI RAS is the analysis of NDVI values and comparison with the index variation of the previous years [12].

The temporal dynamics of the vegetation was estimated using archive geoportal data of the IKI RAS for the period of 2001-2015. (http://pro-vega.ru).

NDVI areas were mapped with satellite images for the first half of September for a 25-year period from 1990 to 2015. Necessary multispectral images made by the spectroradiometer TM (Landsat-5 satellite) and the spectroradiometer OLI (Landsat-8) were downloaded from the geoportal of the US Geological Survey, using GloVis search (http://glovis.usgs.gov) for the selected polygons.

Height radar data of the Digital Elevation Model SRTM (Shuttle Radar Topography Mission) were downloaded from the FTP-server of the U.S. Geological Survey. To conduct relief morphometric analysis, a number of the corresponding morphometric maps were established and analyzed (along with the data of field observations): hypsometry, slopes, and aspects. Also, topographic modeling of three-dimensional images was conducted. To identify patterns of spatial distribution of plant communities the method geobotanical profiling was used. As a result of field studies we conducted analysis of phytocenotic diversity on the basis of geo-botanical and landscape descriptions.

While identifying vegetation species, Mongolian [13] and Buryatia [14] keys to identification of plants were used.

3. Semiarid climate zone
Among the desertification types discovered by FAO-UNEP [15], on the greater part of the Selenge River basin, especially in its Mongolian part, the vegetation cover degradation is the most widely spread.

It is revealed in structural changes of the steppe, forest steppe, and pasture phytocenosis, the successions of their species by synanthropic ones, and decreased projective cover and grass height. In
places with the highest development of degradation and land desertification processes caused by a high density of grazing animals on easily deflated sand and sabulous soils, digression processes of steppes and forest steppe geosystems are increased even more. As a result, soil cover is being destroyed, affected by trampling and subsequent deflation, while the existing types of microrelief are being reformed. We noticed an especially strong manifestation of these processes in the poorly populated pine *Pinus sylvestris* L. and drought resistant elms *Ulmus pumila* L. in the Kharaagol sandy area (absolute height values of 735-815 m).

According to the scheme of the landscape and the ecological district division located in the central part of the Selenge River basin, the Kharaagol model polygon is situated in an area of high ecological intensity, caused by both natural and anthropogenic factors. Let us consider the key site of 19.16 km² situated in the northern part of the Kharaagol polygon, 3 km southeast of the Darkhan city. The biggest part of this site, located on the separated slopes of low hill terrain of the Orkhon-Kharaagol interfluve (maximal height marks are 810-870 m), has steppe caragana-cereal-fringed sagebrush (*Artemisia frigida* – *Leymus chinesis* – *Caragana microphylla*) vegetation. As geobotanical studies have shown, the small-leaved caragana *Caragana microphylla* (Pall.) Lam. dominates in the projective vegetation cover (17-20 %). Fringed sagebrush, *Artemisia frigida* Willd. is also widely spread, as well as Chinese wild rye *Leymus chinensis* (Trin.) Tzvelev, etc. Most of the land is used as pasture.

Using access to the satellite monitoring service “Vega” to monitor the vegetation condition, average NDVI curves were built for the Kharaagol key site for the first 15 years of the twenty-first century [12]. Some nonuniformity of the NDVI distribution was observed throughout the years, caused by different climate conditions. It should be pointed out that in 2007, 2008 and 2012, the NDVI values were rather high, 0.6, which is related to the higher values of temperature and moisture regime during the summer months of these years. The important feature of the system «Vega» is a possibility of the research with meteorological information. It gives the chance to receive spatial distribution of meteorological parameters for any date of the vegetation period. The average summer value of the NDVI in 2011 was 0.45 for this site, which proves sparse vegetation during this year (figure 1).

![Figure 1](image_url)

**Figure 1.** Variations of averaged NDVI on 2001-2015 for the north area of the Kharaagol polygon. The upper-right inserted image is the scheme of the site; the upper left inserted image is a 3D-view on the base of DEM SRTM.

NDVI indices were calculated and visualized for the territory of the key site, based on Landsat TM
multispectral space images made for September data of a 25-year difference: 1990 and 2015 (figure 2, table 1). While conducting field measurements, GPS-tracks were prepared for the site’s borders, which were later converted into vector shape files, functioning as a mask for marking the borders of the sites. The NDVI areal mapping with a 0.1 pitch was conducted only within the limits of marked closed polygons.

| NDVI   | 17.09.1990 | 12.09.1994 | 30.08.2001 | 08.09.2010 | 03.09.2014 |
|--------|------------|------------|------------|------------|------------|
| S, km² | S, %       | S, km²     | S, %       | S, km²     | S, %       |
| 0.0-0.1| 1.0        | 1.0        | 1.0        | 0.0        | 0.0        |
| 0.1-0.2| 0.12       | 0.12       | 0.12       | 0.12       | 0.12       |
| 0.2-0.3| 5.44       | 5.44       | 5.44       | 5.44       | 5.44       |
| 0.3-0.4| 10.19      | 10.19      | 10.19      | 10.19      | 10.19      |
| 0.4-0.5| 3.30       | 3.30       | 3.30       | 3.30       | 3.30       |
| 0.5-0.6| 0.10       | 0.10       | 0.10       | 0.10       | 0.10       |
| Total  | 19.15      | 19.15      | 19.15      | 19.15      | 19.15      |

Comparing the NDVI images, there is a digression of vegetation conditioned mainly by a high pasture load. In September of 1990, most of the site (53 %) had 0.3-0.4 NDVI values, while in September of 2010, 86 % of its area was 0.2-0.3.

In the field expedition studies of 2011-2015, a natural landscape indication of NDVI areas with different values was conducted. The natural and anthropogenic factors of the dynamics of their changes were studied. The territories of plowed fields, cleared by harvests, and the areas of steppe slope pastures in the stage of high digression, caused by cattle overgrazing and characterized by a projective vegetation cover of under 50 %, correspond to NDVI values of 0.1-0.2 dated September 8, 2010, taking in 8 % of the territory.

The most common NDVI value for September is 0.2-0.3. These are the prevailing split slope erosion denudation steppe landscapes with motley grass vegetation (*Leymus chinesis* – *Artemisia frigida* + *Potentilla acaulis* – *Caragana microphylla*). Because of cattle overgrazing, the vegetation of these landscapes experiences average digression; the value of its projective cover is mostly 65-70 %. Of the total projective vegetation cover, the small-leaved pea tree *Caragana microphylla* (Pall.) Lam. takes 17-20 %. Another 15-16 % is taken by the Chinese lyme grass *Leymus chinensis* (Trin.) Tzvelev, 12-13 % is taken by frigid sagebush *Artemisia frigida* Willd, and 9-10 % is taken by the stemless bloodroot *Potentilla acaulis* L.

NDVI values of 0.3-0.4 can be observed for only 6 % of the site area, in hollows and the far western and upper (absolute height marks of 810-870 m) parts of the slopes. The projective cover of the phytocenoses vegetation reaches 80-85 %. Among popular species, there are *Carex duriuscula* C.A. Mey., which takes 27-33 % of the projective vegetation cover, the small-leaved caragana *Caragana microphylla* (Pall.) Lam. takes 30-33 %, the Chinese lyme grass *Leymus chinensis* (Trin.) Tzvelev takes 10 %, and the sage-leaf mullein *Phlomis tuberosa* L. takes 10 %.

In September 1990, some of these phytocenoses located in the western part of the area had NDVI values of 0.4-0.55. To all appearances, these phytocenoses had considerable projective cover (around 90-97 %); the highest share belonged to ling, feather grass, and mixed grasses, *Phlomis tuberosa* L. in particular. It was proved by studies conducted on territories adjacent to the key site. The reason for phytocenosis digression is also cattle overgrazing.

A different picture is observed in the southern area of Kharaagol model polygon located on the sand massif of the Kharau River left bank, 18 km south of steppe key area. In 2010, areas of the territories with NDVI values of 0.2-0.3 and 0.3-0.4 decreased somewhat compared to 1990, but areas with 0.1-0.2 values increased sufficiently (twice). This proves a tendency of vegetation cover degradation, similar to that in the northern part of the polygon.
Natural landscape studies conducted in 2008-2015 on the Kharaagol sandy area and its surrounding areas showed that the main factor of degradation of the vegetation covering it is the grazing and drift of farm animals, primarily sheep and goats, as well as horses and cattle to a lesser extent.

The natural landscape indication of NDVI areas with different values on this massif showed that the NDVI values of 0.1-0.2 appear mostly on barchans, dunes, and desert inter-barchan and inter-dune reductions with traces of intensive cattle grazing with a projective vegetation cover of 3-15%. Sand areas with a projective vegetation cover up to 3% have NDVI values of 0-0.1. The prevailing NDVI values for most of the massif, 0.2-0.3, correspond to those for the cover of pine (*Pinus sylvestris* L.) and small elms (*Ulmus pumila* L.). The current decrease in area as compared to 1990 is conditioned not only by farm animal grazing and drift but also by illegal deforestation in some parts and weak reforestation. Denser pine forests with a lot of shrubs make up 14-15% of the sand massif area. They are located in the top southern part (absolute height marks are 780-815 m), with the NDVI values of 0.3-0.4.
According to the Mongolian State National Statistics Committee [16], a tendency to increase the number of farm animals was observed on the territories of Selenge and Darkhan-Uul aimags in 2000s. Express surveys conducted for arats having a household within the territories of the Kharaagol model polygon showed that nearly half of them immigrated here (to be closer to main market of animal products) with their herds in the 2000s from other periphery Mongolian aimags, the western (mostly) and Gobi.

4. Arid climate zone
On the territory of Dundgov aimag (Mid-Gobi), moving from north to south, there is a gradual landscape substitute: desertified steppes of semi-deserts are changed for deserts with saxaul (Haloxylon sp.).

Studies showed that in conditions of insufficient moisture (an annual sum of atmospheric condensation less than 100 mm on the territory of Ulziit somon of the southern part of Dundgov aimag, a maximal value of 150 mm in the north, or a complete absence of fresh surface water), Gobi landscapes are affected by degradation processes easily, especially by the physical weathering, deflation, and degradation of vegetation. Even though the general pasture load is low on the territory of Dundgov aimag because of the rather low density of the animal base, the soil surface is trodden around bases within a 0.5-0.7 km radius, and there is hardly any vegetation cover (projective cover from 0 to 1 %).

Up north from the aimag center Mandalgovi, southern dry steppe landscapes dominate. They are located on 70-80 % of the territory. Desertified steppes take up 10-20 %, while saline and alkali saline soil comprise under 8 %. South from Mandalgovi, within the limits of the Mid-Gobi model polygon, desertified steppe landscapes prevail (65-75 %). The southern steppes take up 20-30 %, and the saline ones comprise less than 9 % of the territory.

The average NDVI value for the last decade aggregated for the model Mid-Gobi polygon is 0.12, which proves poor vegetation (figure 3).

Comparison of natural geobotanical studies conducted in 2011-2015 and the results for ecological groups of the Gobi areas of 2010 proves this conclusion, representing the increased share of euxerophyte plants in projective cover for different areas at 12-15 %, indicating continuous invasion of euxerophyte desert species of plants in the north. Thus, the share of euxerophytes has increased in the projective cover from 77 % in August 2010 to 96 % in August 2012 on the key site situated in the lowland, stony, desertified steppes 20 km south of Mandalgovi.

The tendency of xerophytization of Gobi vegetation shows NDVI index analysis of the Mid-Gobi territory polygon from Landsat TM images made in September 1990 and 2011. Thus, if in September 1990, 75 % of the polygon area had a 0.0-0.1 NDVI value, in September 2011, 92 % of the areas had values of 0.0-0.1 values. The natural landscape indication of areas conducted with different NDVI values showed that most (92 % of the area) values 0.0-0.1 can be observed in stony desertified steppes with predominant Allium polyrrhizum Turcz. ex Regel, which was popular in the southern Gobi areas in the 1990s. Areas with NDVI values of 0.1-0.2 currently comprising only 8 % of the Mid-Gobi polygon area are observed for ling and needle grass (Achnaterum splendens – Carex duriuscula) genuses of saline, stone-free valleys.
Meteorological data analysis proved that in the 2000s there was more severe drought during the summer periods than in the previous century, which, in our opinion, is the main factor for the digression tendency in the Gobi vegetation.

5. Conclusions
The performed studies for different channels of optical range, using methods based on the consideration of differences in spectral reflection, together with field natural changes, prove that the degradation of the vegetation cover is increasing for the last two decades and causes of land degradation can be natural or man-made.

Remote sensing methods, based on the analysis of spatial and temporal differentiation of biophysical vegetation parameters, quickly allow a determination of areas of ecological intensity conditioned by the degradation of vegetation cover and desertification.

Cattle overgrazing is observed on the studied areas. It conditions overload for pastures and leads to the digression of their vegetation cover. Therefore, livestock farmers and other land users have to use pasture rationally, changing grazing areas from time to time and thus regulating the grazing rotation.

The vegetation digression during 25-year period is traced across almost the entire territory of the selected polygons. These climatic zones of Central Asia experience different trends of desertification processes associated with both climatic variability (mainly aridization) and anthropogenic influence.

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