ОЦЕНКА ИЗМЕНЕНИЯ ЛАНДШАФТОВ ЗАСУШЛИВЫХ КЛИМАТИЧЕСКИХ ЗОН ПО БАЙКАЛО-ГОБИЙСКОМУ ТРАНСЕКТУ НА ОСНОВЕ ВРЕМЕННЫХ СЕРИЙ NDVI И НАТУРНЫХ ИССЛЕДОВАНИЙ

Саяпина Д.О., Жарникова М.А., Цыдыпов Б.З., Гармаев Е.Ж.

Байкальский институт природопользования СО РАН, Улан-Удэ, Россия
E-mail: chipa832@mail.ru

В рамках выполнения научно-исследовательских работ по различным проектам СО РАН и Президиума РАН в 2008-2015 гг. заложен ряд модельных полигонов и ключевых участков натурного мониторинга геосистем для изучения динамики процессов деградации и опустынивания земель с засушливыми климатическими условиями в различных широтных зонах (51-44° с.ш.) по меридиональному трансекту (105-107° в.д.). Данное исследование позволило выявить основные факторы и тренды развития процессов деградации и опустынивания земель в различных климатических зонах по Байкало-Гобийскому трансекту.

Наиболее чувствительным компонентом к воздействию опустынивания на ландшафты является растительность. Выполнены крупномасштабные работы по выявлению и анализу изменения растительного покрова засушливых климатических зон России и Монголии с использованием комплекса натурных и дистанционных исследований.

Для модельных полигонов, расположенных в сухой субгумидной, семиаридной, аридной и экстрааридной климатических зонах России и Монголии вдоль меридионального трансекта, построены графики временного хода (2001-2015 гг.) вегетационного индекса NDVI и карты его разновременных значений за первую половину сентября с 25-летним интервалом времени (1990-2015 гг.) по космическим снимкам Landsat TM, ETM+ и OLI. Оценка временной динамики растительности проведена по архивным данным спутникового сервиса мониторинга состояния растительности «Вега» Института космических исследований РАН (Москва). Выявлены особенности значительной межгодовой изменчивости индекса NDVI. Проведена натурная ландшафтная индикация выделенных ареалов NDVI, подкрепленная анализом растительности по экологическим группам по засухоустойчивости.

Маской для выделения границ ключевых участков послужили полученные во время полевых работ GPS-треки границ участков, конвертированные впоследствии в векторные шейп-файлы.

С целью проведения морфометрического анализа рельефа тестовых участков построены и проанализированы (в совокупности с данными натурных наблюдений) карты гипсометрии, уклонов и экспозиции склонов на основе глобальной цифровой модели рельефа SRTM v. 4.

Всего выполнено 180 полных геоботанических описаний, проведены геоботанические профили, заложены мониторинговые площадки, определена биологическая продуктивность характерных фитоценозов. Для первичной сортировки описаний и их обработки с использованием экологических шкал используется программное обеспечение ИБИС. Получены сводные таблицы видового состава, географические и эколого-биоморфологические спектры, виды ранжированы по шкалам увлажнения и богатства, засоленности почв, дан экологический статус сообществам. При идентификации видового состава растительности использованы конспект флоры и определители растений Монголии и Бурятии.

Почти по всей территории выделенных полигонов прослеживается дигрессия растительности за данный период. В данных климатических зонах Центральной Азии происходят разные тренды развития процессов опустынивания, связанные как с климатическими колебаниями (преимущественно аридизацией), так и с антропогенным воздействием.

LANDSCAPE DYNAMICS ASSESSMENT OF DRY CLIMATIC ZONES ON THE BAIKAL-GOBI TRANSECT FROM NDVI TIME SERIES AND FIELD INVESTIGATIONS

Sayapina D.O., Zharnikova M.A., Tsydypov B.Z., Garmaev E.Zh.

Baikal Institute of Nature Management SB RAS, Ulan-Ude, Russia
E-mail: chipa832@mail.ru

Introduction.

Land degradation and desertification processes are widespread in natural and economic territories of Russia and Mongolia. Over 85% of the Mongolian territory is located in dry climate zones: dry sub-humid, semiarid, arid, and extra-arid. The vegetation is the first experience the impact of desertification [4], and that's why investigation of its changes have a particular importance.

Our research deals with vegetation dynamics of dry climatic zones of Russia and Mongolia from NDVI time series analysis and field investigations. We cooperated with Prof. Chimeddorj from the Mongolian State University of Agriculture (Ulaanbaatar) and Dr. Udval from Research Institute of Animal Husbandry (Ulaanbaatar). A number of model monitoring polygons has been established in different latitudinal zones of the Mongolian territory 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.

Materials and methods.

The temporal dynamics of the vegetation was estimated using archive geoportal data of the Russian Space Research Institute, Russian Academy of Sciences (IKI RAS) for the period of 2001-2015. 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 spectro radiometer TM (Landsat-5 satellite) and the spectro radiometer OLI (Landsat-8) were downloaded from the geoportal of the US Geological Survey, using GloVis search (http://glovis.usgs.gov) for the selected polygons (for Kharaagol polygon path = 132, row = 26; for Mid-Goby polygon path = 131, row = 28).

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.

Over the last decades, 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 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 IKI RAS is the analysis of the temporal variation of the Normalized Difference Vegetation Index (NDVI) and its comparison with the index variation of the previous years [5].

While identifying vegetation species, Mongolian [3] and Buryatia [1] key to identification of plants were used.

Semiarid climate zone.

Among the desertification types discovered by FAO-UNEP [2], 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 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 [6] 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 km^2 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 geobotanicalstudies 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 [5]. 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.

NDVI indices were calculated and visualized for the territory of the key site, based on Landsat TM multi-spectral space images made for September data of a 25-year difference: 1990 and 2015. 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.

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 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 tuberose 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 Kharaa 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. Comparative analysis of changes in NDVI values with climate parameters (amount of atmospheric condensation, temperature indices, and relative humidity) did not reveal a correlative dependence for the 20-year period.

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 [6], 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.

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 physicalweathering, 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. 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 euxeropyte 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 (*Achnaterumsplendens – 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.

Conclusions.

The performed studies for different channels of optical range, using methods based on the consideration of differences in spectralreflection, together with field natural changes, prove that the degradation of the vegetation cover is increasing. 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.

References:

1. Anenkhonov O.A., Pykhalova T.D., Osipov K.I., et al. Key to Identification of the Plants in Buryatia. Ulan-Ude: Buryat Science Center. 2001. 670 p. (*In Russian*).
2. FAO/UNEP. Provisional Methodology for Desertification Assessment and Mapping. Rome. 1981. 83 p.
3. Grubov V.I. Key to Identification of Vascular Plants of Mongolia. Leningrad: Nauka. 1982. 443 p. (*In Russian*).
4. Gunin P.D., Miklyaeva I.M., Bazha S.N., et al. Peculiarities of degradation and desertification of the herbal communities of forest steppe and steppe ecosystems of Southern Transbaikalia // Arid ecosystems. 2003. N 9 (19-20). pp. 7-21. (*In Russian*).
5. Lupyan E.A., Savin I.Y., Bartalev S.A., et al. Satellite service “Vega” for monitoring of vegetation conditions // Modern Problems of Earth’s remote sensing. 2011. N 8 (1). pp. 190-198. (*In Russian*).
6. Mongolian Statistical Yearbook 2009. Ulaanbaatar: Mongolian National Statistical Office. 2010. 448 p.