Vegetation cover dynamics of Russia and Mongolia border territories

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Abstract. Desertification is one of the most complex environmental problems in the Central Asian region. In addition to climatic factors affecting land degradation, in the border territories of Russia and Mongolia the intensification of desertification processes is influenced by human activities. A cartographic analysis of meteorological parameters, as well as vegetation state and dynamics spatial distribution based on the NDVI, was carried out. Dry zones occupy 65% of the area of Russia-Mongolia border territories. The prevailing climate zone is a semi-arid. The features of the dynamics of vegetation in the wet (1982-1999) and drought (2000-2015) periods are revealed. In the period from 1982 to 2015 a positive trend of NDVI is observed for 78% of the border areas and negative for 22%. During the wet period the area of negative trends for both Russia and Mongolia amount 1.5% of the territory, primarily due to deforestation. The drought period is characterized by a nearly twentyfold increase in the areas of negative NDVI trends for the whole border territory. The analysis of the correlation of meteorological parameters and vegetation revealed that in drylands with negative NDVI trend, climate-induced desertification covers 63%, and anthropogenic 37% of the total area affected by desertification.

1. Introduction

Much attention has been paid in recent years to studying the effects of global climate change. One of such effect is an increase of territories prone to aridization, which, together with the growing anthropogenic load, leads to intensification of desertification processes. The problem of land degradation is acute in many regions of Central Asia, including the border territories of Russia and Mongolia, where transformation processes in landscapes are associated with changes in the structure and territorial organization of the economy. The significant vulnerability of terrestrial ecosystems to negative natural and anthropogenic processes is one of the consequences of a combination of climate change in this area and unsustainable nature management. Such processes include vegetation degradation, soil erosion and deflation, secondary salinization, etc.

One type of land degradation is degradation of vegetation. Satellite information obtained from multispectral imaging sensors is widely used to estimate vegetation cover state and dynamics. Examples of such imaging sensors are MODIS, SPOT Vegetation and AVHRR sensors, an important characteristic of which is the high temporal resolution. Although the images obtained from these systems have a low spatial resolution, they are suitable for constructing continuous time series, unlike satellite with high spatial resolution cameras. These time series are used to analyze the dynamics of the surface state, including vegetation cover.
A widespread method for estimation of vegetation cover is the use of various vegetation indices, including NDVI, which based on the reflection and absorption of solar radiation by vegetation in the near infrared and red regions of the spectrum. NDVI time series analysis is one of the most common methods for determining the dynamics of vegetation cover [1-8].

The aim of the work is evaluation and analysis of long-term changes of the vegetation cover in the border areas of Russia and Mongolia based on the NDVI.

2. Models and Methods

2.1. Study area

The state border between Russia and Mongolia is located on the territory of the South-Siberian mountain physiographic region. The landscapes structures of the transboundary territory are characterized by great complexity. It is due to the strong dissection of the relief and, as a result, clearly expressed mosaic patterns of climate zones and distribution of vegetation. Landscape belts abruptly replace each other. Alpine tundra is usually found above the mountain taiga zone. Steppe landscapes are formed in some places in the mountain taiga on the southern and relatively dry slopes. Over the last 70-80 years forest vegetation has been repeatedly exposed to fires and deforestation.

The most common type of land use in this area is natural pastures. In general, moderately disturbed pastures dominate in the study areas. Almost unchanged landscapes are located in sparsely populated areas at high altitudes, where cattle grazing is limited. Anthropogenically disturbed landscapes are located near settlements and in places of temporary campsite and watering places. Overgrazing leads to a change in the species composition of vegetation, reduced productivity and denudation, compaction and destruction of the turf layer of soil.

For comparability, the study selected border administrative territorial units (districts, somons), which allowed for a comparative analysis of indicators.

To allow comparative analysis of indicators of the study territories we select administrative territorial units (districts, somons). We choose transboundary gradients to measure and evaluate ongoing processes, which are reflecting the indicators of the state, dynamics, and the ratio between identical processes on both sides of the border.

2.2. Material and methods

We used NDVI time series of the AVHRR spectroradiometer of NOAA satellites series [9]. The data is a 15-day composite of the maximum values of the vegetation index. The spatial resolution of images is 1/12 of the angular degree of the Earth's surface, which is about 8 km for the territory under consideration. Images of periods from 1982 to 2015 are used.

To estimate the distribution of arid climatic zones in the border territory of Russia and Mongolia, the UNEP aridity index (AI) is calculated. AI is the ratio of annual precipitation to potential evapotranspiration [10]. To calculate AI we use the meteorological data set ENVIREM with a spatial resolution of 1 km², which is averaged over the period from 1961 to 1990 (the current baseline climatic period), was used. [11].

NCEP/NCAR reanalysis data were used for spatial comparison of NDVI trends and meteorological parameters [12]. These data are presented by NOAA/Climate Prediction Center (https://www.esrl.noaa.gov/psd/), and has a spatial resolution of 0.5 angular degrees. A correlation analysis of the time series of meteorological parameters and maximum values of annual NDVI for the period from 1982 to 2015 was carried out.

Time series processing was carried out using the software developed by the authors [13]. We carried out a data pre-processing, consisting of three stages The first step is to restore the missing values. Incorrect NDVI values are replaced by its average for the entire period. If there are no two NDVI values in a row, then this pixel is not involved in next analysis. In the second step we use the Savitsky-Golay filter to delete outliers. To eliminate the influence of the vegetation index of open soil and snow on the trend, the time series are cropped to the vegetation period. In the third step, the filtered time series is
subject to a seasonal decomposition procedure using a simple moving average filter with a window width equal to the length of the vegetation period. The data obtained after the seasonal decomposition are used to build a linear regression model and determine the slope (trend).

3. Results and Discussion

We obtain map of climatic zones according to the aridity index, where the following gradations are adopted: extra-arid (AI <0.03); arid (0.03 <AI <0.2); semi-arid (0.2 <AI <0.5); dry sub-humid (0.5 <AI <0.65); humidic (AI > 0.65) (Figure 1).

As a result of the analysis of cartographic material, we found that arid zones (i.e., dry sub-humid, semi-arid and arid) cover 65% of the area under consideration. In Russia, arid zones cover more than 50% of the territory and 80% in Mongolia (Table 1). The common climatic zone is semi-arid zones (about 40% of whole border territory), which is mostly located in Mongolia and has a continuous character of distribution. In the borderland of Russia, the semi-arid zones prevail in the steppes of Eastern Transbaikalia, in the south of the Selenga middle mountains and in the north of the Ubsunur basin. The arid zone appears only in Mongolia in the west part of the country in the Great Lakes Basin, where the large Mongol-Els sandy massif is also located to the south.

|                | Russian part | Mongolian part | Total |
|----------------|--------------|----------------|-------|
| Arid           | 0.0          | 1.0            | 0.5   |
| Semi-arid      | 25.2         | 54.9           | 39.3  |
| Dry sub-humid  | 26.6         | 23.8           | 25.3  |
| Humid          | 48.2         | 20.3           | 34.9  |

Humid (wet) zones are confined to the mountain-taiga landscapes of the Khamar-Daban, Dzhidinsky, Yablonovyy, Malkhansky, Khentiy ranges, mountains near Lake Khubsugul, the spurs of the Western Sayan. Here rainfall can reach 1600 mm per year due to the barrier effect. In Mongolia, humid areas occupy only 20% of the territory, while in Russia less than half.

For the spatial estimation of the desertification processes in the border territory of Russia and Mongolia, we created NDVI trend maps (Figure 2). To calculate the linear trends of NDVI we used the developed information and methodological support, where the initial data were AVHRR radiometer images from 1982 to 2015.
Figure 2. NDVI trends map of the border territory of Russia and Mongolia from 1982 to 2015.

During the 34-year period a positive trend of NDVI is observed for 78% of the border territories, and negative for 22%. The latter value can be interpreted as the areas subjected to desertification processes according to the vegetation degradation indicator. A similar ratio of positive and negative trends is observed in Russia and Mongolia. In the territory of Transbaikalia long-term variations of precipitation have a pronounced cyclical nature. The last dry phase is beginning in 1999 [14]. Considering that the change in vegetation of the steppe communities of the arid zones in Russia is primarily due to variations of precipitation and anthropogenic factors [15-17], it is advisable to analyze the spatial pattern of NDVI trends separately: for the wet period from 1982 to 1999, and for the dry period from 2000 to 2015.

During the wet period the share of negative trends for Russia and Mongolia was only 1.5%. The dry period is characterized by a nearly twentyfold increase of negative NDVI trends areas, which was 29%. The share of negative trends during the the dry period in the border area of Russia is 31.4%, in Mongolia – 26.4%. A noteworthy detail is that in the dry season there are strongly negative trends (< -0.005 / year), which are confined to forest landscapes and characterize fires and subsequent logging. An interesting feature of the dry period is the appearance of a vast zone with positive trends in the eastern part of the border territory of Russia and Mongolia. It might be this phenomenon is explained by the fact that Transbaikalia and Mongolia are located at the junction of the influence of the Arctic and Pacific air masses, which provide variability in bringing moisture to the region.

One of the approaches of detection of climatic and anthropogenic influence on vegetation is the analysis of the correlation between series of NDVI and climatic parameters which may affect the state and dynamics of vegetation. As moisture is the main factor limiting vegetation growth in arid regions, correlation analysis was carried out for NDVI and precipitation. The main idea of differentiation of climatic and anthropogenic desertification is the hypothesis that a positive correlation between NDVI and precipitation is characterized for climatic desertification, and anthropogenic impact leads to negative trend. To find desertification process we analyzed only NDVI with a negative trend. The analysis of correlations of NDVI AVHRR and rainfall NCEP/NCAR revealed that in arid zones subjected to degradation of vegetation the share of climatically induced desertification is 63%, and anthropogenic is 37% (Figure 3).
4. Conclusion

Developed maps of aridity, NDVI trends, and their connections with meteorological parameters are indicators of changes in vegetation cover. Based on the cartographic analysis we got the conclusions presented below.

65% of the border area of Russia and Mongolia belong to the arid climate zone - the lands most subject to desertification processes.

In the period from 1982 to 1999, the border territory of Russia and Mongolia is characterized by a positive NDVI trend associated with an increase in the amount of precipitation in the specified period. In the period from 2000 to 2015 degradation of vegetation cover is observed on 29% of the border territory.

Anthropogenic negative trend in dry zones occupies 37% of the territory. Degradation of vegetation in other areas are primarily due to climatic factors.

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