Global Climate Change and Its Consequences in Baikal Siberia and Adjacent Territories

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Abstract. The air temperature, precipitation and NDVI trends were calculated for the wet (1982-1999) and dry (2000-2018) periods for the territory of Baikal Siberia and adjacent territories. Temperature rise is observed for the entire study area; at the same time, zones with low growth rates of surface temperature are interspersed with zones with high growth rates, both in latitudinal and longitudinal directions. The wet period is characterized by positive trends in the amount of precipitation for almost the entire study area. During the dry period, negative dynamics of the amount of precipitation is observed for the predominant part of this territory. As a result of the analysis of the spatial distribution of NDVI trends, it was revealed that during the wet period, positive trend values prevail – up to 77%. During the dry period, a multiple increase in negative NDVI trends in arid zones was established, which shows their greatest sensitivity to the moisture regime. For the first time, the shares of the contribution of the anthropogenic and climatic factors to the degradation of the soil and vegetation cover of Russia, Mongolia and China within the region under consideration have been revealed.

1. Introduction

The present study is devoted to the problem of climate change, which is currently recognized by the international community as one of the most important challenges of our time. According to the Climate Doctrine, the strategic goal of the climate policy of the Russian Federation is to ensure safe and sustainable development in the context of a changing climate and the threats and risks involved. Climate change is becoming a factor that can have an enormous impact on the environment, on atmospheric processes, on the operation of economic sectors and other areas of activity. In this connection, studying the transformation of the natural environment as a result of climate change and intensification of anthropogenic load in the territory of Baikal Siberia and adjacent territories is both urgent and necessary due to the confined nature of the studied territories to the mega-watersheds of three world basins: the Arctic Ocean, the Pacific Ocean and the Central Asian Internal Drainage Basin.

Natural and anthropogenic ecosystems are being significantly impacted by climate change caused by the steady increase in greenhouse gas emissions. The observed changes summarized in the 2015 IPCC (The Intergovernmental Panel on Climate Change) report “Climate Change” (the Sixth Assessment Report is currently being prepared, 2021) are manifested in a 0.85°C [1] increase in global average surface air temperature, a rise in sea level, an increase in greenhouse gas concentrations in the atmosphere, a decrease in glaciers and snow cover, etc. These assessments often have gaps due to a lack of data and a limited number of studies. The territory of Baikal Siberia and adjacent territories within Central Asia and the Baikal region is characterized by an exceptional diversity of ecosystems due to the natural conditions of boreal and arid regions of Eurasia, and is one of the main strategic areas of the eastern border of the Russian Federation. Transformation of the natural environment...
of the study area has a wide range of manifestations and is characterized by a number of negative processes such as vegetation degradation, soil erosion and deflation, droughts and floods, forest fires, etc., which, in turn, affects the economy of the region.

For a better visualization of the diversity of ecosystems, we created a map of climatic zones by moisture for the official current baseline period (1961-1990) based on the aridity index (AI), i.e., the ratio of annual precipitation to potential evapotranspiration (Figure 1, Table 1). ENVIREM meteorological data were used for the calculations [2].

### Table 1. Classification of climatic zones by aridity index.

| Climatic zones | Aridity index |
|----------------|---------------|
| Arid           | 0.03 < AI < 0.20 |
| Semi-arid      | 0.20 < AI < 0.50 |
| Dry sub-humid  | 0.50 < AI < 0.65 |
| Humid          | AI > 0.65      |

The study area covers all climatic zones of the Earth from humid to hyper-arid zones; the steppe belt with dry sub-humid and semi-arid climates plays a special role.

2. Materials and methods

Local and regional assessments of the natural environment transformation were based on remote sensing data, archive meteorological data, grid archives of climatic variables, as well as ground-based field observations.

Meteorological data that form the basis for a comprehensive analysis of the transformation of natural complexes were provided by the World Data Centre – All-Russian Research Institute for Hydrometeorological Information (http://www.meteo.ru) [3], the Global Historical Climate Network Daily database (http://climexp.knmi.nl), NCEP/NCAR reanalysis [4] and the CRU TS 4.03 grid archive (Climate Research Unit, 0.5×0.5 spatial resolution) [5]. The aridity of the climate was determined by the mean annual values of climatic variables implemented by the ENVIREM project, which took into account the influence of the relief and other factors of the underlying surface [2].

The GIMMS NDVI3g time series from NOAA’s AVHRR was used to analyse changes in vast areas [6]. Local areas were surveyed using higher resolution Landsat and Sentinel images [7], as well as UAV aerial survey data. The GFW (Global Forest Watch) data set created in the result of cooperation between the University of Maryland, Google, US Geological Survey, NASA, ESRI, Vizzuality, US Agency for International Development, and others was used to assess forest cover loss [8]. The GFW Tree Cover Loss by Dominant Driver product was used to determine the factors influencing the loss of forest cover [9].

Assessments of various characteristics of the natural environment were obtained by standard generally accepted methods, but they often require adjustments and additions related both to the use of heterogeneous remote and in situ geodata, and to the specifics of the region and objects under study. Heterogeneous data are subjected to analysis with the help of various freely distributed and commercial software products, such as Statsoft Statistica, Agisoft Photoscan, measuring device software, etc. A significant part of the data is processed using algorithms and programs of our own design: a package for processing spatial and temporal series of meteorological data [10], a software package for processing and analysis of temporal series of remote sensing [11], a program for calculating spatial correlation [12], etc.
3. Climate change and regional assessment of the transformation of natural complexes

Geoecological assessment of the scale of modern transformation of natural complexes, determined by the interaction of natural and anthropogenic factors, indicates the presence of a large number of areas of degraded land in the study area. In many respects their presence is caused by irrational use of natural resources, not always fully taking into account the peculiarities of local natural-climatic conditions.

In the Russian part of the study area, degraded lands have become widespread in the second half of the twentieth century largely due to irrational arable land use: plowing steep and gentle slopes without sufficient attention to soil-protective and anti-erosion technologies. This led to a significant spread of various degradation processes: erosion, deflation, dehumification of soils, formation and growth of rills, gullies, other erosive forms of relief, etc. In the 1990s, due to the reduction of agricultural production in the territory under consideration, many low-productive lands on slopes and sandy soils were withdrawn from arable use. In this regard, most of the slopes started to naturally regenerate woody, mostly pine, vegetation that has grown on them before. In the territory of Mongolia, formation of lands degraded by natural and anthropogenic processes is caused both by natural conditions (sharp continental and arid climate, prevalence of easily deflated and easily washed away soils and soils with a light texture, low degree of their vegetation coverage, extremely rare distribution of permanent surface water bodies, mostly deep groundwater deposits, etc.) and anthropogenic factors (mainly overgrazing in certain local areas, non-compliance with the principles and traditions of nomadic animal husbandry, spontaneous laying of roads, cattle routes and trails.

It was found that during the period from 1961 to 2019 in the north of Central Asia there is a widespread increase in surface air temperature – a significant increase occurs in the south of Eastern Siberia and Mongolia; the largest linear trends are observed in Western Mongolia and in eastern PRC and exceed 0.04°C/year (more than 2.32°C). The vast area of the study region experiences temperature growth at a rate of 0.03°C/year, i.e. the absolute increase over the whole period is 1.74°C (Figure 2).

![Figure 2. Linear trends of surface air temperature for 1982-2018, °C/year.](image)

The dynamics of precipitation in the study area has an uneven character. In arid zones (Transbaikalia, Northern Mongolia) and eastern provinces of China there is a decrease in precipitation – from 30 to 110 mm for 1991-2019, while in the rest of the territory there is an increase in precipitation. The cyclic nature of precipitation was revealed – thus, in the arid zones of the Republic of Buryatia (Eastern Transbaikalia) there was a wet period from 1982 to 1999, and a dry period from 2000 to 2017 (Figure 3).

Thus, it was determined that during the period from 1961 to 2019 the temperature growth in most of the study area is 1.74°C and exceeds the growth rate of the average global temperature by 2 times. Arid climatic zones experience a decrease in the amount of precipitation, and their cyclical regime of precipitation is revealed.
The diversity of physical geographic conditions together with climate change determines the peculiarities of spatial and temporal dynamics of vegetation cover in recent decades. It has been revealed that more than 60% of the territory is located in zones with arid climate, which are most vulnerable to climatic shifts.

We calculated linear NDVI trends from 1982 to 2015. It was revealed that a decrease in NDVI is observed for almost 20% of the territory under study. Negative trends are mainly prevalent in the northern part of the study area, including the territory of Irkutsk Region and Transbaikalia. NDVI values less than 0.1 are observed for the vast territory of the Gobi Desert, as well as for water bodies and the glacier belt. In general, positive NDVI trends are characteristic of the humid climatic zone.

The NDVI trends were also calculated for two periods: wet (from 1982 to 1999) and dry (from 2000 to 2015) (Figure 4).

Although the dynamics of precipitation for the entire study area is heterogeneous, this division was made because in the north, where negative NDVI trends are observed, the change from wet to dry phase of moisture falls at the turn of the millennium. It was revealed that in wet period positive values of NDVI trends prevail – up to 77%. In the dry period, the share of negative trends in arid zones increases many times, which shows their greatest sensitivity to the humidification regime. Coniferous forests of the boreal zone in the north are more exposed to forest fires, which also affects the dynamics of NDVI.

Figure 3. Linear trends of precipitation (mm) for the periods: (a) 1982-1999; (b) 2000-2018.

Figure 4. Spatial distribution of GIMMS NDVI3g linear trends for the (a) 1982-1999 wet period and (b) 2000-2015 dry period.
To identify climatic and anthropogenic contribution, a correlation analysis between NDVI series and climatic parameters which may influence the state and dynamics of vegetation was carried out. The main idea of differentiation of climatic and anthropogenic contribution to vegetation dynamics is the hypothesis that climatic influence implies positive correlation between NDVI of steppe vegetation and precipitation and NDVI of forest vegetation and temperature, while the anthropogenic one is negative, with only NDVI time series with negative trend considered. As a result, the anthropogenic contribution to land cover degradation in the studied region was determined – for Russia, the contribution was 13.9%, for China and Mongolia, 10.6 and 2.9%, respectively.

4. Conclusion
For the first time, methodologies for assessing the transformation of landscapes at the local and regional levels have been developed using remote sensing data, as well as field surveys of above-ground phytomass. A series of multi-scale maps of the current state and dynamics of geosystem components, landscape maps, aridity, temperature and precipitation maps, NDVI, including their trends were developed.

The shares of the contribution of anthropogenic (from 3 to 14%) and climatic factors to the degradation of the land cover were revealed for the first time. NDVI trends were calculated for two periods: wet period from 1982 to 1999 and dry period from 2000 to 2015. It was revealed that in the wet period positive values of the trends prevail – up to 77%. In dry period there is multiple growth of negative NDVI trends in arid zones.

Thus, step-by-step solution of the set tasks on the basis of the original methodology of assessment of landscapes modification and information concept of cartographic monitoring allowed to assess the transformation of the natural environment in conditions of spatial and temporal heterogeneity of climatic trends.

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