Estimation of the state and dynamics of forests in the flood zone of the Nizhneboguchanskaya HPP based on satellite imagery

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Abstract. The paper investigates changes in the species structure of forests over a 20-year period (2001-2020) for the zone of the alleged flooding of the Nizhneboguchanskaya HPP and adjacent areas using geographic information systems and Earth remote sensing data. Areas of forest destroyed as a result of felling and fires were identified. The paper gives a quantitative estimation of these changes. A map of the dominant tree species for the study area was obtained. The satellite imagery of medium spatial resolution (Sentinel, Landsat) was used as the initial data, as well as information products Burned Area and Forest Cover Loss of the University of Maryland based on satellite data and field research data. It was found that the number of coniferous plantations in the study area decreases. On the contrary, the proportion of non-forested areas as well as deciduous species increases.

1. Introduction

The construction of a hydroelectric power station has a complex impact on the environment, i.e., on the atmosphere, hydrosphere, lithosphere, affecting all components of existing ecosystems [1]. It is necessary to first assess the state of the ecosystem in the flood zone to forecast changes occurring during the construction and commissioning of new HPPs.

It is necessary to study in detail the current state of the natural environment in the zone of influence of hydroelectric power plants and reservoirs, in particular, the state of forests as the most important part of the ecosystem. The future changes can be simulated on the basis of this information in order to minimize environmental damage and optimize environmental risk management.

2. Area of study

The flood zone of the Nizhneboguchanskaya HPP is a territory of the Angara River with a length of about 100 km, with a maximum width of up to 7 km. The site is located in the Boguchansky and Kezhemsky administrative districts of the Krasnoyarsk Territory. It starts 14 km above the village of Boguchany and ends at the dam of the Boguchany hydroelectric power station.

The study area of this paper includes a flood zone and adjacent territories, which will be subject to the maximum impact of flood. The area is a 20 km wide buffer zone along the Angara River bed. The studied area is of 185 thousand hectares (figure 1).
Figure 1. Scheme of the study area.

The study area is located on the territories of Boguchansky, Gremuchinsky, Khrebtovsky, Nevonsky and Kodinsky forestries. It belongs to the subzone of the southern taiga of Central Siberia. In accordance with the forest vegetation zoning by G.V. Krylov, it is located in the Chuno-Angarsk sub-province of larch-pine forests; it is a part of the Central Siberian province of light coniferous forests. The area is mainly represented by larch-pine and pine forests. Spruce and spruce-fir forests are less typical [2].

According to the data of the 50-60s of the last century, 42% of the area of the studied region is occupied by pine-dominated stands, with a predominance of larch, i.e., 24%. Deciduous plantations occupy 19% of the area, birch occupies 16% and aspen occupies 3% of this area. Dark conifers prevail on the 15% of the territory. According to the its structure, spruce occupies 8%, Siberian fir occupies 4% and Siberian cedar occupies 3% of the territory. The forest covers the territory of 91% [3].

The intensive economic activity is carried out in the region. The region has a high degree of disturbance due to the forestry development and forest fires.

3. Changes estimation of in forest vegetation

The paper estimated forest changes over a 20-year period from 2000 till the present. For this purpose, we used two images obtained at the beginning and at the end of the study: the Landsat-7 survey dated August 27, 2000, and the Sentinel-2 survey dated September 14, 2020. The images have undergone standard preprocessing, including radiometric and geometric correction procedures. The application of remote sensing data for mapping the types of the earth's surface is one of the main areas of their application and is widespread throughout the world. A standard procedure is the application of automated decryption (classification) [4].

Homogeneous spaces in terms of spectral characteristics were distinguished on the images for the classification. We applied an automatic maximum likelihood classification with training. According to [5], a maximum likelihood method is the most frequently used and most accurate for this kind of problems. As reference objects (training sample), as well as to assess the quality of the classification, ground data obtained earlier in the course of expeditionary operations were used. These data represent about 60 sample plots. The main inventory characteristics of forest stands are described for each plot.

The work on processing satellite imagery was carried out in the geographic information system ArcGIS.

As a result of the classification, maps of the dominant tree species of the study area were obtained. Four classes of dominant species were identified: pine, larch, dark coniferous and deciduous plantations,
and the fifth class presents areas not covered with forest (they included water surfaces, meadows, thickets of shrubs, fresh felling, burning, open soils, etc.).

It was found that the forested area occupied 84% of the study area in 2000. Among the classes with forest vegetation, deciduous stands (birch, aspen), i.e., 31%, and pine, i.e., 29% had a dominant position in area. Dark coniferous plantations (spruce, fir), i.e., 13%. Larch, i.e., 11%. Non-forest land occupied 16% of the territory.

In 2020, there was an increase in the share of deciduous plantations, i.e., 39%, which occurred mainly due to a decrease in the area occupied by pine forests. It amounted to 23%, and a slightly decreased area of larch stands, i.e., 10%. The area of dark coniferous stands did not change and amounted to 13%. The total area covered by forest has slightly changed, i.e., 85%, and, accordingly, the area of non-forest land, i.e., 15%.

Figure 2. Long-term dynamics of the species structure of forests.

Figure 2 shows how the areas of the four main dominant species and non-forest lands in the study area changed at three time slices: the data were taken from the scientific literature for 1950 [3] and the data are based on the results of the classification of satellite images for 2000 and 2020.

4. Estimation of violations

Forest violations cover of anthropogenic and natural origin have been determined over a 20-year study period. For this, the following publicly available satellite data were applied:

- survey of Landsat satellites for the entire study period, spatial resolution of 30 meters;
- survey of Sentinel-2 satellites for the period from 2016 to the present, spatial resolution of 20 meters;
- Forest Cover Loss product of the Global Forest Change project, i.e., data on the annual loss of forest cover of the Earth, for the period from 2000 to 2019, based on long-term Landsat data, spatial resolution 30 m (http://earthenginepartners.appspot.com/science-2013-global-forest) [6];
- Burned Area product, i.e., daily data on areas covered by fire for the period from 2000 to 2020, based on MODIS data, spatial resolution of 500 meters (https://modis-fire.umd.edu/ba.html) [7].

On the territory of the study, two main types of violations were identified. They are loggings and forest fires, and also a rather significant contribution was made by industrial felling during the construction of power lines. Violations were identified by joint analysis of the above satellite data, namely, in the presence of characteristic values of spectral brightness in the visible and infrared wavelength ranges [8] in Landsat and Sentinel images, spatially coinciding with the presence of data on forest loss or fires in the corresponding Forest Cover Loss products and Burned Area. Thus, vector layers were obtained containing the contours of disturbances for each year from 2001 to 2020. The distribution of felling and fires by year is presented in figure 3.
The total logging area for the period 2001-2020 in the study area was 17,314 hectares. The logging area is 14,835 hectares, the number is 1,662. The average logging area is 8.9 hectares, minimum 0.1 hectares, maximum 145 hectares.

The logging area during the construction of power transmission lines is 2,458 hectares.

The total area of fires is 5,954 hectares; their number is 27. The average area of one fire is 220.5 hectares, minimum 6.6 hectares, maximum 2,512.7 hectares.

The correlation of the map of prevailing forest species, obtained by us earlier by automatic classification of the Landast image for 2000, with the contours of felling and fires, allows us to determine the frequency of these violations for each of the tree species. Thus, loggings for the period 2001-2020 disturbed: 6,661 hectares of pine (39% of the total felling area), 4,444 hectares of deciduous (26%), 3,533 hectares of dark coniferous stands (20%), 2,654 hectares of larch forests (15%). Fires for the period 2001-2000 disturbed: 2,737 hectares of pine (46% of the total area of fires), 1,601 hectares of dark coniferous stands (27%), 907 hectares of larch forests (15%), 709 hectares of deciduous (12%).

5. Conclusion
As a result of intensive economic activity, coniferous plantations characteristic of this region is replaced by deciduous ones. Obviously, the process of reforestation proceeds through a change in species composition. Over the past 50 years, the area of pine plantations and larch forests has significantly decreased, and forest cover has decreased.

In the period from 2001 to 2020, loggings and fires disturbed about 13% of the study area, or 23,300 thousand hectares. The logging area is three times larger than the area of fires and averages about 850 hectares per year, with a total area of 17.3 thousand hectares. The logging volume throughout the study period remains relatively stable.

The fires killed about 6,000 thousand hectares of forest. The area and frequency of fires varies greatly throughout the study period, since largely depends on the weather conditions of the fire season. The most susceptible to forest fires are areas occupied by coniferous plantations. About 90% of the fires of the study area were detected there.

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