Application of remote sensing technologies for studying urban forests in conditions of technogenic impact

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Abstract. In this work, an attempt was made to assess the possible change in the photosynthetic potential of the forests of New Moscow, depending on the degree of their remoteness from the territories with technogenic impact, based on the data of remote sensing of the earth. Because of constructing the time series of the spectral index NDVI, the value of the photosynthetic potential of homogeneous forest areas at different distances from the old borders of Moscow was estimated. Studies have shown that the average NDVI values of forests increase with distance from the borders with Old Moscow. The lowest NDVI values (0.70) are typical for forests located at a short distance from Moscow. In the central part of New Moscow, the index is 0.72, and the highest NDVI values (0.75) are observed within the settlements located in the south near the border with the Kaluga region.

1. Introduction
One of the most important factors ensuring the environmental safety of Moscow is the presence of large areas of green spaces on the territory of the capital region [1]. Within the administrative boundaries of the city, the largest forest tracts are located within New Moscow, annexed to the capital in 2012 [2]. Most of them are currently classified as specially protected green areas (SPGA) and perform environment-forming and environmental protection functions, which is extremely important for the formation of favorable living conditions within the entire city [3]. However, the processes of urbanization that was actively developing in the Moscow region at the end of the 20th and the beginning of the 21st centuries, and especially after 2012, led to both a reduction in the area of forests and deterioration in their condition [4], and therefore caused a decrease in their stabilizing functions.

The effectiveness of forests performing environmental and environmental protection functions largely depends on their biological productivity, which determines the stability and ability of forest ecosystems to recover after anthropogenic disturbances, as well as their ability to deposit atmospheric carbon and release oxygen, thereby contributing to air purification [5]. In turn, the biological productivity of any plant communities depends on the efficiency of the photosynthesis process, due to which a building material - carbon is obtained from atmospheric carbon dioxide, and oxygen is released into the atmosphere. The activity of photosynthesis processes depends on many factors - on the species composition of forests, their age, growing conditions, etc. Impacts caused by anthropogenic activities negatively affect the efficiency of photosynthesis processes.

In our work, an attempt was made to assess the possible change in the photosynthetic potential of the forests of New Moscow, depending on the degree of their remoteness from the main factors of negative impact, based on remote sensing data (RSD), of the possible change in the photosynthetic
potential of the forests of New Moscow, depending on the degree of their remoteness from the main factors of negative impact associated primarily with the objects of old Moscow.

2. Materials and methods

In this work, summer space images of different years from the Santinel-2 satellite with a spatial resolution of 10 m were used as the main materials. In some cases, satellite images of high spatial resolution (less than 10 meters) obtained using the Google Earth service were used to refine the contours of key areas. Also in the work was used the map "Vegetation of the Moscow region" at a scale of 1: 200,000, which was compiled under the guidance of G.N. Ogureeva in 1996 and was updated in 2019 by E.G. Suslova [6]. It was used to analyze the features of the spatial distribution of forests of different species composition within New Moscow, and were also selected and then digitized using remote sensing data, the contour of single-breed key areas to assess their photosynthetic activity [7].

The main methods in the work were methods of remote sensing, as well as statistical methods, implemented by means of GIS [8]. RSD methods included the implementation of thematically oriented synthesis to obtain color images that are most informative for the study of forest vegetation, as well as the calculation of index images (spectral indices). Spectral indices are indicators calculated as a result of operations with different spectral ranges (channels) of multispectral images. The most commonly used are vegetation indices, i.e. vegetation indices [9]. To solve our problem, we calculated the vegetation index NDVI and estimated its long-term variations characterizing the vegetation cover within key areas.

When constructing time series of spectral indices, including the NDVI index, an integrated approach to the analysis of multispectral satellite data is used [10]. The time series are built on the basis of a series of satellite images at different times and, in fact, represent a sequence of index values within each pixel at different points in time, on the basis of which the average value is then calculated. This approach, when analyzing time series for a certain period of time (for example, the season of the year), makes it possible to characterize the vegetation of the territory with much greater reliability than when considering one-time values of the vegetation index for individual dates. Consideration of the time series allows us to partially correct the errors introduced by the phenological stage of vegetation development at the time of the survey, weather conditions, strong clouds, haze, peculiarities of weather conditions of the year, etc. The GIS package QGIS-3.16, MultiSpec programs, Google Earth and LandViewer | EOS.

3. Results

In our work, the assessment of the possible change in the photosynthetic potential of the forests of New Moscow was carried out primarily depending on the degree of their remoteness from the old border of the city, which is the main factor of the negative impact on the urban forests of New Moscow. Three settlements were selected as model territories within New Moscow: Sosenskoye, Krasnopakhorskoye, Rogovskoye, which are located at different distances from old Moscow. In accordance with the plan for the integrated urban development of the city, they accordingly fall: Sosenskoye - in the "urbanized zone with a high density of administrative and business development" as close as possible to old Moscow; Krasnopakhorskoye - to a more remote "zone of low urbanization with a concentration of educational and health care institutions"; Rogovskoye - to the most remote "recreational zone with low-rise residential buildings".

The NDVI is very sensitive to breed composition. Therefore, in order to provide the possibility of comparing the calculated values of the NDVI index for model territories at different distances from the borders of Moscow, it was necessary to select key areas within them, which are woodlands of similar species composition. For this, a 1996 map of vegetation of the Moscow region was used at a scale of 1:200,000, updated in 2019. Its analysis showed that the species composition of mixed forests located within the three selected model areas is quite similar. In general, the predominant species are small-leaved species - aspen and birch, there is also oak, linden, spruce and pine.
To increase the degree of reliability of further calculations, it was decided for the analysis not to be limited to the choice of 1 forest area within each of the model territories. A total of 23 key forest areas were selected: in the Sosensky settlement - 5, in Krasnopakhorsky - 8, in Rogovsky - 10 forest areas. All key sites were selected on the basis of vegetation maps of the Moscow region within the territories under aspen-birch forests with spruce, oak and linden (figure 1). The location of the selected forest areas is shown by red punches in the image with the calculated NDVI index, on which, for a clearer identification of vegetation, the color scale starts from a value of 0.1 - thus, all objects falling within the range from -1 to 0.1 are highlighted with one color, which allowed more clearly identify areas with vegetation.

Further, each of the 23 selected forest areas was digitized and entered as a separate object into the corresponding polygonal vector layer. The detailing of the boundaries of forest areas was carried out using OSM maps, several generated synthesized images and a calculated image of the NDVI index obtained from the Santinel-2 image for July 2020 (figure 2). The main task that was solved in this way is to exclude the inclusion of key areas of non-forest areas or forests of a different species composition in the contour. The created vector layer was uploaded to the LandViewer online service, where NDVI time series were built for each of the 23 forest areas (figure 3), which were used to calculate the average values for the summer period for the last three years - 2018, 2019, 2020.

4. Discussion
After building the time series, an Excel file was downloaded from the LandViewer online service containing the following data: the minimum and maximum NDVI values and the average index value. In addition, the file contains information about such statistical indicators as standard deviation, variance of a random variable, lower quartile, higher quartile, median, 10th percentile, and 90th percentile. Data obtained from images taken outside the summer months have been deleted in the tables. Based on the remaining data for the summer season, for each of the 23 forest areas for the three analyzed years (2018, 2019, 2020), the average values for the year were calculated. So, within the settlement of Sosenskoye, the average value was calculated for 5 sites, within the settlement of Krasnopakhorskoye - for 8, within the settlement of Rogovskoye - for 10. These results were analyzed and compared. The calculation results are presented in table 1 and demonstrate a decrease in the value of the NDVI index of forest areas when approaching the old city border.
Studies have shown that the average NDVI values of single-breed forest areas increase with distance from the borders with Old Moscow. The lowest NDVI values (0.70) are typical for the Sosensky settlement located at the borders of Old Moscow within an urbanized zone with a high density of administrative and business development. The next largest values are observed in the settlement Krasnopakhorskye, located in the central part of New Moscow within the zone of low urbanization - 0.72. And, finally, the highest NDVI values (0.75) are observed within the Rogovskoye settlement, which is located on the border with the Kaluga region in a recreational area with low-rise residential buildings. The main factors of negative impact on the urban forests of New Moscow are associated with the industrial and transport infrastructure, mostly confined to the territory of old
Moscow. The transport arteries of New Moscow itself also exert some influence, primarily the Kaluzhskoe highway that runs through the whole of New Moscow.

Table 1. Average NDVI values for forest areas within the three model areas.

| Settlement \ Year | Forest number | 2018 | 2019 | 2020 | Average |
|-------------------|---------------|------|------|------|---------|
| Sosenskoe         | 1 0.67 0.71 0.77 | 2 0.72 0.75 0.76 | 3 0.69 0.71 0.62 | 4 0.71 0.59 0.68 | 5 0.72 0.68 0.69 |
|                   |               |      |      |      | 0.70    |
|                   | 2 0.75 0.74 0.74 | 3 0.65 0.71 0.65 | 4 0.73 0.71 0.67 | 5 0.73 0.72 0.66 | 6 0.75 0.77 0.76 |
|                   |               |      |      |      | 0.72    |
|                   | 7 0.77 0.76 0.68 | 8 0.75 0.74 0.66 | 1 0.79 0.78 0.77 | 2 0.70 0.77 0.75 | 3 0.71 0.73 0.66 |
|                   |               |      |      |      |         |
|                   | 4 0.71 0.78 0.79 | 5 0.78 0.77 0.72 | 6 0.78 0.77 0.79 | 7 0.76 0.75 0.70 | 8 0.78 0.76 0.73 |
|                   |               |      |      |      | 0.75    |
|                   | 9 0.74 0.73 0.66 | 10 0.78 0.77 0.74 | 11 0.78 0.76 0.73 | 12 0.78 0.77 0.74 | 13 0.78 0.77 0.74 |

5. Conclusion

Within the boundaries of New Moscow, the state of the forests is not the same. A stronger anthropogenic impact is exerted on the northern regions, which leads to a depressed state of vegetation and, consequently, to a decrease in their photosynthetic potential. In the southern settlements, where there are no large settlements and roads, the state of the natural environment is more favorable, therefore the forests are not so oppressed.

Thus, the studies carried out have shown that the need to make urgent design decisions to preserve forest plantations within New Moscow, which currently have the status of OZNT, is quite obvious and necessary. At the moment, the status of OZNT suggests broad opportunities for the use of these forests. However, the study of the current state of forest areas allows us to draw conclusions about the need to take urgent measures to preserve them. The obtained data on the differentiation of the index of the photosynthetic potential of forests, depending on their proximity to the boundaries of the old city, allows us to solve the problem of prioritizing objects when solving the problem of protecting the forests of New Moscow. It is quite obvious that the preserved forest areas, especially the large, least transformed and fragmented, located mainly in the southwest of the territory under consideration, most likely need to be assigned a higher protective status.

The data obtained as a result of the conducted research can be used to solve the problems of ecological design of the urban environment and to make early decisions for the formation of an optimal network of protected areas of different status in the Moscow region.
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