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THE USE OF THE SATELLITE IMAGERY FOR THE ASSESSMENT OF THE FOREST FIRE DANGER

In the article the possibility of using satellite imagery of Landsat 8 for assessing forest fire danger is considered. As a software platform for assessing the fire danger the geographic information systems with a number of plugins were used. To assess the forest fire danger it is suggested to calculate the spectral indices and surface temperature according to the satellite imagery. It was calculated the following indices: the vegetation index NDVI (EVI), NDWI and TVDI. It was necessary to calculate the average values of the indices for the whole object of evaluation of forest fire situation. A comparison of mean values of data indices with their values for individual sites and the definition of fire danger for these sites were carried out. The interpolation of the obtained values of fire danger areas within the boundaries of forest inventory sub-compartment (forest compartment) was done. As a result, they were assigned one dominant area fire rating class. The end product is a vector polygon layer of classes of fire danger for every forest stands containing an attribute table of the forest characteristics and classes of fire danger, which will allow to design fire protection measures for the purposes of the forestry.

Key words: satellite imagery, Landsat 8, vegetation index, forest fire danger, geographic information system.

Introduction. Forest fires are a serious problem for the population in the world, because in addition to direct damage, including the loss of human life, the cost of extinguishing and restoration of the affected areas, the cost of wood burned, the ecological balance in the territory is violated [1].

The problem of the forecast of forest fire potential due to natural (drought, ground lightning) or anthropogenic (arson, careless behavior of people in the forest, the impact of roads and railways, etc.) factors is very urgent [1].

Therefore timely and accurate assessment of forest fire danger plays an important role. The basis of this assessment – forest fire danger indices – mathematical formulas formalizing the influence of precipitation, air temperature and humidity, moisture content of forest fuels, human activities, thunderstorm activity and other factors enabling to predict the possibility of fires in a particular area [2].

Main part. Forest fires under the influence of a variety of conditions are distributed on the territory and time very uneven. Conditions affecting the appearance and behavior of the fire can be divided into three main groups: silvicultural (permanent), weather (variable), as well as additional (storm activity and anthropogenic pressures) [3]. The impact of these conditions is expressed in the assessment of forest fire danger.

Therefore, there are various methods for assessing the fire hazard, which are based on:

– meteorological approach that takes into account the most significant weather conditions: wind speed, solar radiation, air and soil temperature, rainfall, humidity (e.g., methods of N. P. Kurbatskaya, V. G. Nesterov [3–5]);

– the use of deterministic and probabilistic models, which are based on physical and chemical laws of the combustion, as well as statistical data [1, 3]. At present, the method of predictive modeling of forest fire danger [1–3], which takes into account the scenario of co-occurrence of anthropogenic load and thunderstorm activity, the properties of forest fuel, weather conditions at the statistics, experimental data and the results of numerical simulation is created andbeing intensively developed;

– the use of remote sensing data, which most frequently use the so-called "index" images for their work with the spectral information. On the basis of the combination of the brightness values in certain channels, informative to highlight the object under study, and the calculation of these values of "the spectral index" of the object an image is made corresponding to the index value in each pixel, which allows you to select the object under study or to assess its condition. Spectral indices used for the study and assessment of the state of vegetation, got the common name of vegetation indices [6].

Currently, there are more than 160 variants of vegetation indices. The calculation of the majority of vegetation indices are based on two of the most stable (independent of other factors) sections of the curve of the spectral reflectance of plants. For example, vegetable indices ("the indices of greenness") are calculated according to the data in the narrow spectral bands. They summarize and reflect the influence of factors such as chlorophyll content, leaf area, compactness and the structure of the vegetation cover (NDVI, EVI, etc.) [6].

There are indices that determine the content of carbon in the form of lignin and cellulose (e.g., PRSI), which are present in large quantities in the wood and in the dead or dry plant tissues. The increase in these indicators may reflect a process of "aging" and the death of the plant, which points to a possible increase in dry forest fuel. Indices are also used to assess the moisture content in the vegetation cover (NDWI, NDII, etc.). High moisture content is characteristic of healthy vegetation that is growing faster and is more resistant to fires.

To calculate the vegetation indices the data of the satellite imagery (Landsat 8, Terra Modis et al.), containing a variety of ranges, the main of which being red (Red), blue (Blue), green (Green), infrared channels (near (NIR) and near shortwave (SWIR)) as well as thermal channels (TIRS) are used.

The main advantage of vegetation indices is the ease of their production strictly according to the materials of space shooting and a wide range of solved with their help problems. In assessing the forest fire danger on the basis of space imagery Landsat 8 system key vegetation indices associated with vegetation (NDVI (EVI)), humidity (NDWI) and temperature (TVDI) in the geographic information system were identified [6].

The vegetation index NDVI (Normalized Difference Vegetation Index) – the normalized difference in brightness in the red $\left(B_{\text{RED}}\right)$ and near-infrared $\left(B_{\text{NIR}}\right)$ areas of a space image:

$$\text{NDVI} = \frac{B_{\text{NIR}} - B_{\text{RED}}}{B_{\text{NIR}} + B_{\text{RED}}}. \quad (1)$$

NDVI indices in calculating the forest fire hazard are used to analyze the amount of vegetation (and hence, the amount of forest fuel). The higher the index value, the more vegetation in the studied territory. It has a scope from 1 (intensive dense vegetation) to –1 (the oppressed in terms of chlorophyll surface – open soil, asphalt, concrete, etc.).

In contrast to the index NDVI, the index EVIL [6] allows you to allocate more gradations in areas of high green biomass and has advantages for vegetation monitoring, as the effect of the soil and the atmosphere in the values of the index are minimized. In this regard, when using the data of space imagery, which has the above disadvantages, the EVI index should be calculated (Enhanced Vegetation Index), which is similar in its importance to the NDVI. To do this, use the following equation:

$$\text{EVI} = 2.5 \cdot \frac{B_{\text{NIR}} - B_{\text{RED}}}{B_{\text{NIR}} + 6 \cdot B_{\text{RED}} - 7.5 \cdot B_{\text{BLUE}} + 1}, \quad (2)$$

where B_{NIR}, B_{RED}, B_{BLUE} – digital pixel values of the infrared, red, and blue channels of satellite images.

Index NDVI [3, 6] for evaluating the fire hazard is used to detect the presence of moisture in the vegetation cover. The index of NDVI (Normalized Difference Water Index) is defined as the ratio of the difference and the sum of the absorption coefficients of B_{NIR} and B_{SWIR} channels:

$$\text{NDWI} = \frac{B_{\text{NIR}} - B_{\text{SWIR}}}{B_{\text{NIR}} + B_{\text{SWIR}}}. \quad (3)$$

There are other indices to determine the degree of provision of plants with water, but most of them use mid-infrared channel (MIR), so their application is possible only with the use of space imagery with this channel, which is not available on satellite images of Landsat 8.

The calculation of surface temperature is required to determine the possibility of ignition of combustible forest materials which, in turn, is an important aspect in the evaluation of forests fire hazard.

Space methods for determining the surface temperature are based on the use of thermal imaging channels from satellites NOAA AVHRR, Terra Modis, which are most commonly used for this purpose. But for the purposes of forestry, they are not always applicable because of their low spatial resolution (500–1,000 m), as opposed to 8 Landsat images (resolution 100 m), which are preferred because of the fact that the size of the stands in forestry are less than the resolution of the images Terra Modis and NOAA AVHRR. It is will complicate the precise definition of fire danger for each allotment.

Temperature and vegetation index TVDI – Temperature Vegetation Dryness Index (Sandhold, 2002) was originally used for the assessment of the humidity and temperature of the soil and vegetation:

$$\text{TVDI} = \frac{T_S - T_{S\min}}{T_{S\max} - T_{S\min}}, \quad (4)$$

where T_S – the surface temperature; $T_{S\min}$ – minimum surface temperature; $T_{S\max}$ – maximum surface temperature.

The spatial distribution of the index is a correlation surface temperature and NDVI index with a wide range of moisture conditions. The investigations of Goward et al. (1985) showed a strong inverse proportional relationship between the surface temperature (T_S, $T_{S\min}$, $T_{S\max}$) and index NDVI, due to cooling by evaporation of moisture of living biomass.

The definition of forest fire danger envisages the establishment of specific classes for the flammability of individual sections of forest land as you step through the following stages:

1) comparison of the average values of these indices and their values for individual sections obtained as a result of the classification and definition of classes of fire danger of these areas;

2) joining the tables of attributive data of vector indices NDVI (EVI), NDVI, TVDI, which is performed in order to provide all the necessary values for determining the fire danger indices in the attributive data table of a single vector layer;

3) calculation of the average values of these indices, which are determined as the arithmetic

average value of the entire object of evaluation of forest fire situation in general. After finding the arithmetic values of the necessary vegetation indices a comparison of the results with the index of each specific site is made. To this end, the difference between the arithmetic mean value of the relevant index and an index value of a specific area is calculated;

4) the interpretation of the values of classes. For the resulting difference values a particular class of fire danger is determined which is stored in the attribute data table for each highlighted on a vector layer as a result of satellite image interpretation, does not coincide with the boundaries of selected (may include several classes of fire danger). Therefore, it is more appropriate to interpolate the obtained values of the classes of fire danger within the boundaries of forest stands (blocks) depending on the size of each class of fire hazards that occur in the forest stand on the basis of satellite images.

As a result, each allotment or forestry block is assigned one predominant area fire rating class. This operation is performed on the basis of main interpolation procedures of the used geo-information system with the help of the original vector map layers, resulting from forest management (allotment, block), as well as a vector layer with the classes of fire danger of objects obtained by the results of interpretation.

The final information product is a polygon vector layer class of fire danger for each forest stand containing taxation data of the spaces and classes of fire danger in the attribute table, which in future will allow to design the fire protection measures for the purposes of forestry.

Conclusion. Currently, a cosmic way of monitoring of forest fires with the Belarusian space vehicle for Earth remote sensing, allowing to provide data on the occurrence of fires in the forest fund is also used.

The use of space imagery in the assessment of fire danger allows indirectly to consider both the meteorological factors and characteristics of forest stands. This meteorological factors are taken into account by calculating specific indices (normalized humidity, temperature and vegetation) and the surface temperature, whereas the characteristics of the forest vegetation – in the form of vegetation indices. All analyzed parameters were obtained using only satellite imagery. This greatly simplifies the collection of initial data.

Thus, the developed methodology allows to take into account weather factors and the characteristics of forest stands and create quarterly maps of forest fire risk areas.

The joint use of this approach of the determination of forest fire danger with the current method can bring the following estimate and forecast of forests fire danger to a new qualitative level.

References

1. Baranovsky N. V. *Matematicheskoye modelirovaniye naiboleye veroyatnykh stsenariyev i usloviy vozniknoveniya lesnykh pozharov. Dis. kand. fiz.-mat. nauk* [Mathematical modeling of the most probable scenarios and conditions of forest fires. Cand. dis.]. Tomsk, 2007. 153 p.

2. Hubenko I. M., Rubinstein K. G. Comparative analysis of methods for calculating the indices of fire danger. *Trudy Gidrometeorologicheskogo nauchno-issledovatel'skogo tsentra Rossiyskoy Federatsii* [Proceedings of the Hydrometeorological Research Center of the Russian Federation], 2012, no. 347, pp. 207–222 (in Russian).

3. Hodakov V. E., Zharikova M. V. *Lesnyye pozhary: metody issledovaniy* [Forest fires: research methods]. Kherson, Green D. S. Publ., 2011. 470 p.

4. Kurbatsky N. P., Dorrer G. A., Dorogov B. I. Calculation of the distribution of sources of fires in the forest. *Lesnoye khozyaystvo* [Forestry], 1978, no. 7, pp. 76–78 (in Russian).

5. Katz A. L., Gusev V. L., Shabunina T. A. *Metodicheskiye ukazaniya po prognozirovaniyu pozharnoy opasnosti v lesakh po usloviyam pogody* [Methodological guidelines for predicting fire dangerof forests due to weather conditions]. Moscow, Gidrometeoizdat Publ., 1975. 16 p.

6. Cherepanov A. S., Druzhinina E. G. Spectral properties of plants and vegetation indices. *Geomatika* [Geomatics], 2009, no. 3, pp. 28–32 (in Russian).

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