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MONITORING OF FOREST CONDITIONS DURING FIRE DANGER

A variety of information on forest ecosystem can be obtained by using remote sensing techniques nowadays. The use of space data of forest monitoring is economically beneficial, because it allows to quickly obtain objective information needed by forest users to solve practical problems. Satellite data provides wide coverage of forest lands, high accuracy of results, and high frequency of received data. Space images of the territory of Ovruch district of Zhytomyr region of Ukraine were selected for the study in the summer of 2020. The definition of the rock composition is carried out by methods of the guided classification, namely Bayesian classifier. It is found that 70% of forests are pine, the aspen, hornbeam, birch, alder and ash breeds of tree are found in smaller numbers. In Ukraine according to statistical data for 2000-2020, 51,4 thousand hectares of forest plantations were damaged and destroyed by forest fires. Therefore, objective and timely information on the fire effects is necessary for the solving a wide class of applied problems of forestry. Determining the area of damaged forests is an important task in assessing the ecological and the economic damage caused to forest management by forest fires. In the work technologies for defining the forest area, in which the fire occurred, are reviewed using the space images of Landsat 8 sattelite. For detecting burned areas and levels of damage a normalized NBR pre and post fire index and DNBR index are used. For forecasting forest fires a mathematical model based on Bayesian theorem and a quarterly thematic map with classes of fire danger are created. To check the accuracy of the results of the projected model, a combination of the thematic map with a fire layer of the defined areas is carried out. This software product is flexible and versatile enough, it can be easily adapted to use not only for the determination of burned forest lands, but also for other territories.

Keywords: information system; space imagery; remote sensing of the Earth; Quantum GIS; fire index; Bayesian formula; probability of fire.

INTRODUCTION

Forests are the main terrestrial component of maintaining natural balance in the biosphere, a source of renewable biological resources in a period of global climate change. Objective data on forest resources, the dynamics of planting and forest management, their biodiversity and geography are a complex task for creating scientific and technical accounting and management of forests. This task is also affected by the negative anthropogenic factor, which sometimes leads to irreversible consequences. In Ukraine in the 80s and 2000s major forest fires were recorded. However, in 2020 large fires occured in the forests of Kyiv and Zhytomyr regions and led to destruction of large area of forest lands. The modern level of analytical methods and computer programs allows to significantly increase the monitoring of forest areas and forecast fire hazard in forests.

Forecasting forest fires is a determination of their probability of occurrence and their spread in the time and space, based on analysis of data of forest monitoring. The following data are required for forecasting:

- class of fire hazard according to weather conditions;
- Location and area of forest land of I-III fire hazard classes;
- orthographic data (type of relief: plains, hills, mountains, plateau, ravines);
- presence of potential sources of fire on the examined forest area;
- data on retrospective analysis of the spread of fires in time (number of fires by year, month, week) and territory (forestry, quarter, allocation).

Therefore, objective and timely information on the consequences of fires, obtained on the basis of integration of the forecast model and GIS technologies, is extremely necessary for solving various problems in updating forest, updating of data on forest planting, protection of natural forest fund.

Various information on forest ecosystems can be obtained by means of remote sensing methods of Earth (Earth remote sensing) nowadays. The use of space data of forest monitoring is economically beneficial, because it allows to quickly obtain objective information needed by forest users to solve practical problems. Satellite data provides wide coverage of forest lands, high accuracy of results, and high frequency of received data [1–9].

Analysis of recent research and publications. Analysis of modern scientific and information sources in the field of research of fire-hazardous areas and creation of predictive models of forest fires revealed a number of fundamental and perspective works.

In researches by Vasilieva A.V., Krasniashchikh A.V., Korotaieva V.V. the development of the hardware and software complex of detection and monitoring of forest fires on the basis of the unmanned aircraft was considered. In work [10] a method of combining images of thermal and TV channels is used, it details the architecture of special software. Khudov V., Kuchuk G., Makoveichuk M., Krizhny A. focus their analysis on known methods of image segmentation obtained from on-board optical-electronic surveillance systems [8].

The construction principle is analytical, simulation and statistical mathematical models. Analytical models of forest fires are described in the works of Grishin A.M., Kutsenko L.M., Vasilieva S.V. [12; 13], in which the mathematical and physical model is created, the basic model of equations is given, the structure of the fire front and the boundary conditions of its spreading are considered. However, the number of solutions of systems of equality do not have sufficient simplicity, methods in the conditions of uncertainty require a large number of physical characteristics and complex mathematical calculations, therefore they are not suitable for carrying out operative and tactical measures.

To develop a long-term forecast of changes in fire safety for mixed forest types in the world already use developed complex of FORRUS-S programs, which is intended for simulation modelling and analysis of dynamic processes taking place in forests. The baseline information for the model construction is the allocation of tax and plans of forest plantations. The software-technical solution is a prototype of the software module, which allows to functionally integrate into one system four mathematical modules of various components of the system and the processes of circulation of elements [17; 18].

The urgency of this work lays in the absence of a universal system, in which the integration of mathematical model, GIS technologies and predictive model of the expert being tracked, which being flexibly adapted to all types of forest plantations would greatly expand the possibilities of making good managerial decisions.

The purpose and objectives of the study. The purpose of our research is to develop an information system that will analyse the consequences of forest fires using remote sensing technologies and make predictions about detection of fire hazardous areas.

THE MAIN PART

In order to maximize management efficiency, reduce costs and objectively determine the forest inventories, it is expedient to implement remote sensing methods of the Earth. They are widely used for forest monitoring due to the availability of satellite images in large areas, and the data obtained have considerable information value and with proper processing can give a lot of useful information on forest land: Area detection, tree species composition, changes in forest plantations, spread of forest fires, logging. When analysing spectral channels of satellite images, it is possible to get information on forest health, the degree of destruction caused by pests or age. In general, you can find out the information on the forest inventories with just a set of images and a specialized program. Remote measurement data can be used as an alternative to more expensive ground-based observation and measurement. Both space images and aviation photography results can be used to determine the forest condition. For detailed analysis of forest, space images of very high resolution (sub-meter) resolution (GeoEye-1, Quick Bird, Word View) are the best to use but in terms of economy and sufficiency for estimation of fire safety, the optimal use of high resolution (meter) images is optimal.

The territory of Ovruch district of Zhytomyr region was selected for the research. Data of space images of the summer period of 2020, which were made by Landsat 8 satellite are used. Images are freely available and can be obtained from sites such as EOS Land Viewer or USGS Earth Explorer. Images are in GeoTIFF format with WGS 84 geographic coordinate system and WRS-2 reference system. They contain eleven spectral channels that are of different sets which used for different purposes (table 1).

Actualization of forest condition is carried out by the methods of guided classification, which consists in:

- defining classes of forest lands;
- performing the classification of space shot, which is a combination of spectral channels 3, 4, 5, 6, 7, 8;
- construction of a vector map layer of forest arrays on the basis of a raster layer of resulting classification.

The class definition is to generate statistical pixel calculations for each species. The choice is made by marking the control sites on the image, where we exactly know the tree species. We make this choice with the forest map. On the basis of these statistical calculations, signatures of classes are formed.

Guided classification uses the Bayesian classifier: Based on signatures of certain classes, a system of equations is formed which determines the probability of belonging of a pixel of a space image to the corresponding class, and for each pixel of a space image probability of its belonging to a certain class is estimated (fig. 1).

Table 1

Spectral channels of Landsat 8 imagery

Name	Wavelength (μm)	Resolution (m/pixel)	What better shows
Coastal Aerosol	0,433 – 0,453	30	Shallow water, thin particles of dust
Blue	0,450 – 0,515	30	Deep water, atmosphere
Green	0,525 – 0,600	30	Vegetation
Red	0,630 – 0,680	30	Anthropogenic objects, soil, vegetation
Near-infrared	0,845 – 0,885	30	Waterfront, vegetation
Short wave infrared 1	1,560 – 1,660	30	Cloudiness, soil moisture and vegetation
Short-wave infrared 2	2,100 – 2,300	30	Cloudiness, soil moisture and vegetation
Panchromatic	0,500 – 0,680	15	Black and white images, precise details
Wispy clouds	1,360 – 1,390	30	Wispy clouds
Thermal infrared 1	10,30 – 11,30	100	Thermal mapping, estimated soil moisture
Thermal infrared 2	11,50 – 12,50	100	Improved thermal mapping, estimated soil moisture

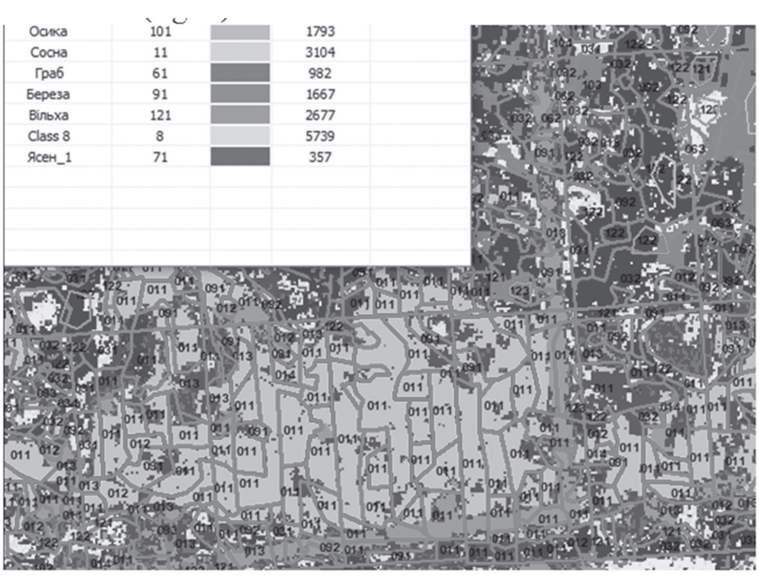


Fig. 1. Classification of the species composition on forest departments of Ovruch district

It is found that 70% of forests are pine. In forests there are also the aspen, hornbeam, birch, alder and ash breeds of tree. Pine forests are known to be the most potentially dangerous objects given the forest fires. In recent years, the number of forest fires of coniferous species, mostly in Polissia, namely in Zhytomyr region, has increased. According to the results of the analysis of data by the laboratory of ecology Ukrainian Research Institute of Forestry and Agroforestry in Ukraine 2000-2019 51,4 thousand hectares of forest plantation was damaged and destroyed by forest fires. In 2020, the loss from forest fires in Zhytomyr and Luhansk regions of Ukraine passes the limit of tens of thousands of hectares. Therefore, objective and timely information on the consequences of fires is necessary for solving a wide class of applied tasks of forestry, including planning of protection and forest protection, forest use and reforestation, updating of data on forest resources.

Technology of detection of burned areas

Space image data made by Landsat 8 satellite pre and post fire are used to determine the areas affected by fires respectively. The images contain the same geographical area of fires in Ovruch district. To determine the burned areas, a comparison of the normalized NBR index pre and post fire is used and calculated according to the formula:

$$NBR = \frac{NIR - SWIR}{NIR - SWIR}, \qquad (1)$$

where NIR is the near-infrared channel (channel 5 from table 1), SWIR is the short-wave infrared channel 2 channel (channel 7 from table 1).

This index shows forest areas affected by fire. The result of the normalized index of the mentioned areas with a scale from –1,00 to 1,00, where –1,00 — completely unaffected areas, and 1,00 — completely burned, is shown in fig. 2, where the images pre and post fire are located.

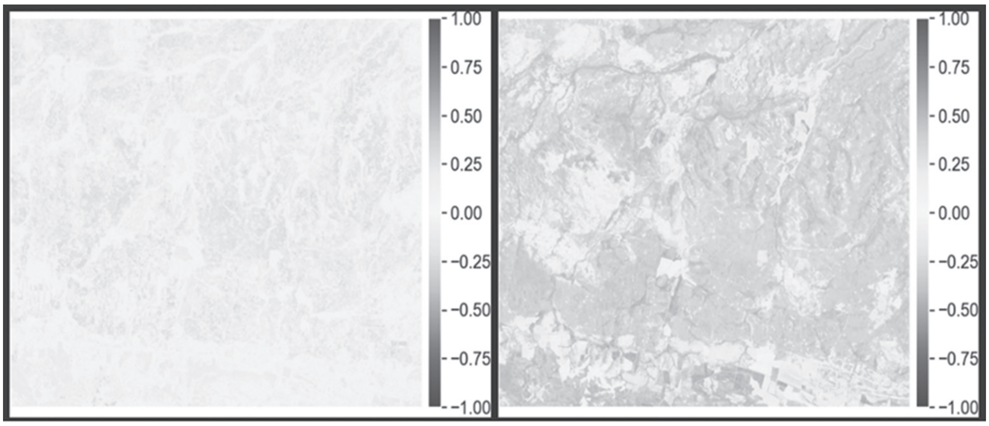


Fig. 2. Display NBR index pre and post fire

To compare the change in the NBR index between the pre fire and post fire period, the DNBR index is used, which is based on the formula:

$$DNBR = (pre\ fire\ NBR) - (post\ fire\ NBR), \quad (2)$$

where pre fire NBR is the NBR index before the fire, post fire NBR is the NBR index after the fire.

To determine the levels of damage to the territory, the obtained data of DNBR indicator are classified: The level of growing territory on the graph is indicated by dark green colour, unburned — light-green, low-affected — beige, medium-affected — orange and strongly-affected territory — dark-red (fig. 3).

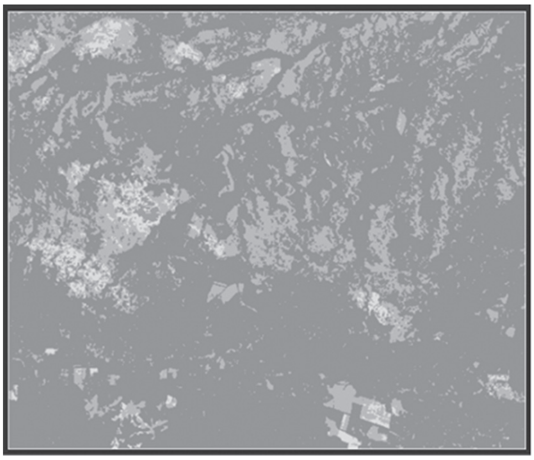


Fig. 3. Display the DNBR index

The system exports the received data on area of fire in GeoTIFF format, which preserves the geographic coordinates of the object and ensures compatibility of the received information with different geographic systems.

Forecast of forest fire by Bayesian method

To forecast forest fires and their timely warning, the foresters and the forest protection engineers need to know the probability of forest fires during a fire-hazard period, which will depend on the forest characteristics and climatic conditions, on the territory of each forestry. To do this, we use the Bayesian theorem, one of the basic theorem of probability theory, which calculates the probability of the event on condition that another event related to it has already taken place. Bayesian's formula helps to more accurately reflect the probability of the event, taking into account both known data and new data. For practical application of formulas, it is necessary to carry out a lot of calculations, therefore the Bayesian's assessments have begun to be actively used with rapid development of information technologies.

Let K event happen only simultaneously with one of the hypotheses $H_1, H_2, \ldots, H_n$ that form a complete group of incompatible events, that is $\sum_{i=1}^{n} P(H_i) = 1$. Then, according to the Bayesian theory, the probability of an event K, which can only occur when one of the events occurs H_1, is equal to the sum of the probabilities of each of the hypotheses to the corresponding conditional probability of the event K:

$$P(K) = \sum_{i=1}^{n} P(H_i) \cdot P(K/H_i). \quad (3)$$

For the event K is characterized by a complex of features $k_1, k_2, \ldots, k_v$ that in turn can still be divided into the ranks $k_{j1}, k_{j2}, \ldots, k_{jm}$, which will be followed by research.

Then, to determine the probability of hypotheses, provided that event K has already taken place, the generalized Bayesian formula is used:

$$P(H_i/K)=\frac{P(H_i)\cdot P(K/H_i)}{\sum_{i=1}^{n}P(H_i)\cdot P(K/H_i)}, \quad (4)$$

where $P(H_i)$ is the prior probability of hypothesis, H_i, K — an event, which is characterized by a certain complex of features k_1, k_2,..., k_ν, n is the total number of possible hypotheses, $P(H_i/K)$ — a posterior probability of hypothesis H_i after the received results on a set of features of the event K, $P(K/H_i)$ — the event probability K with a hypothesis H_i, which is calculated according to the formula:

$$P(K/H_i) = P(k_1/H_i)\cdot P(k_2/H_i)\cdot \ldots \cdot P(k_\nu/H_i). \quad (5)$$

To forecast forest fires, their timely warning and rapid elimination, it is necessary to know the probability of their occurrence during a fire-hazard period, which depends on the forest characteristics of forest plantations.

For the analysis Mozharivs'k forestry in Ovruch district was chosen. The area of forest lands of the forest is 8298 hectares. Having statistical data on all the forest characteristics of the quarter, we will make a fire risk assessment of each quarter separately across the forestry and define classes of fire hazard.

Let K it be an event that characterizes the occurrence of a fire in the forest. The area of forest lands of Mozharivs'k forestry is divided into 85 blocks, so we have hypotheses H_1, H_2,...,H_{85}. In order to determine the probability of each hypothesis, it is necessary to divide the area of the quarter by the total area of all examined quarters of the forest, that is

$$P(H_i)=\frac{S_{H_i}}{S}. \quad (6)$$

As the example we shall take territory 64 of the quarter. The probability for this quarter is equal to $P(H_{64})=\frac{S_{H_{64}}}{S}=\frac{28{,}4}{286{,}5}=0{,}10$.

The following factors that influence the occurrence of fire: feature k_1 — a composition of forest plantations, feature k_2 — a planting density, feature k_3 — an age of forest plantations, feature k_4 — forest type. In order to determine the probability of occurrence k_i of the feature in a quarter H_i, it is necessary to divide the area of the forest in a quarter, which has the feature k_i, by the area of the whole quarter, that is

$$P(k_{ij}/H_i)=\frac{S_{k_{ij}}}{S_{H_i}}. \quad (7)$$

Feature k_1 — tree stands composition is a part of tree species that are in the forest plantation. The main forest plantations in Mozharivs'k forestry are: k_{11} — Usual pine (Up), k_{12} — Silver birch (Sb), k_{13} — Ordinary oak (Oo), k_{14} — Black alder (Ba), k_{15} — Aspen (As). The most fire hazardous are pine plantations, so for this characteristic one need to determine the area of the territory where usual pine grows. For quarter 64 we have: $P(k_{11}/H_{64})=\frac{26{,}86}{28{,}4}=0{,}95$.

The feature k_2 — wood density is the indicator of density of the tree trunk stands per unit area. The most fire-hazardous ones are forest stands with density of 0,7, 0,8, 0,9. So, one can define the following groups by the stand density: k_{21} — density 0,7 – 1; k_{22} — density 0 – 0,6. Let's determine the probability of the feature for Quarter 64: $P(k_{21}/H_{64})=\frac{24{,}1}{28{,}4}=0{,}85$.

The feature k_3 — age of trees is young pines aged under 40 years (group 2 and of class 3) refer to the class 1 of natural fire hazard. In such forest stands, fires almost always go to the top, causing significant damage, and the elimination of such fires is difficult. Thus, one can distinguish the following age groups: k_{31} — groups of age 2 and 3 (young growth classes 1 and 2 up to 40 years), k_{32} — groups 4-8 (others, over 40 years). Thus, we determine the probability for each class of fire hazard in quarter 64:

- Class 1 of fire hazard — forest stands aged 2 and 3-year group:

$$P(k_{31}/H_{64})=\frac{S_{k_{31}}}{S_{H_{64}}}=\frac{6{,}1}{28{,}4}=0{,}21;$$

- Classes 2-4 of fire hazard are the age groups of 4-8 years:

$$P(k_{32}/H_{64})=\frac{S_{k_{32}}}{S_{H_{64}}}=\frac{22{,}3}{28{,}4}=0{,}79.$$

A feature k_4 — a type of forest is a part of the forest or their combination, characterized by the same forest conditions, the same composition of tree species, the number of strata, similar to a fauna, and require the same economic measures under equal economic conditions. The main ones are the forest conditions of the same forest type on a definite area. The most fire hazardous are forest stands with indexes class 0,1 – 1 of fire hazard, and index 2 — class 2 of fire hazard (table 2).

Table 2

Classes of fire hazard by the type of forest conditions for forest stands over 40 years

Feature	Class of fire hazard	Types of forest conditions	Explanation
k_{41}	Class 1	A0P	Very dry pine tree forest
		A1D	Dry pine forest
		B1OP	Forest conditions of dry oak-pine forest
		C1HOP	Forest conditions of hornbeam-oak-pine forest
k_{42}	Class 2	A2P	Fresh pine forest
		B2OP	Forest conditions of fresh oak-pine forest
		C2HOP	Forest conditions of fresh hornbeam-oak-pine forest
k_{43}	Class 3	A3P	Moist pine tree
		A4P	Damp pine tree
		B3OP	Forest conditions of moist oak-pine forest
		B4OP	Forest conditions of damp oak-pine forest
		C3HOP	Forest conditions of moist hornbeam-oak-pine forest
		C4HOP	Forest conditions of damp hornbeam-oak-pine forest
k_{44}	Class 4	A5P	Wet pine tree forest
		B5BP	Forest conditions of wet birch-pine forest
		C5BA	Forest conditions of moist black alder forest

Thus, let's determine the probability by each class of fire hazard in Quarter 64 by the feature :

♦ Class 1 of fire hazard are forest stands under 40 years of all indexes and the forest stands over 40 years with indexes 0,1:

$$P(k_{41}/H_{64}) = P(k_{31}/H_{64}) = \frac{S_{k_{31}}}{S_{H_{64}}} = \frac{6{,}1}{28{,}4} = 0{,}21;$$

♦ Class 2 of fire hazard are the forest stands over 40 years with index 2:

$$P(k_{42}/H_{64}) = \frac{S_{k_{42}}}{S_{H_{64}}} = \frac{21{,}9}{28{,}4} = 0{,}78;$$

,

♦ Class 3 of fire hazard are the forest stands over 40 years with indexes 3,4:

$$P(k_{43}/H_{64}) = \frac{S_{k_{43}}}{S_{H_{64}}} = \frac{0{,}4}{28{,}4} = 0{,}01.$$

Let's determine the probability of the occurrence of fire in Quarter 64 considering classes of fire hazard K_1, K_2, K_3 respectively:

$$P(H_{64})\,P(K_1/H_{64}) = P(H_{64})P(k_{11}/H_{64})P(k_{21}/H_{64})P(k_{31}/H_{64})P(k_{41}/H_{64}) =$$
$$= 0{,}10 \cdot 0{,}95 \cdot 0{,}85 \cdot 0{,}21 \cdot 0{,}21 = 0{,}004;$$

$$P(H_{64})\,P(K_2/H_{64}) = P(H_{64})P(k_{11}/H_{64})P(k_{21}/H_{64})P(k_{32}/H_{64})P(k_{42}/H_{64}) =$$
$$= 0{,}10 \cdot 0{,}95 \cdot 0{,}85 \cdot 0{,}79 \cdot 0{,}78 = 0{,}05;$$

$$P(H_{64})\,P(K_3/H_{64}) = P(H_{64})P(k_{11}/H_{64})P(k_{21}/H_{64})P(k_{32}/H_{64})P(k_{43}/H_{64}) =$$
$$= 0{,}10 \cdot 0{,}95 \cdot 0{,}85 \cdot 0{,}79 \cdot 0{,}01 = 0{,}0006.$$

Thus, in quarter 64 the most likely is class 2 of fire hazard. Similarly, for all other quarters, according to formula (3), we define fire hazard classes.

In Mozharivs'k forestry classes 1-4 of fire hazard are found: class 1 — 6485,6 ha, class 2 — 1210,3 ha, class 3 — 516 ha and class 4 — 86,1 ha.

Now, according to the Bayesian formula (4) for each quarter we estimate the fire occurrence on condition that one of the classes of fire danger has already been detected there K_1, K_2, K_3, K_4, that is

$$P(H_i/K_m)=\frac{P(H_i)P(K_1/H_i)}{P(K_m)},\ m=1,2,3,4.$$

For quarter 64 where class 2 of fire hazard is found, the probability of occurrence of fire is

$$P(H_{64}/K_2)=\frac{P(H_{64})P(K_2/H_{64})}{P(K_2)}=\frac{0,05}{0,077}=0,65.$$

The creation of a cartographic database for estimation of probability of fires in forest areas

As described above, the probability of a fire in a particular forest area is determined by the time-age composition of the forest sites in the estimated quarter and the moisture condition in this forest site (table 3,4). To calculate the probability, a cartographic base which describes the characteristics of forest areas and forest sites is formed. The database includes two main classes of objects, attributes of which are given below, and classifiers «Main element of the forest», «Age group», «Feature of moisture».

Table 3

Class of forest quarters

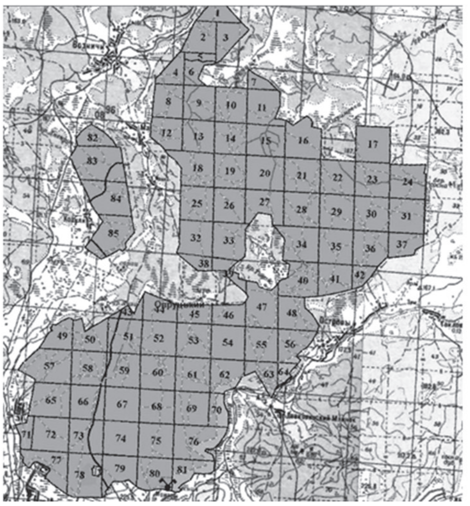
Name of attribute	Data type	Explanation
Number of quarter	Integer	Number of quarter
Name of quarter	Text	Marking of quarter
Pirology Value	Float	Fire index
Area	Float	Area of quarter

Table 4

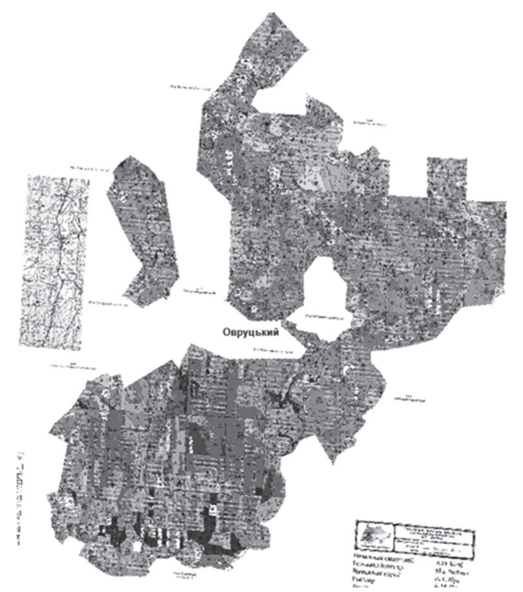
Class of forest sites

Name of attribute	Data type	Explanation
Number of forest site	Integer	Number of quarter
Name of forest site	Text	Marking of quarter
Pirology Value	Float	Fire index
Area	Float	Area of quarter
Forest Element	Integer	Main forest element
Old Group	Integer	Age group

The cartographic database was filled by digitizing the raster maps of Mozharivs'k forestry (fig. 4).



a



b

Fig. 4. The raster map of forest quarters (*a*) and forest departments (*b*) of Mozharivs'k forestry

The result of digitizing are vector layers of quarters and departments with the defined characteristics of forest areas, on the basis of which the probability of occurrence of fires in forest quarters is calculated. Fig. 5 shows a thematic map of distribution of probability of occurrence of fire, calculated by Bayesian formula, where classes of danger are marked by colours: class I — blue, II class — red, III class — orange, IV class — green.

Fig. 5. Thematic map of distribution of probability of fire

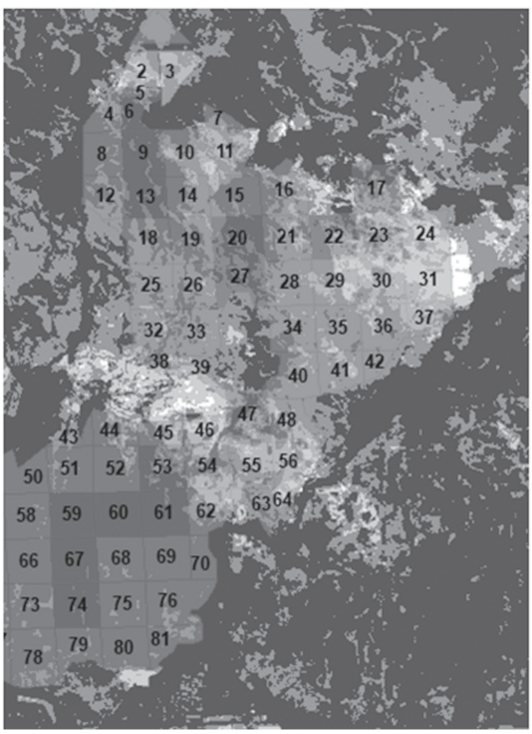


Fig. 6. Combination of thematic map of fire probability with the layer of defined consequences of fire

An interesting combination of thematic map with raster layer of fire index (fig. 6) obtained by means of the method of determination of burned areas by fire with formulas (1) and (2).

The combination of the map with the raster layer shows that our forecast model is correct and can be used by forestry specialists.

Discussion of the results

Recently, for the effective organization of terrestrial assessment of quantitative characteristics of forest lands, satellite images are increasingly used, which can significantly increase the completeness of detection and accuracy. Objective and up-to-date information on fires, obtained through the integration of forecasting model and technologies of geographic information systems, is essential for solving various tasks in reforestation, updating data on forest plantations, protection of natural forest resources. The Bayesian method helps to predict forest fires in certain areas of forestry and use the information obtained to prevent fires in a timely manner. This assessment depends on many factors, among which the taxonomic characteristics of forest plantations and climatic conditions are particularly important. Currently, the formula includes four features, but in the process of future research, it may be expanded. To verify the accuracy of the results of the created forecast model, it is necessary to combine the thematic map with a layer of defined areas of fires.

Conclusion

Information system of analysis of forest fires consequences using remote sensing technologies has been developed and forecast on detection of fire-hazardous areas has been made. Actualization of forest lands with use of space images on the basis of the guided classification by the Bayesian method was carried out. The results of the normalized NBR index definition before and after the fire were analysed based on space images made by Landsat 8 satellite during the summer period of 2020 in Ovruch district of Zhytomyr region of Ukraine. The forecast model of probable occurrence of forest fire by the Bayesian method was also created. A thematic map with distribution of fire hazard classes for each forest district was created. To check the accuracy of the results of the projected model, a combination of the thematic map with a fire layer of the defined areas is carried out.

This information system is a convenient and universal software product that can adapt to any forest macro system. The further direction of improvement is the introduction of artificial intelligence and machine learning, which will allow to obtain the result of analysis even more precisely and with maximum speed for rapid responding and decision making.

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МОНІТОРИНГ СТАНУ ЛІСІВ У ПЕРІОД ПОЖЕЖОНЕБЕЗПЕКИ

Сьогодні різноманітну інформацію про лісові екосистеми можна отримати за допомогою методів дистанційного зондування Землі. Використання космічних даних моніторингу лісів є економічно вигідним, оскільки дає змогу швидко дістати об'єктивну інформацію, необхідну лісівникам для розв'язання практичних задач. Супутникові дані забезпечують широке охоплення лісових угідь, високу точність результатів, а також високу частоту отриманих даних. Для дослідження було вибрано космічні знімки території Овруцького району Житомирської області України влітку 2020 року. Визначення породного складу проведено методами керованої класифікації, а саме класифікатором Байєса. Встановлено, що 70% лісів є сосновими, у меншій кількості зустрічаються осикові, грабові, бере-

зові, вільхові та ясеневі породи дерев. За статистичними даними впродовж 2000-2020 років в Україні було пошкоджено і знищено лісовими пожежами 51,4 тис. га лісових насаджень. Тому об'єктивна і своєчасна інформація про наслідки пожеж необхідна для вирішення широкого переліку прикладних завдань лісового господарства. Важливим завданням у процесі оцінювання еколого-економічного збитку, нанесеного лісовому господарству внаслідок лісових пожеж, є визначення площі пошкоджених лісів. У статті розглянуто технології визначення території лісу, де відбулася пожежа, з використанням космічних знімків супутника Landsat 8. Для виявлення спалених пожежею територій та рівнів ураження застосовано нормалізований індекс згарища NBR до та після пожежі й індекс DNBR. Для прогнозування лісових пожеж розроблено математичну модель на основі теореми Байєса та створено тематичну карту з класами пожежної небезпеки поквартально. Для перевірки точності результатів сформованої прогнозної моделі здійснено суміщення тематичної карти з шаром визначених територій згарищ. Такий програмний продукт є досить гнучким та універсальним, він може бути легко адаптованим для застосування не тільки для визначення спалених лісових угідь, а й для інших територій.

Ключові слова: інформаційна система; космічні знімки; дистанційне зондування Землі; Quantum GIS; індекс згарищ; формула Байєса; імовірність виникнення пожежі.

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МОНИТОРИНГ СОСТОЯНИЯ ЛЕСОВ В ТЕЧЕНИЕ ПОЖАРООПАСНОГО ПЕРИОДА

Сегодня разнообразную информацию о лесных экосистемах можно получить с помощью методов дистанционного зондирования Земли. Использование космических данных мониторинга лесов экономически выгодно, так как позволяет быстро получать объективную информацию, необходимую лесоводам для решения практических задач. Спутниковые данные обеспечивают обширный охват лесных угодий, высокую точность результатов, а также высокую частоту полученных данных. Для исследования были выбраны космические снимки территории Овручского района Житомирской области Украины летом 2020 года. Определение породного состава проведено методами управляемой классификации, а именно классификатором Байеса. Установлено, что 70% лесов сосновые, в меньшем количестве встречаются осиновые, грабовые, березовые, ольховые и ясеневые породы деревьев. По статистическим данным на протяжении 2000-2020 годов в Украине было повреждено и уничтожено лесными пожарами 51,4 тыс. га лесных насаждений. Поэтому объективная и своевременная информация о последствиях пожаров необходима для решения широкого перечня прикладных задач лесного хозяйства. Важной задачей при оценке эколого-экономического ущерба, причиненного лесному хозяйству в результате лесных пожаров, является определение площади поврежденных лесов. В статье рассмотрена технология определения территории леса, где прошел пожар, с использованием космических снимков спутника Landsat 8. Для обнаружения сожженных пожаром территорий и уровней поражений используется нормализованный индекс пожарищ NBR до и после пожара и индекс DNBR. Для прогнозирования лесных пожаров разработана математическая модель на основе теоремы Байеса и создана тематическая карта с классами пожарной опасности поквартально. Для проверки точности результатов созданной прогнозной модели произведено совмещение тематической карты со слоем определенных территорий пожарищ. Данный программный продукт достаточно гибок и универсален, он может быть легко адаптирован для применения не только для определения сожженных лесных угодий, но и для других территорий.

Ключевые слова: информационная система; космические снимки; дистанционное зондирование Земли; Quantum GIS; индекс пожарищ; формула Байеса; вероятность возникновения пожара.