UDC 004.94:630
DOI: 10.15587/1729-4061.2022.265039

DEVELOPMENT OF THE INFORMATION SYSTEM FOR MONITORING TIME CHANGES IN FOREST PLANTATIONS BASED ON THE ANALYSIS OF SPACE IMAGES

This study considers the issue of assessing the time changes in forest plantations and constructing an algorithmic and software system for monitoring these changes. Modern systems that study vegetation changes do not have the necessary functionality and do not cover the range of observations discussed in this paper. Existing research methods are intended only to record changes that occur in forest ecosystems and take into consideration the peculiarities of a certain natural zone, which limits their use. At the same time, it should be understood that the requirements for modern systems should include additional components that could make the system universal and mobile. A comparative analysis of satellite images acquired from remote sensing by the Landsat 8 satellite system has been carried out to determine the areas affected by forest fires. During the classification, spectral analysis was used, and an index of fires was determined to indicate the burned areas. To analyze the changes that occur in forests due to fires, correlation-regression analysis is used. It has been proven that the area of sanitary felling after fires and the area of forest land traversed by fires demonstrated the greatest interconnection. The extrapolation and forecasting were carried out using a regression data model, the effectiveness of which is confirmed by a coefficient of determination of 0.87. The dependences built make it possible to conclude that by 2030 the number of forest fires will increase while the area of burned forests will not decrease. The developed mobile application could be popular among a significant group of users to monitor fire events. The practical result is the introduction of the built system, which makes it possible to quickly monitor forest plantations after fires and assess the areas that were affected

Keywords: information system, satellite images, forest lands, monitoring, correlation-regression analysis, time changes

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Received date 28.06.2022
Accepted date 05.09.2022
Published date 30.10.2022

***How to Cite**: Svynchuk, O., Bandurka, O., Barabash, O., Ilin, O., Lapin, A. (2022). Development of the information system for monitoring time changes in forest plantations based on the analysis of space images. Eastern-European Journal of Enterprise Technologies, 5 (2 (119)), 31–41. doi: https://doi.org/10.15587/1729-4061.2022.265039*

1. Introduction

Forests are an important part of the existence of our planet. They occupy a significant part of the earth's surface and are the most common and valuable. Forest resources create the main source of oxygen, and increase the humidity of the air. Forests regulate the intensity of snowmelt and the water level in rivers, stabilize the composition of the atmosphere, delay gusty winds and the movement of sands, preserve useful fauna and microorganisms. Forests are also an important element of the landscape, which provide valuable raw materials to the national economy. For many millions of people, they are an important recreation area. Thus, the forest is an important sanitary and hygienic factor that enables the life and health of humans and all life on Earth.

The natural processes of forest development are influenced by the methods and intensity of felling trees, growing forests, protecting and saving them from fires, harmful insects and diseases, and the constant use of forest products. Great damage is caused by unauthorized logging, which destroys protected forest funds. For several centuries, forests have been intensively used throughout the planet, causing shortages of wood and forest products. This trend is constantly growing. In the 21st century, there has been a rapid decline in the world's forest reserves, forest areas, and forest resources. Forest fires are a destructive factor in ecosystems.

Many mathematical models have been constructed that examine the consequences of forest fires and methods for neutralizing them [1–4]. Most models have certain disadvantages, which do not allow them to be universal. Theoretical models are based on fundamental physical-mathematical and chemical laws. Verification of such models is quite complicated but, given their complexity, they solve many theoretical issues and are purely theoretical. In statistical models, data on the rate of fire propagation are systematized, with a variable number of parameters, the correlation coefficient of each independent variable is determined. The main disadvantage of these models is the use of statistical data only and the forecast of data only with a certain probability. Semi-empirical models apply general physical laws in the form of simplified dependences, the coefficients are selected by generalizing experimental information. Owing to automated systems that contain a mathematical apparatus, models are simplified. Therefore, scientists continue to build new and improve existing models with their further introduction into forestry to predict and prevent the occurrence of this natural disaster.

The development and implementation of measures to analyze the state of vegetation require comprehensive reliable information about its condition over a long time. It is advisable to monitor forest ecosystems over a long period using satellite observation data, which is one of the effective ways to study the transformation of vegetation. The use of space forest monitoring data is cost-effective, as it makes it possible to quickly acquire objective and timely information necessary for foresters to solve practical tasks. Satellite data provide a wide coverage of forest lands, high accuracy of results, as well as a high frequency of data obtained, which are extremely necessary for solving various problems in reforestation, updating data on forest plantations, and protecting the natural forest fund.

Thus, studies to tackle the analysis of the time series of satellite images to build a system for monitoring the state of vegetation of the most wooded areas of the examined area are relevant. The results of such studies would make it possible to systematically monitor qualitative and quantitative changes in forest plantations and make decisions to neutralize the consequences of fires to preserve a valuable forest fund.

2. Literature review and problem statement

Monitoring forest ecosystems using satellites is an effective method of monitoring the state of forests. The following satellite systems are used – Terra Modis, Landsat, NOAA/AVHRR, which help resolve various tasks in forestry. With the help of the acquired satellite images, it is possible to detect the level of forest cover of a certain territory, and areas affected by forest fires, to determine the area of plantations affected by various pests.

Various acquisition methods and algorithms for processing original images help accurately determine the qualitative and quantitative characteristics of the state of different territories of our planet. Works [5, 6] described the method of obtaining data based on correlation theory, which makes it possible to effectively recognize and classify them. It is shown that the construction of a suitable classifier could significantly improve the efficiency of further image processing operations: localization, recognition, search, and tracking of objects. However, such studies were conducted only for objects such as human faces, small details, and artificial images. In [7], a method of multi-scale image processing of remote sensing based on the algorithm for creating an artificial bee colony is proposed. This algorithm is adaptive to changes in the environment, which has advantages in an application for optimization problems and reduces the number of unnecessary objects in the image. However, it will not be able to effectively recognize objects in space images if there was cloudy weather. Works [8, 9] report studies of space-time segmentation of visual data for their implementation for different networks and complex systems. However, high computational complexity, large dimensionality of the search space, and complex topology of the field of acceptability lead to the loss of precious time when using these optimization methods.

Satellite data provide a wide coverage of different territories of the planet, not excluding forests, high accuracy of results, as well as a high frequency of data obtained. In [10], 30 vegetation indices are considered for decryption of the acquired images. The efficiency of using vegetation indices GEMI, PVI3, TSAVI for the interpretation of forests – demarcation of vegetation, soils, and underlying surface – is analyzed. In paper [11], the authors consider the need to use geographic information systems and remote zoning data for forest monitoring. To improve the mobility and efficiency of monitoring, the method of visualization of the normalized vegetation index NDVI is used. However, papers [10, 11] do not monitor the areas affected by forest fires and assess the areas burned by fires, with a classification of the degrees of fire damage.

Monitoring of forest ecosystems can also be carried out using software and hardware systems based on unmanned aerial vehicles (UAVs). Paper [12] demonstrates the great potential of high-resolution UAV data and photogrammetric methods that make it possible to acquire multispectral images and make estimates of various vegetation indices. The main limitation of this approach is the absence of ground-based radiometric measurements that could give a better quantitative idea of the ground situation. Monitoring was carried out only within the framework of agriculture. In [13], for better decryption of satellite images, a method of segmentation of images with multiple Gaussian transformations is proposed. The main disadvantage of this method is the presence in the segmented image of a large number of noisy objects. Works [14, 15] describe models of the functioning of the system for transmitting large data flow. The problem is to ensure a given level of survivability of a computer network on a mobile platform at the stage of its design by developing an appropriate criterion. Paper [16] considers methods for increasing the channel noise immunity of the UAV control channel by encoding information using ultra-short pulse signals and time positional-pulse modulation. However, it has not been proven how much these methods give an increase compared to classical methods.

Work [17] assesses the state of forest plantations based on the materials of satellite images to highlight the boundaries of taxing quarters. It is shown that the obtained data and algorithm can be used to build digital maps of plantings, tourist maps of a park, distribution into functional areas, etc. However, the issue of evaluating a series of images of forest plantations over the years was not considered. Studies [18, 19] describe methods for assessing the fire hazard of the forest, which will help make the right decisions to avoid a natural disaster. The issue of assessing the areas of forests covered by fires and forecasting the future occurrence of this natural disaster with further consequences was not considered. Paper [20] considers the solution to the problem of developing and researching a system for controlling the parameters of the environment of an artificial ecosystem and the use of fuzzy logic to establish relationships between parameters. The issue of controlling and monitoring the microclimate of the entire ecosystem remains unresolved. Work [21] considers the application of the theory of fuzzy sets to solve the task of assessing the speed of photosynthesis of plants and the method of deciding on the nature of the process of photosynthesis, taking into consideration the NDVI index. The question of comparing the evaluation results for a series of images is unexplored.

Thus, our review of literary sources [5–21] revealed that they lack analysis based on a mathematical apparatus that detects the influence of harmful factors, and it is not specified where and how the information obtained and processed is stored. The issues of efficiency in determining forest areas that were affected by forest fires, with their further classification, assessment of burned areas, and analysis of relationships between parameters that negatively affect the tree stand remain unsolved.

Most international programs and sites use sources such as InciWeb, an incident management system from the Americas operated by the National Wildfire Coordination Team, which collects ignition data [22]. Also, information can be acquired from Cal Fire, the Geological Survey of America, NASA, and a number of individual US government agencies that control forest fires around the world [23].

Earth Observing System is a special NASA program that includes a series of artificial satellites. The main task is a long-term global observation of the earth's surface. The artificial satellites Landsat 7, Terra (EOS-AM), Aqua, Aura, CloudSat, CAPILSO, SMAP, OCO-2, Landsat 8, and ICESat-2 have active missions. To monitor the forest, there is the EOS Forest Monitoring application, which provides users with the ability to monitor the state of forest plantations using satellite images and conveniently manage forest lands [24].

WorldView on NASA's website is a forest fire monitoring system that helps track various climate events, including forest fires. WorldView allows users to familiarize themselves with the means of tracking and viewing data. The system is more designed for visual representation, due to which it is convenient to see both information from past years and the current state [25].

The Fire Finder mobile application makes it possible to find data on forest fires in America; they are displayed on a satellite map that can track their progress. The information is provided from government sources: InciWeb and Cal Fire [26].

The Wildfire Info mobile app covers data on forest fires across the planet and is updated every ten minutes. Maps of heat points by region show the activity of fires over the past forty-eight hours from the VIIRS and NASA MODIS satellites. The application also includes maps of current fires, new reports on the situation and weather within the radius of forest fires, as well as current news about forest fires. The newest features of the application include location information from the "Map Tools" menu, which can be clicked to quickly access the pop-up window with time zone, address, and latitude/longitude [27].

ClearCut is an online platform developed by Quantum. It uses modern technologies and makes it possible to automatically collect data on the reduction of forest cover using machine vision technologies and neural networks. Every 3–5 days, the software acquires data from the satellite, compares it with previous data, and generates a report on changes in forest cover. This program deals only with comparing new information with the old one and detecting a decrease in forest cover, it works only with images, does not find relationships between data, and does not make predictions [28].

Our analysis of the investigated mobile application systems revealed that they are not universal and have certain disadvantages. In particular, some of them track forest fires within certain countries. No system has the functionality to identify dependences between the data it operates on and does not predict them. In addition, applications do not have feedback, namely real-time user support. Therefore, the development of new or improvement of existing systems in this area is expedient.

Having analyzed the available web applications for monitoring research, it was found that the programs in question work but have a number of drawbacks:

– support, modernization, and addition of new functionality are complicated by the use of outdated and rare technologies;

– the user interface does not meet modern design requirements;

– there is no or limited functionality for the analysis and visualization of local data;

– there is almost no visualization of microclimatic indicators.

Thus, the result of our analysis of existing systems and research results is the fact that there is a serious shortage of computer systems in the field of forest monitoring. All this suggests that it is expedient to build an information system that would solve the problem associated with increasing the efficiency of processing satellite images to monitor time changes in forest plantations with subsequent forecasting. This could make it possible to identify the most negative factors affecting the state of forest ecosystems and neutralize them at the initial stage of impact.

3. The aim and objectives of the study

The aim of this study is to improve the efficiency and reliability of space image processing to monitor time changes in forest plantations. This will make it possible to ensure a wide coverage of forest lands, as well as high accuracy of results, because objective and timely information on monitoring forest plantations is necessary to solve a wide class of applied problems in reforestation, updating data on forest plantations, and protecting the natural forest fund.

To accomplish the aim, the following tasks have been set:

– to develop a database for assessing the areas of territories affected by forest fires;

– to build a mobile application with information content and a geolocal reference.

4. The study materials and methods

4. 1. The object and hypothesis of research

The object of this study is time changes in global forest ecosystems.

The hypothesis of the study assumes that the development and application of an information system will improve the reliability of forecasting time changes in forest plantations.

4. 2. Determining the normalized indices of fires

To determine the territory of the forest, which was traversed by a forest fire, it is advisable to use images from the Landsat 8 satellite. These images can be acquired from the EOS LandViewer website for free. They should contain the same region before and after the fire. If a different territory is included in the image, the image can be cropped using the American free cross-platform geographic information system QGIS. The images are in GeoTIFF image format with the WGS 84 geographic coordinate system WRS-2 reference system and are characterized by various spectral channels, which are given in Table 1.

Table 1

Spectral channels of the Landsat 8 image [29]

No.	Title	Wavelength (μm)	Resolution (m/pixel)	Application
1	CoastalAerosol	0.433–0.453	30	Shallow water, fine dust particles
2	Blue	0.450–0.515	30	Deep water, atmosphere
3	Green	0.525–0.600	30	Vegetation
4	Red	0.630–0.680	30	Anthropogenic objects, soil, vegetation
5	Near infrared	0.845–0.885	30	Coastlines, vegetation
6	Short-wave infrared 1	1.560–1.660	30	Cloud penetration, soil and vegetation moisture
7	Short-wave infrared 2	2.100–2.300	30	Improved permeability of cloud cover, soil moisture and vegetation
8	Panchromatic	0.500–0.680	15	Black and white images, clear details
9	Cirrus clouds	1.360–1.390	30	Cirrus clouds
10	Thermal infrared 1	10.30–11.30	100	Thermal mapping; estimated soil moisture
11	Thermal infrared 2	11.50–12.500	100	Improved thermal mapping

In order to identify burned areas by forest fires, it is necessary to determine the Normalized Burn Ratio (*NBR*) from the following formula:

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

where *NIR* is channel 5, *SWIR* is channel 7 from Table 1, respectively.

Then the differential index *DNBR* is determined:

$$DNBR=(prefireNBR)-(postfireNBR), \quad (2)$$

where *prefireNBR* is an indicator of the burn index before a fire, *postfireNBR* is an indicator of the burn index of after a fire.

Based on *DNBR*, it is possible to determine the level of fire exposure to the territory:

– enhanced regrowth – $DNBR<-0.1$;

– unburned territories – $-0.1\leq DNBR<+0.1$;

– low damage level – $+0.1\leq DNBR<+0.27$;

– average damage level – $+0.27\leq DNBR<+0.66$;

– high damage level – $DNBR\geq+0.66$.

4. 3. Methods for analyzing time changes in forest plantations

To analyze the changes that occur in forests due to forest fires, unauthorized and sanitary felling, and reproduction of forests, various mathematical methods are used [30–33]. If statistical information is represented in the form of time series, then it is possible to build trend lines based on known data. The resulting line is then extrapolated to retrieve new data. The analysis is advisable to carry out when there is a sufficient amount of statistical information while the environmental conditions are quite stable. One of these forecasting methods is extrapolation and correlation regression analysis.

Extrapolation is one of the main methods of predicting the dynamics of changes in the signs of a phenomenon. The essence of this method is to determine the main trend of change based on a dynamic series of statistical data, and the spread of this trend to the future (within the forecasting period). Extrapolation can be effective under the following conditions:

– the time series has a statistically significant trend;

– patterns that existed in the past are preserved in the future;

– the factors that determine the development of the process remain unchanged.

Simple extrapolation methods, in particular by the average level of the dynamics series and by the average growth rate of the series, are based on the assumption that certain characteristics of the series remain unchanged in the future. Extrapolation according to the average level of a number of dynamics is used if the series does not have a development trend. In this case, the levels of the series fluctuate around the average value, and therefore, the forecast is calculated as the arithmetic mean of all levels of the series.

Correlation-regression analysis is used to identify the dependence of one value on another among the information received and to predict the necessary data. In practice, one of the types of stochastic relation is most often used – the correlation. Most methods for measuring the strength of the correlation involve comparing the deviations of the absolute values of the parameters from their averages:

$$corr(X,Y)=\frac{\mathrm{cov}(X,Y)}{s_X s_Y}=\frac{M\left[(X-M_X)(Y-M_Y)\right]}{s_X s_Y}, \quad (3)$$

where M_X and M_Y are the mathematical expectations of the quantities *X* and *Y*, s_X and s_Y are the mean quadratic deviations of *X* and *Y*, respectively.

Types of correlation: 1.00 – functional relationship; 0.90–0.99 – very strong relationship, 0.70–0.89 – strong relationship, 0.50–0.69 – significant relationship, 0.30–0.49 – moderate relationship, 0.10–0.29 – weak relationship, 0.00 – no relationship.

After identifying dependences, regression analysis is used to describe dependences and build a model for forecasting using the following algorithm:

– select the function that best describes the dependence of the selected features;

– find all the unknown parameters of the function for its construction;

– compare the substitution results to the function of the factor attribute with the real resulting feature;

– after substituting all the data, calculate the average absolute deviation, the standard deviation, and the coefficient of determination, which help conclude the quality of the model.

5. Results of research on monitoring the time changes in forest plantations based on the analysis of satellite images

5. 1. Assessment of the area of territories affected by forest fires

In order to implement the method of assessing the areas of territories affected by fires, a database has been developed that is designed to store satellite images and fires, as well as information about them. It consists of five tables (Fig. 1):

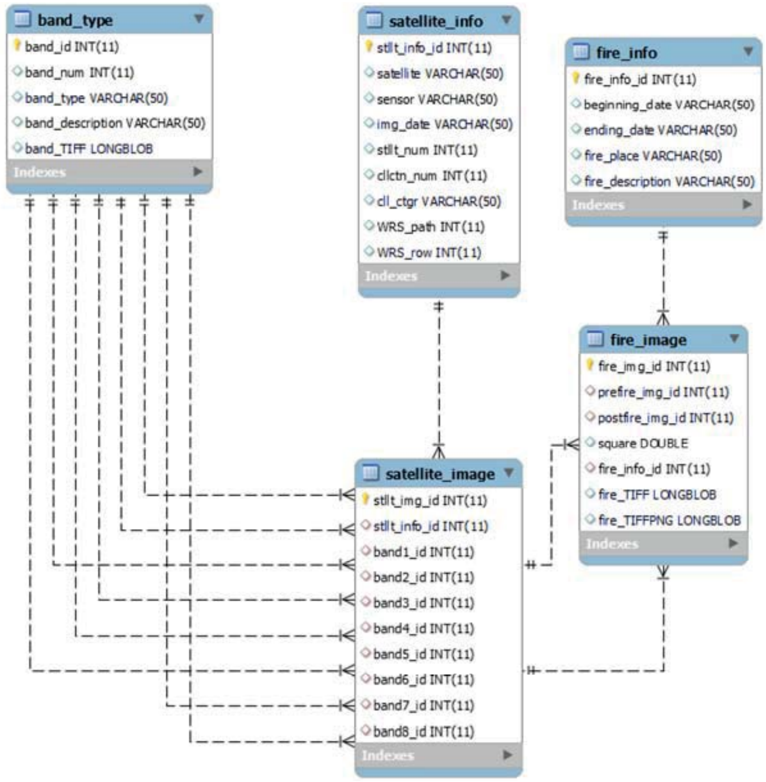


Fig. 1. Physical database model

– satellite_info – to store information about the satellite Landsat 8 (sensor number and name of the satellite, using which the satellite image was taken, the date when the image was acquired, the number of the collection and category of the image, as well as the geographical coordinates of the image in WRS format);

– band_type – to store information about a separate spectral channel of a satellite image (channel number, type of channel characterizing the purposes for which the channel is intended to be used, as well as a brief description and file in GeoTIFF format);

– satellite_image – to store information about the availability of channels and information about the image;

– fire_info – to store information about the fire (the date when the fire began and the date of its elimination);

– fire_image – to store the *DNBR* index in GeoTIFF format and links to images before and after the fire (space images before and after the fire, the area of burnt areas, a GeoTIFF file containing data from the *DNBR* index that characterizes the level of fire exposure of the territory, and a PNG file for visual display of this index in the graphical interface).

Fig. 2, *a*, *b* shows the graphical results of calculating the *NBR* index before and after forest fires with a scale from –1.00 to 1.00, where –1.00 are the non-affected areas, and 1.00 are completely affected areas.

Fig. 3 shows the graphical result of the *DNBR* index with the levels of the affected areas:

– growing territory – dark green color;

– unburned territory – light green color;

– low impacted area – beige color;

– medium affected area – orange color;

– the territory is badly affected – dark red color.

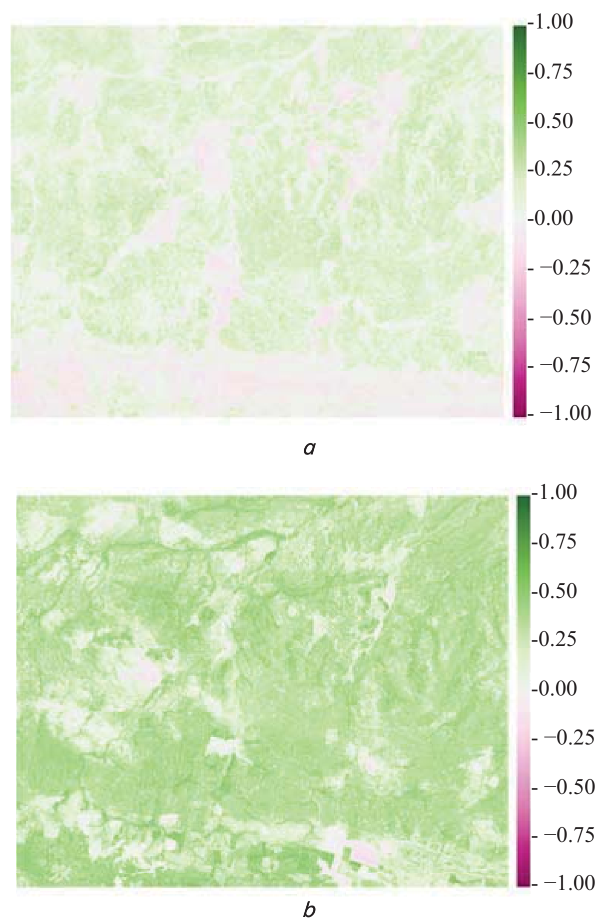


Fig. 2. Graphic display of the *NBR* index: *a* – before the fire, *b* – after the fire

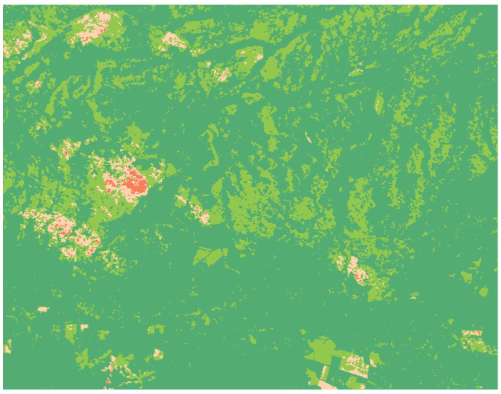


Fig. 3. *DNBR* index visualization

After determining the levels of damage, the area of damaged territories by forest fires is calculated.

The system is universal, the capabilities of which include adding new information, making changes, and storing them in the database.

5. 2. Results of the correlation-regression analysis of time changes in forest plantations

A sufficient amount of statistical data is necessary to analyze the state of forests. The database of the information system makes it possible to get information about the number of fires for a certain period and the area of forest land affected by fires. The rest of the data is on the website of the State Statistics Service: the value of the area of forest reproduction, the area of sanitary felling after fires, the amount of damaged forest, and damage caused by forest fires. Based on this information, the dynamics of changes in various indicators of forestry were determined. A study has been conducted on how the consequences of forest fires affect the volume of deforestation in Ukraine. Fig. 4 shows a plot of the area of forest land covered by fires, and Fig. 5 – a plot of the area of land on which sanitary felling was carried out after fires over the past 20 years. The plots in Fig. 4, 5 demonstrate that they repeat the shape of each other, that is, after fires that leave behind large areas of damaged trees, it is imperative to carry out sanitary felling of trees that cannot recover. Since 2006, their number has grown rapidly, by three times.

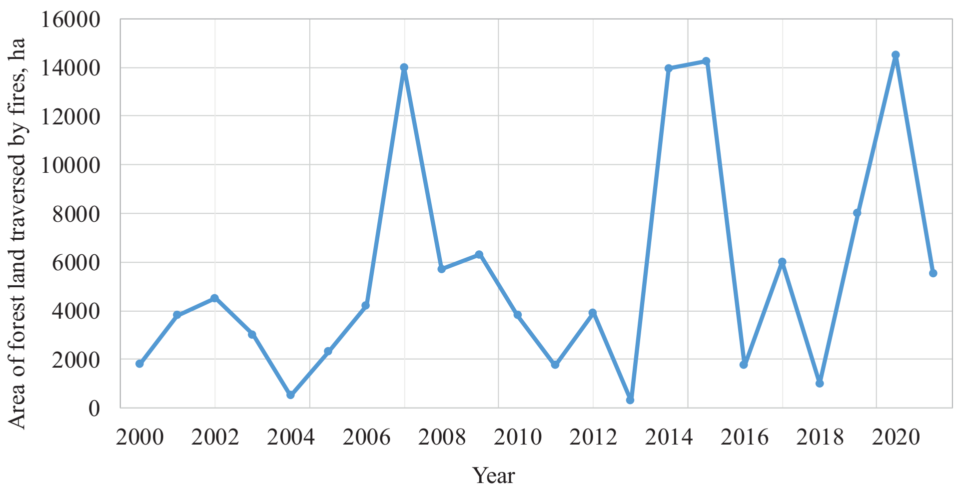


Fig. 4. Areas of forest land traversed by fires during 2000–2020

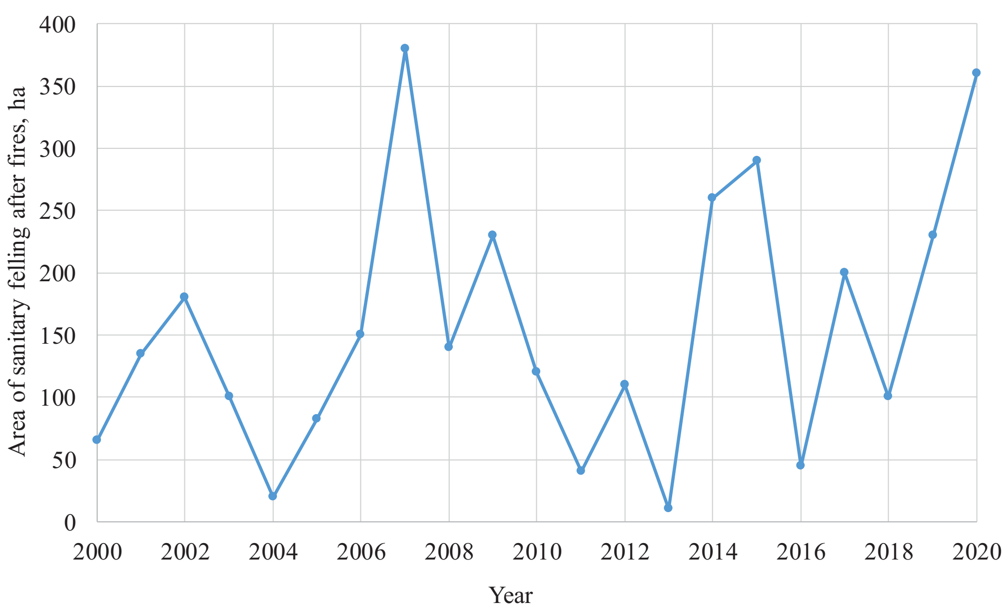


Fig. 5. Areas of sanitary felling after fires during 2000–2020

Using the correlation matrix, we determine how closely these indicators are interconnected and what other forestry indicators affect them (Fig. 6):

1 – an area of forest reproduction, ha;
2 – an area of sanitary felling after fires, ha;
3 – damage caused by forest fires, thousand UAH;
4 – burned and damaged forests on stumps, m^3;
5 – an area of forest lands covered by fires, ha;
6 – number of forest fires, units.

	1	2	3	4	5	6
1	1.00	0.20	0.46	0.40	0.20	-0.02
2	0.20	1.00	0.71	0.71	0.93	0.58
3	0.46	0.71	1.00	0.96	0.63	0.26
4	0.40	0.71	0.96	1.00	0.58	0.39
5	0.20	0.93	0.63	0.58	1.00	0.36
6	-0.02	0.58	0.26	0.39	0.36	1.00

Fig. 6. Correlation matrix for forestry indicators

According to the results of the correlation matrix, it can be concluded that the following indicators have the greatest interconnection: "Area of sanitary felling after fires" and "Area of forest land traversed by fires", "Damage caused by forest fires" and "Burned and damaged forests on stumps". "Area of forest regeneration" and "Number of forest fires" are the least correlated. Other indicators are interconnected by a moderate positive correlation. Thus, forest fires are not the main reason for the decline in tree cover in Ukraine, although the area of forest land covered by fires is very significant.

The plot in Fig. 7 shows the constructed regression model for the area of sanitary felling: the blue line is the real data provided, and the red line is the data predicted using linear regression.

The effectiveness of this model is confirmed by the following parameters:

– average absolute deviation – 27.19 ha;
– standard deviation – 32.85 ha;
– coefficient of determination – 0.87.

A plot of the regression line has been constructed to predict changes in the area of forest lands covered by fire (Fig. 8). The regression line shows the trend of the numerical series for this indicator.

Fig. 9 shows the extrapolation of the values of the indicator of the area of land covered by fire, on the basis of which a forecast was made for 10 years ahead. The extrapolation is based on the trend.

The plot in Fig. 9 is also a plot of the data predicted using linear regression. These results are from substituting into a regression model of extrapolated values of the indicator, on the basis of which the forecast is made. Consequently, by 2030 the number of forest fires will improve, and, accordingly, the area of burned forests will not decrease.

This model makes it possible to predict the necessary indicators of forestry and, based on the results acquired, make appropriate management decisions to preserve the forest fund.

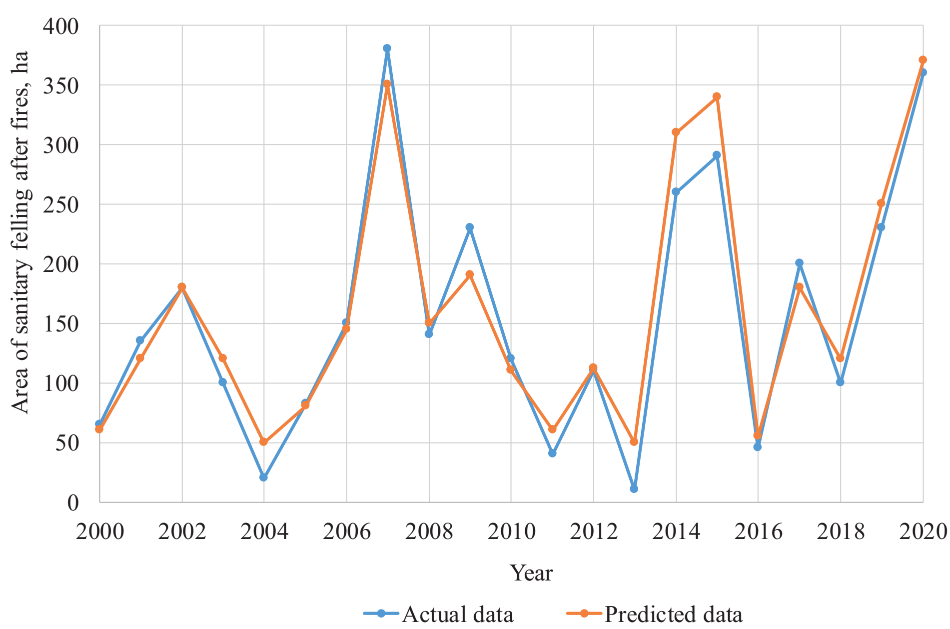


Fig. 7. Comparison of real and predictable data using a regression data model for the area of sanitary felling

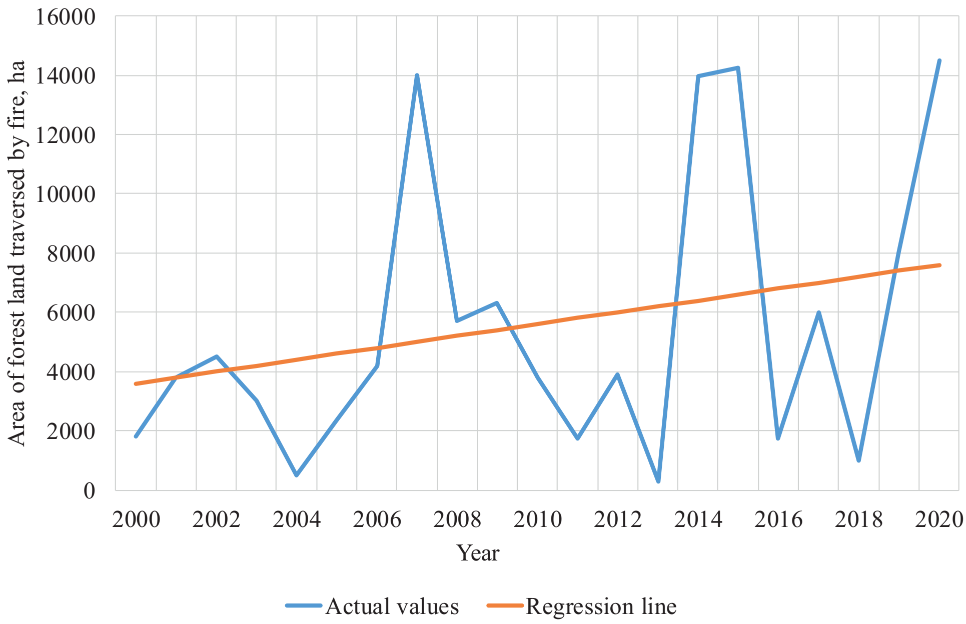


Fig. 8. Plot of the regression line for the area of forest land traversed by fire

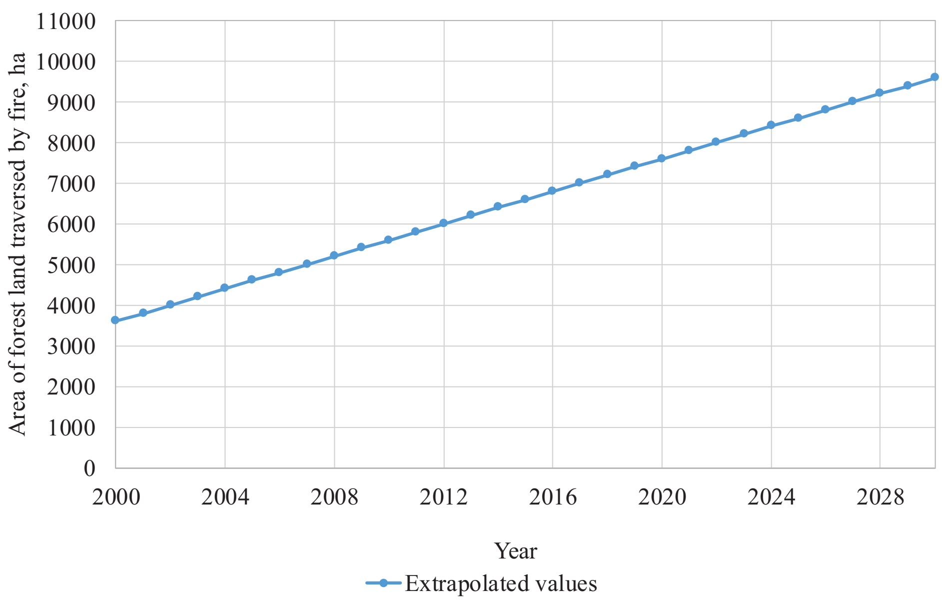


Fig. 9. Plot of extrapolated and predicted data

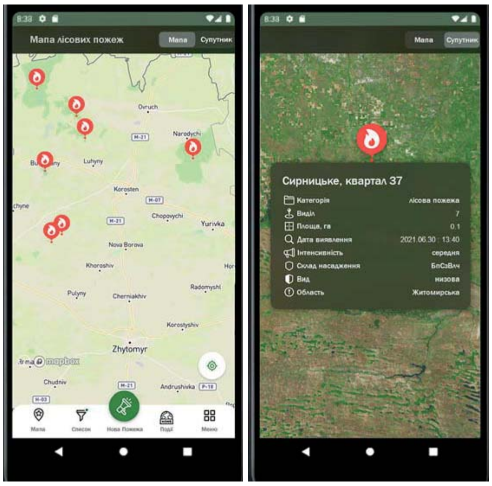
5. 3. Information mobile application for monitoring forest fires

The mobile application is part of the developed information system and was built to inform the public about the fire events in the region with the ability to notify about the occurrence of forest fires. The application has access to the database of the system with the ability to display numerical and graphic data on the smartphone screen.

On the main page of the application, there is a tab bar on which the buttons "Map", "List of fires", "New fire", and "Events" are located. The map shows forest fires for a certain period of time (week/month/year) in the region where the user is currently located, which is determined by the GPS navigator built into the phone (Fig. 10, *a*). When you click on a specific fire, its detailed description is displayed: category, propagation, area, date of fire detection, intensity, the composition of plantings, type of fire, and region (Fig. 10, *b*).

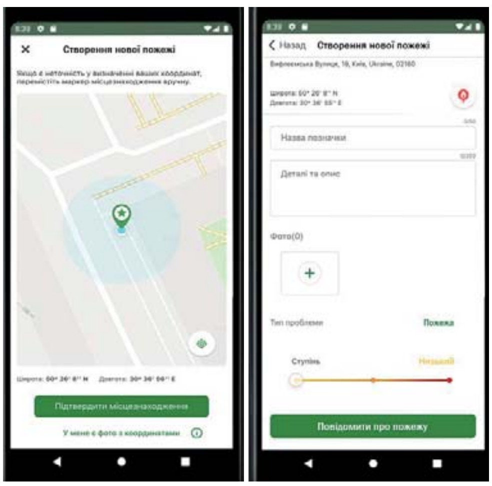
When a forest fire is detected, the user has the opportunity to add it as a new one using the appropriate functionality by filling in the basic data about it: intensity (low, medium), details and description of the occurrence, location of the fire (Fig. 11). Once confirmed, the fire will be added to the relevant authorities for review. A forest fire is treated accordingly so that the work of fire departments can be organized more efficiently. It is much easier for the user to report a forest fire owing to this functionality because there is no load on the emergency service lines. He can also ask questions that interest him or write an email.

To visualize the statistical data on fires that are already in the database of the information system, one can build plots. Fig. 12 shows the statistics of forest fires by year and there is a choice of the display by area of fires or by number.



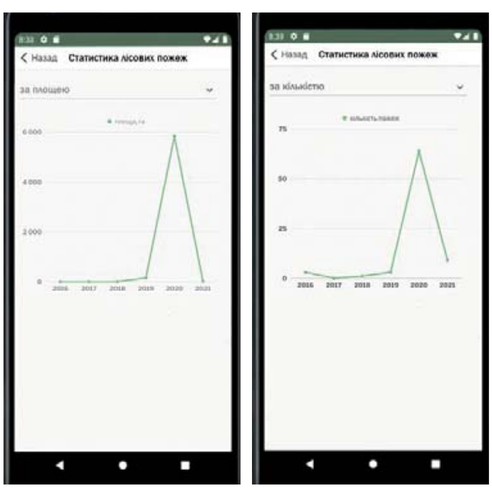
a *b*

Fig. 10. Map with forest fires: *a* — forest fires in the region; *b* — detailed information about the forest fire



a *b*

Fig. 11. Adding a fire: *a* — location of the forest fire; *b* — description of a forest fire



a *b*

Fig. 12. Statistical information on forest fires: *a* — by area; *b* — by quantity

To inform the user about various measures to prevent and combat forest fires carried out in the region, a tab "Events" has been developed with daily updates of the news feed. Also, the application will provide the necessary information for users around the clock about the current state of the fire situation in the forest depending on the location and will remind the safety rules during their stay in the forest owing to notifications. All of this will minimize the likelihood of fires by promoting public awareness of fire safety in forests, and, as a result, reduce losses from forest fires.

6. Discussion of research on changes in the time series of forest plantations

In the modern scientific space, the construction of a monitoring system for researching changes in forest stands based on remote sensing is complicated by the lack of an adequate cataloging apparatus for satellite images that would be available to work with them. Therefore, the construction of an information system with the ability not only to process satellite images but also to enter them into a database, store and, if necessary, reuse is an up-to-date task.

Existing systems do not make it possible to quickly calculate the areas affected by fires, relying on traditional calculation methods, which are approximate and time-consuming [23–25]. Therefore, the method of assessing the areas of territories affected by forest fires, which is implemented by pre-processing and classification of low-resolution Landsat 8 satellite images, makes it possible to automate this process.

In the absence of existing analogs, this information system is of great practical importance. Its use will expand the possibilities in the study of vegetation cover not only in a certain area but in any locality because the system is universal. The built database, which is part of the system functionality, not only stores the necessary information but also makes it possible to extract it if necessary (Fig. 1). The main advantage is that the database uses the Longblob modification to store GeoTIFF satellite images and it makes it possible to structure them.

The construction of this information system is based on a modular architecture. At the same time, a number of advantages are observed:

– development and modification of each individual component, which is much more convenient than creating a monolithic model system;

– a modular structure allows for gradual software development;

– different components can be written by different developers in different programming languages;

– the model is easily integrated with other models;

– components are interchangeable in the case of recompilation of the model, which allows for comparative testing of different models of the same system.

The disadvantage of this system is that low-resolution images are used to assess areas affected by forest fires, which are free and inaccurate. High-resolution images will provide a better study of objects in forest ecosystems, but they are expensive.

Existing systems [23–28] do not have the functionality to identify dependences between the data it operates on and do not predict them. The information system using correlation and regression analysis identifies factors that negatively affect forest plantations. The database of the system makes it possible to extract statistical information about forest fires. The data sampling is incomplete, so the rest must be searched on statistics websites. The system makes it possible to track the dynamics of changes in various studied indicators (Fig. 3, 4), and the correlation matrix (Fig. 5) – to determine the closeness of the relationship between forestry indicators using (3). Forest fires and sanitary felling have been found to have the greatest impact on reducing the wood stand. Our built regression model makes it possible to get a long-term forecast for any parameter (Fig. 8).

Since modern smartphones have become an integral part of human life, the use of a mobile application becomes a convenient means of rapid response and a means of monitoring any changes in a particular location. Existing mobile applications help monitor the fire situation in the country [28, 29] but they do not have feedback from the population. Owing to the GPS navigator built into the phone, the user will instantly determine his location and he has the opportunity to inform the relevant authorities about an emergency in the forest. He can also ask questions that interest him or write an email. The built application will provide the necessary information for users on a daily basis about the current state of the fire situation in the forest in the region, reminding safety rules during their stay in the forest owing to notifications. All of this will minimize the likelihood of fires by promoting awareness of fire safety in forests, and, as a result, reduce losses from forest fires.

The limitation of the method for assessing the areas of territories affected by forest fires is that it is not always possible to upload high-quality satellite images due to their significant cost. At the time of the shooting, the satellite camera can capture foreign objects (water, clouds, smoke), which are an obstacle to the processing of images and require additional methods to eliminate their impact. The accuracy of the implementation of correlation-regression analysis depends on the completeness of statistical data. The mobile application requires modern mobile devices, which, due to their high cost, are not affordable for the majority of the population. In areas that are close to forests, there is not always an Internet connection. In the future, the development of this study is a comprehensive system that will contain modules that will calculate losses from unauthorized logging and fires, as well as the construction of a simulation model that will reproduce the pattern of a fire and the natural growth of trees.

7. Conclusions

1. The built database, which is part of the functionality of the system, not only stores the necessary information but also makes it possible to extract it if necessary. The main advantage is that it saves satellite images in GeoTIFF format and makes it possible to structure them. The use of the database is the basis of the method for assessing the area of territories affected by forest fires. This makes it possible to improve the effectiveness of assessing the areas of territories while determining the degree of their damage.

2. It follows from our correlation-regressive analysis that the closest interconnection is between the density of sanitary felling after fires and the area of forest lands traversed by fires, as well as between the damage caused by forest fires and the damage to forests on stumps. The area of forest regeneration and the number of forest fires are the least correlated. Using a regression model, it was found that forest fires are not the main cause of a decrease in tree cover, although the areas affected by forest fires are significant. The reliability of the model is confirmed by the coefficient of determination, the value of which is close to unity. This model makes it possible to predict any indicators of forestry and, based on the results acquired, make appropriate management decisions to preserve the forest fund.

3. The mobile application was built to inform the public about the fire situation in the region with the ability to notify about the occurrence of forest fires. Owing to the GPS navigator built into the phone, the user will instantly determine his location and report the detected forest fire, that is, two-way communication of the population with the state inspections of forest funds protection is ensured. The user will be able to receive the necessary information around the clock about the current state of the fire situation and safety rules during his stay in the forest owing to notifications. The application has access to the database of the system with the ability to display numerical and graphic data on the smartphone screen.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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