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Methods of analysis and visualization of active fires and burnt areas of geospatial data

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ABSTRACT

The paper deals with the characteristics of remote sensing systems for forest fires and the analysis of their consequences in terms of burned areas. . The capabilities of the American system FIRMS and the complex European system EFFIS are considered. Algorithms and methods for processing medium resolution satellite observations (MODIS) are analyzed. These images are from Terra and Aqua satellites, namely Land MOD14 / MYD14 for active fire detection and MCD45 for burned areas. The results of a comparative analysis of the best known services MCD45A1, MCD64A1, MCD14ML and ESA's Fire_CCMCD45 service from MCD45 are presented. Their capabilities for monitoring burned areas were compared. It is shown that in the absence of a common state system of remote sensing in Ukraine, it is necessary to use the capabilities of modern, publicly available geographic information systems. For example, the cloud service Google Earth Engine (GEE) is used to retrieve and process satellite data on forest fires and their consequences. The use of GEE makes it possible to obtain geospatial data of forest fire zones and their consequences. These parameters are determined by the date, region, type of multichannel satellite and its channels (layering). Based on this information, a method for processing, analyzing and visualizing geodata of forest fires and their consequences was developed. The method consists of five steps, namely: obtaining input data from publicly available geographic information web services; pre-processing (filtering) of multi-channel satellite images; calculation of indexed images; their thresholding; storing the original data in cloud storage. The following recommendations are developed: on the selection of spectral indices; construction and use of radiometric correction masks; clouds; and a water mask. The study on the possibility of methods to detect forest fires and their consequences is implemented using Google Earth Engine. Comparative characteristics of the number and area of forest fires obtained from the general statistical data using the proposed method are given. The implementation of the proposed method has increased the efficiency of detection of dangerous areas.

Keywords: Geographic information systems; GIS; MODIS fire; MCD45 burnt areas; active fires and burnt areas detection

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INTRODUCTION AND STATEMENT OF RESEARCH PROBLEMS

One of the most dangerous phenomena threatening environmental security and affecting ecosystems is fire.

Repeated fires in a given area are evaluated in modern natural management as an exogenous local catastrophic factor that leads to a change in natural ecosystems.

Every year, hundreds of thousands of hectares of forest are lost and tens of thousands of tons of combustion products are released. Thus, according to studies, 80 to 100 tons of smoke particles and 10-20 tons of a mixture of gasses are released from one hectare in the atmosphere: carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO2) and ammonia (NH3) [4]. About 40 % of annual greenhouse gas emissions come from the burning of forest products. To prevent forest fires and their consequences, many countries around the world have created and deployed their own monitoring systems based on remote sensing systems (remote sensing) to obtain geospatial data [2] Examples of such international systems include FIRMS (The Fire Information for Resource Management System) College of Maryland with support from NASA, the European Forest Fire Information System (EFFIS), medium resolution satellite velocity processing algorithms and techniques (MODIS) aboard the Terra and Aqua satellites, and NASA visible infrared radiometer and suite (VIIRS) aboard the NASA / NOAA Suomi National Polar-Orbital Partnership (Suomi NPP) and NOAA-20 satellites, etc.

Despite the fact that Ukraine has joined many international environmental protection organizations, unfortunately, today there is not a single information center where you can get up-to-date and reliable information about forest fires [6]. The situation is complicated by the fact that fire areas in natural ecosystems of Ukraine are increasing every year. Thus, in 2021, ecologists registered 2368 cases of forest fires on the area of Ukrainian forests, which, according to the State Forest Cadastre, is over 2 million hectares. 1239 hectares of forest were destroyed. The ecological and economic damage amounted to about 40 million hryvnias [1]. As there is no single information center in the Ukrainian practice of environmental monitoring, three main methods are used to obtain geodata on forest fires. Namely, there are ground and air monitoring (ground patrol, air patrol); stationary detection methods, including IP video surveillance and video analysis (observation points, stationary sensors); comic monitoring and analysis of public data from satellite images.

The first two methods of obtaining geospatial data have drawbacks such as a limited monitoring area and high costs associated with the installation of IP video cameras and other specialized sensors and equipment for observation posts. Moreover, in order to obtain a complete picture of wildfires, information must be collected from different locations. [6]. Satellite data from remote sensing systems can now be obtained in large areas. The availability of free access allows the control of forests throughout Ukraine. But the reception and processing of data is not always timely. Therefore, the urgent task is to develop a methodology for analysis and visualization of geospatial satellite data on forest fires and their consequences, and then to create a corresponding specialized geographic information system (GIS).

ANALYSIS OF EXISTING SCIENTIFIC ACHIEVEMENTS AND PUBLICATIONS

Geospatial data on forest fires are obtained using remote sensing systems. Analysis of publications [3, 4], [5, 6], [7, 8] provided the following information on common algorithms and systems for detecting active fires and their consequences in terms of burned areas.

MODIS (Moderate-resolution Imaging Spectroradiometer) image [1]. Images obtained with a moderate-resolution spectroradiometer are images from a remote sensing sensor built in Santa Barbara, USA, and launched into Earth orbit by NASA aboard the Terra (EOS AM) and Aqua (EOS PM) satellites [4]. The instruments record data in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and with different spatial resolutions (2 bands per 250 m, 5 bands per 500 m, and 29 bands per 1 km). Together, the instruments survey the entire Earth every 1-2 days.). VIIRS is capable of generating two data streams that provide two different sets of terrestrial products with global coverage every 14 hours.

To monitor active fires, use the standard MODIS Land MOD14 / MYD14 (Fire and Thermal Anomalies) service, which provides information on the locations of active fires. The principle of fire detection is based on the consideration of strong radiation in the mid-infrared range. These data are obtained in the ranges of 4 micrometers (MODIS channels number 21 and 22) and 11 micrometers (MODIS channel number 31) with a resolution of 1 km. An auxiliary range is used to separate the clouds. The fire detection strategy is based on absolute fire detection (when the strength of the fire is sufficient for detection) and detection versus background values (to account for surface temperature variability and sunlight reflectance). The additional channels 1 and 2 (250 meters, rounded to 1 km resolution, 0.65 and 0.68 micron range) and 500 meters 7 are used to detect false alarms such as sun glare or unmasked coastal areas, and to mask clouds microns) and MODIS channel number 32 (resolution 1 km, range 12 microns).

The MCD45 service is used to detect burned areas. The detection algorithm, developed specifically for MCD45, is based on analysis of time series of daily surface reflectivity data. The algorithm uses the two-beam reflectivity function (BRDF) and allows to detect only fresh burned surfaces, excluding surfaces that have burned previously (for example, in the last year or in the last month). The main idea is to retroactively analyze the reflection coefficients of each pixel and predict the next value. If the predicted value differs from the directly observed one by a certain threshold, the analyzed pixels are considered as candidates for classification as “burned”. For the final assignment of a pixel to the “burned” category, it is necessary that it passes the test for temporal stability (which is performed on the basis of data on its reflectivity in the following days).

Currently, the best known products of MCD45 are the MCD45A1, MCD64A1, MCD14ML and the

Fire_CCI services of ESA.

MCD45A1. The algorithm used to create this product is based on the bidirectional reflectivity (change detection) approach to display rapid changes in daily time series of 500 m pixel reflectivity data. Fires that occurred in previous seasons or years are excluded, and only recent fires are mapped [14, 15]. The data are provided in the form of monthly summary data showing, pixel by pixel, the approximate Julian burn day with eight-day intervals before and after the detection date, detection reliability, surface type, and other information. This product has relatively high spatial and temporal resolution and good performance [16, 17], [18].

MCD14ML. MODIS Active Fire Collection 6 (MCD14ML) is created using a context-sensitive algorithm that applies thresholds to luminance temperatures from the MODIS instrument mid-infrared and thermal infrared channels. Active fires are mapped at 1 km resolution during the satellite flyby. To limit false detections, potentially burning pixels are subjected to a series of tests, masking operations, and additional rejection tests. The data, in the form of ASCII files provided monthly, includes the geographic location, date, and some additional information for each pixel of fire detected by the sensors. MCD14ML has a relatively high resolution, i.e., with a product pixel size of 1000 m, a smaller fire of 100 m2 or even 50 m2 can be detected under very good observation conditions [15].

MCD64A1. MODIS Direct Broadcast Burned Area Collection 6 (MCD64A1). MCD64 is the latest product in the MODIS Burned Area product line and replaces the previous package MCD45. It is based on a hybrid approach that uses both the potential of active MODIS fires at a distance of 1 km and input data on surface reflectivity at a distance of 500 m. The data are used to determine the potential of active MODIS fires at a distance of 1 km. Dynamic thresholds are used to detect stable spectral changes. The cumulative maps of active fires are then used to create regional probability density functions to classify burned and unburned training patterns that determine the final definition of burned and unburned pixels [19]. MCD64A1 provides an overall improvement in burned-out area detection compared to previous collections. In particular, the significantly better detection of small fires and the adaptability to different regional conditions in different ecosystems are among the main advantages of this product.

ESA Fire_CCI. The product provides a burnout indicator used to quantify the Essential Climate Variables at ESA-CCI. The product was developed to meet end-user requirements for the product BA. with a higher resolution [20, 21]. The development team chose to explore the possibilities of Envisat MERIS imagery with a resolution of 300 m, acquired approximately every three days depending on latitude. Because the MERIS sensor was designed primarily to measure ocean color and not to monitor land, its use for burn assessment is limited [22]. To overcome these limitations, MERIS data were combined with daily hotspot locations from the MODIS thermal anomaly product (MCD14ML), which also helped reduce the commission errors associated with approaches based solely on reflectivity changes. The algorithm follows a hybrid two-step approach: the MODIS hotspot selection phase, followed by the MERIS NIR range analysis region and NIR spectral index. The resulting product is available in two forms: the Pixel BA product with a resolution of 300 m and the Grid BA product with a resolution of 0.25 degrees.

Examples of the best known specialized analytical geographic information systems (GIS) that use MODIS and VIIRS remote sensing imagery are the U.S. Fire Information for Resource Management System (FIRMS) [24] and the European Forest Fire Information System EFFIS. (The European Forest Fire Information System) [25].

The GIS FIRMS was developed at the College of Maryland with support from NASA and the Food and Agriculture Organization of the United Nations. This system provides information on active fires with little delay. The information is updated every 3 hours.

Fig. 1. **Fragment of the interface FIRMS**
Source: **[26]**

The website of this system contains information about fires and archived data about them. The system also provides a global map of the world for researchers and professionals, including surveillance and emergency services personnel. The advantages of FIMS include its visibility (data are provided worldwide and downloaded in a file in Ukraine), regularity of data collection (several times a day), accuracy of binding in the field, independence of the information provided, ease of use for Internet users, access to the so-called "gluing" of original images in many areas with a convenient synthesis of channels (Fig. 1).

Limitations in the practical use of FIMS are due to the low resolution of the original images by automatic processing algorithms and a significant delay in the provision of the received information, which does not allow tracking fires in real time. The built-in processing algorithms cannot distinguish fires from other sources of thermal radiation (in businesses, oil production areas, etc.). In addition, studies show that MODIS imagery used for monitoring does not allow detection of low temperature, short duration, small fires. Thus, FIMS provides high quality information on upper and lower fires. However, it is not always suitable for monitoring some peat and grass fires [3].

The specialized European GIS EFFIS (The European Forest Fire Information System) is a comprehensive system that covers the whole cycle from warning of forest fires and preparing their removal to identifying the burned forest area and assessing the damage caused by the fire [6].

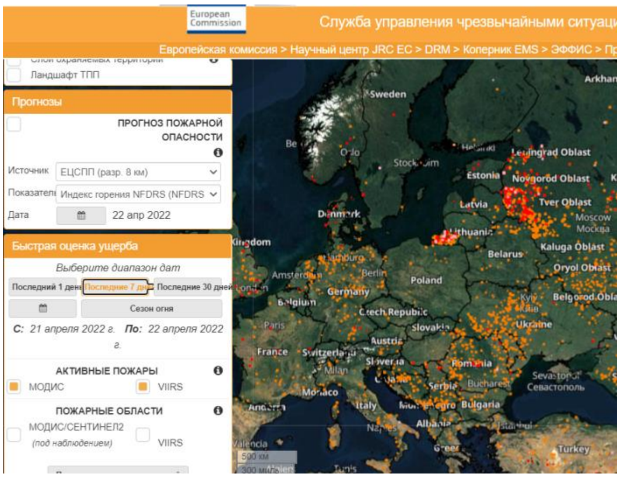

Fig. 2. **Fragment of the interface EFFIS**
Source: **[27]**

In EFFIS, the following modules are distinguished: hazard prediction, forest fire events, fire detection, burned area maps, land cover damage assessment, emission assessment, etc. The fire hazard forecast is based on two meteorological models, the French Meteo-France and the German Wetter Diens, and provides a forecast for the coming week. This data is used to calculate the overall European fire danger index, which is based on the Canadian Fire Weather Index (FWI). The advantages and disadvantages of the practical application are almost the same as for FIMS (Fig.2).

Thus, the analysis of the existing possibilities in the detection of active fires and their consequences in the form of burnt areas in specialized GIS using MODIS and VIIRS images and existing algorithms for their processing allowed to determine the purpose and objectives of this work.

THE PURPOSE AND OBJECTIVES OF THE RESEARCH

Given the lack of permanent GIS with remote sensing image analysis tools to increase the efficiency of detecting wildfires and their consequences, it is proposed to develop a method to analyze and visualize geospatial data from multichannel satellite imagery using the capabilities and advantages of public GIS [28]. As input imagery, it is proposed to create a data catalog (dataset) from the relevant satellites hosted on the open service Google Earth Engine. The source information is the results of visualization of data in the form of fires and their effects on the map.

To achieve this goal, the following tasks are solved:

1) the peculiarities of multichannel data of satellite images and the existing possibilities for their processing are analyzed. 2, a method for analysis and visualization of geodata on forest fires and their consequences was developed;

3) the developed method was implemented with Google Earth Engine;

4) the possibilities of analysis and visualization of geodata in the developed GIS are investigated.

The developed method for analysis and visualization of geospatial data about forest fires and their consequences consists of 5 steps, namely: obtaining input from publicly available web services, pre-processing of multi-channel satellite imagery, calculation of indexed images and their thresholding, and storage of source data in memory.

PRESENTATION OF THE MAIN RESEARCH MATERIAL

Obtaining input data on forest fires

The shapefile format is a spatial vector data format for the software GIS. It is developed and governed by Esri as a largely open specification for data interoperability between Esri and other GIS software products. The shapefile format can describe vector objects spatially: Points, lines, and polygons representing individual regions, for example.

On the website of the Ministry of Development of Municipalities and Territories of Ukraine you can get a shapefile with any object on the territory of Ukraine, showing the boundaries of districts and regions, boundaries of residential areas, nature reserves and others [10, 11].

In order to work with multichannel satellite imagery, you need to specify which sensors to use. Table 1 contains the characteristics of the most commonly used sensors.

The following abbreviations are used to characterize the spectral ranges:

Pan – panchromatic, Vis – visible, NIR – near infrared, SWIR – mid infrared region of the electromagnetic spectrum; B – blue, G – green, R – red bands of the visible spectrum. The analysis of the characteristics of the serners led us to conclude that it is better to use the Sentinel-2 sensor to search for active fires and their effects, as it has a high resolution and the shortest period between images among the publicly available satellites.

In addition to the characteristics of the sensors, the availability of free access to the images and their ease of use are also considered.

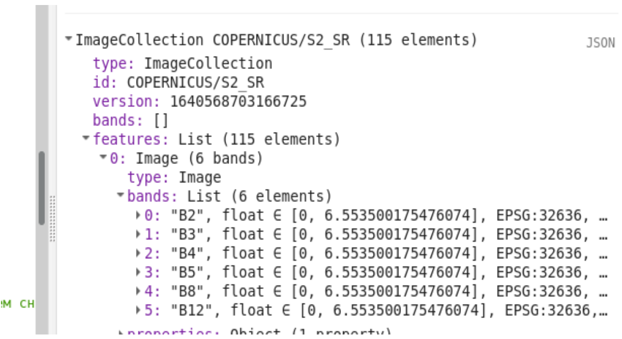

Fig. 3. **A fragment of the GEE screen form from list of channels and number of images analysis of fire impact zones**

Source: **compiled by the authors**

Consider the features of services that have free access to satellite imagery

The US Geological Survey (USGS) has the oldest and largest archive of free geospatial data. You can access it through EarthExplorer. The service provides access to data from USGS-NASA satellites, as well as open data from the Indian Space Research Organization (ISRO) and the European Space Agency (ESA). There are also archived images from the commercial high-resolution satellites IKONOS-2, OrbView-3, and Spot. They have incomplete coverage and a very limited time period and are more suitable for educational purposes. The service can filter the data by date, cloud fraction, and number of sensors and the data can be downloaded directly from the website with processing levels of Level-1, 2, 3. USGS also has an additional portal for downloading GloVis materials.

Sentinel Hub has two portals for working with free data: EO Browser and Sentinel Playground. EO Browser allows you to view, analyze, and download materials from the medium- and low-resolution Sentinel, Landsat -5, 6, 7, and 8, Envisat, Meris, MODIS, GIBS, and Proba-V satellites. The Sentinel Playground portal allows you to view and analyze mosaics of images from Sentinel-2, Landsat-8, and MODIS. You can use up to eight channel combinations for each image.

The Sentinel image collection is stored on the Copernicus Open Access Hub. The portal provides the ability to search, view, and download material from the entire group of Sentinel satellites. The interface and functionality of the service are quite limited, but it contains the latest findings from the satellites [7].

The DataStore of Google Earth Engine (GEE) was used to obtain input images. GEE supports access to the image collection of Landsat, Modis and Sentinel satellites. Using a script through a code editor that uses JavaScript libraries, we access the database of databases. Once you access the image database, you can work with any regionusing GEE (Fig. 3). In the work to analyze the recorded active fires during the year, 364 images were processed that had a spectral channel to record only thermal anomalies. To identify and analyze the areas that were affected by fires (burned areas), 115 images were processed that covered the Moon and had six spectral channels: 'B2', 'B3', 'B4', 'B5', 'B8', 'B12').

Preprocessing of multi-channel satellite images

Radiometric image correction makes it possible to reduce the influence of fluctuations in pixel brightness values caused by incorrect operation of sensors, the influence of relief and atmosphere (Fig. 4a,b).

Public inputs from the GEE DataStore require pretreatment procedures to detect wildfires and their consequences, namely: radiometric correction, cloud filtering, and water surface removal.

Cloud filtering through a created or default mask (creating a cloud-free composite) allows you to identify cloudy and cloud-free pixels. The European Space Agency standard cloud mask for Sentinel-2 images is a vector in GML format and has the following settings Cloud type (dense or pinnate) and the percentage of dense and pinnate pixels. Processing is done with selected data with a spatial resolution of 60 m for spectral regions.

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Table.1. **Characteristics of the most commonly used optical sensors**

Resolution	Sensor	Spectral range of shooting	Spatial resolution (m)	Radiometric resolution (bits)	Temporary permission (days)
Average resolution (100–1000 м)	AVHRR	R, NIR, SWIR	1000	10	1
	MODIS	R, NIR B, G, SWIR	250 500	12	1
High resolution (5 – 100 m)	Proba -V	B, R, NIR, SWIR	100	8	1-2
	Landsat (MSS, ETM+, OLI)	Pan Vis, NIR SWIR	15 30 30 – 60	8	16
	Sentinel-2	Vis NIR SWIR	10 10 – 20 20 – 60	12	5
	SPOT (HRVIR)	Pan Vis, NIR, SWIR	1.5 5 – 20	8	26
Ultra high resolution (< 5 m)	Ikonos	Pan Vis, NIR	1 4	11	3 – 5
	QuickBird	Pan Vis, NIR	0.6 2.4	11	1 – 3.5
	WorldView	Pan, Vis, NIR, SWIR	0.3 – 3.7	11	1.7 – 5.9

Source: **compiled by the authors**

a b

Fig. 4. **Satellite image of Kherson region before filtering atmospheric noise (a) and after (b)**

Source: **compiled by the authors**

Dense / opaque clouds are characterized by a high reflection coefficient in the blue region of the spectrum (B2). Therefore, the B2 reflectance threshold is used for filtering. The SWIR reflection coefficients B11 and B12 are also used to avoid erroneous detection (due to the possible presence of snow cover). Cloud reflectance is high in the SWIR, while snow cover has low reflectance. After processing, resampling is performed with a spatial resolution of 10 m and 20 m for each corresponding spectral band (Fig. 5a,b).

The exclusion of water bodies (sea, rivers and lakes) from the experimental area increases the efficiency of processing by reducing the areas for further calculations. Water objects are filtered based on the created water mask (Fig. 6). The basis for the mask is the calculation of WRI (Water Ratio Index).

$$\boldsymbol{Data_{WRI}} = \left\{\frac{\boldsymbol{BG_{ij}+BR_{ij}}}{\boldsymbol{BNIR_{ij}+BSWIR_{ij}}}\right\}, \quad (1)$$

$$(\boldsymbol{i = \overline{1, Dw}, j = \overline{1, Dh}}),$$

where $BG_{ij}, BR_{ij}, BNIR_{ij}, BSWIR_{ij}$ – pixel values of the image in the green, red, near infrared and middle spectral range; Dw, Dh – image width and height in pixels.

If the value of the index $Data_{WRI}$ (1) equal to 1 or more, this means that the pixel is occupied by a water body.

NDVI (Normalized Difference Vegetation Index) vegetation indices for B8 and B12 channels and NBR (Normalized Burned Ratio) for B4 and B8 channels are calculated to obtain geospatial data on forest fires and their successors (Fig. 7).

a b

Fig. 5. **Satellite image of Kherson region before cloud filtering (a) and after (b)**

Source: **compiled by the authors**

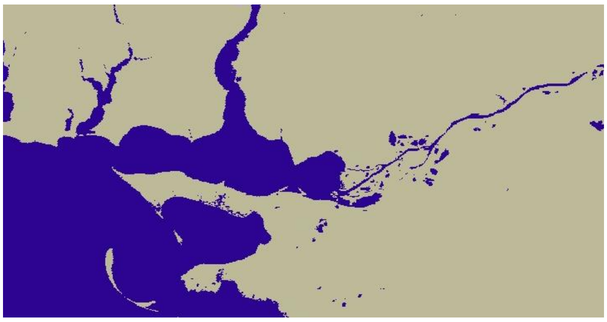


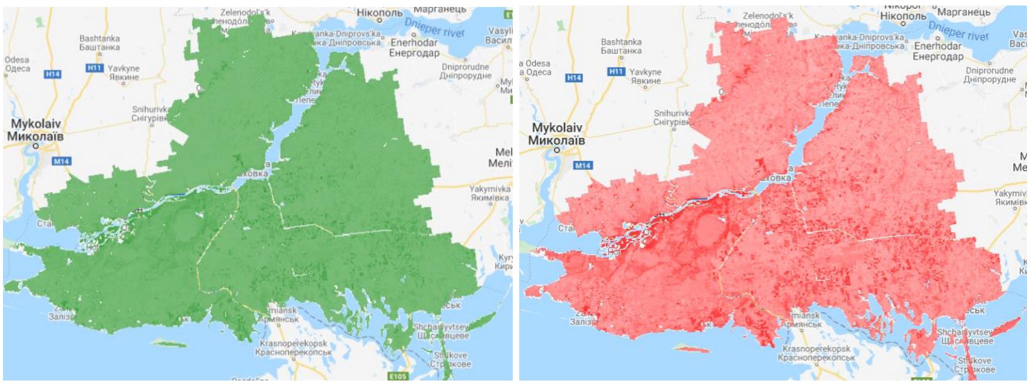
Fig. 6. **Example of an image after treatment with a water mask**

Source: **compiled by the authors**

```
var addNDVI = function(image) {
  var ndvi = image.normalizedDifference(['B5', 'B4']).rename('NDVI');
  return image.addBands(ndvi);
};


var addNBR = function(image) {
  var NBR = image.normalizedDifference(['B8', 'B12']).rename('NBR');
  return image.addBands(NBR);
};
```

a



b c

Fig. 7. **The results of the calculation of the indexes: an example of the script (a) image NDVI (b), NBR image (c).**

Source: **compiled by the authors**

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Calculation of the set indexes of multichannel images

Calculation of value $Data_{NDVI}$ (2) based on the two most stable spectral ranges – red and near infrared. In the red region of the spectrum is the maximum absorption of solar radiation by chlorophyll, and in the near infrared region is the region of maximum reflection of solar radiation. The ratio of these indicators to each other allows you to clearly separate and analyze plant objects from other natural objects.

$$\boldsymbol{Data_{NDVI}} = \left\{\frac{\boldsymbol{BNIR_{ij} - BR_{ij}}}{\boldsymbol{BNIR_{ij} + BR_{ij}}}\right\}, \quad (\boldsymbol{i} = \overline{\boldsymbol{1}, \boldsymbol{Dw}}, \boldsymbol{j} = \overline{\boldsymbol{1}, \boldsymbol{Dh}}) \qquad (2)$$

where $\boldsymbol{BR_{ij}}, \boldsymbol{BNIR_{ij}}$ – pixel values of the image in the red and near infrared spectral range.

Value $\boldsymbol{Data_{NDVI}}$ (2) belongs to the range from-1.0 до 1.0.

When calculating the value $\boldsymbol{Data_{NBR}}$ (3) the near infrared spectral range is sensitive to the structure of vegetation cells, while the middle infrared range is sensitive to plant moisture and tends to increase in open and burned areas.

$$\boldsymbol{Data_{NBR}} = \left\{\frac{\boldsymbol{BNIR_{ij} - BSWIR_{ij}}}{\boldsymbol{BNIR_{ij} + BSWIR_{ij}}}\right\} \quad \left(i = \overline{1, Dw}, j = \overline{1, Dh}\right), \qquad (3)$$

where $\boldsymbol{BNIR_{ij}}, \boldsymbol{BSWIR_{ij}}$, – the pixel values of the image in the near and middle infrared spectral range.

The addNDVI and addNBR functions were used to calculate NDVI and NBR, respectively.

To detect the contour of the burnt areas on the satellite image and calculate their area, the difference of each NDVI, NBR index between the pre-fire and post-fire images is calculated.

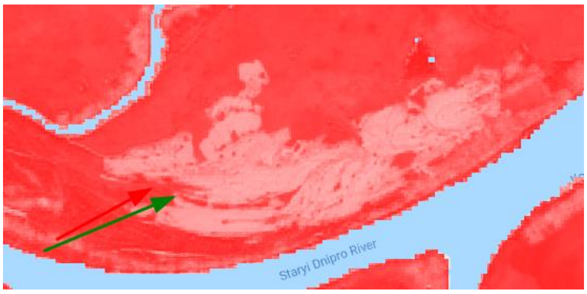
Threshold processing of a set of indexed images

To obtain the burning area on the indexed images, the threshold processing is performed according to the following rules

$$\boldsymbol{S_{ij}} = \begin{cases} \boldsymbol{1}, (\boldsymbol{Data_{NBR_{ij}}} > \boldsymbol{0,3}) \& (\boldsymbol{Data_{NDVI_{ij}}} < \boldsymbol{0,4}) \\ \boldsymbol{0}\text{ , } \boldsymbol{in\ other\ cases} \end{cases}, \quad (\boldsymbol{i} = \overline{\boldsymbol{1}, \boldsymbol{Dw}}, \boldsymbol{j} = \overline{\boldsymbol{1}, \boldsymbol{Dh}}).$$

Obtaining a set of source data

To obtain a final solution, the expert compares the multichannel image on channels 2,3 and 4 with layer S indexed in stage 4 and makes a final decision on the presence or absence of forest fire by adjusting the area of layer S. (Fig. 8) RGB and S layers are kept as a starting point for further statistical analysis. If the expert agrees that the proposed method has been used to select the area of forest fire or its consequences, this is confirmed manually using the landfill tool. Both the RGB and NBR / NDVI layers are stored in cloud storage**.**



a

b

Fig. 8. **Comparison of NBR / NDVI (a) and RGB (b) images**
***Source:* compiled by the authors**

The developed method for detecting forest fires and their consequences, based on the processing of multichannel satellite images, is implemented in the form of GIS on the Google Earth Engine platform (GEE). GEE uses JavaScript or Python to interact with the operator. JavaScript was used in this work.

ANALYSIS OF FOREST FIRE RESULTS AND THEIR CONSEQUENCES IN DEVELOPED GIS GEE

The results of comparing the detection of forest fires according to the developed methodology in GEE GIS with the statistics of the State Emergency Service of Ukraine in Kherson region are shown in table 2 [11, 12].

Table 2. **Comparison of forest fire zone detection results**

Year	Official statistics		Proposed method	
	Number of fires	Burned area, ha	Number of fires	Burned area, ha
2020	169	108	203	140
2019	380	1175	540	1304
2018	84	665	153	898

***Source:* compiled by the authors**

As can be seen from the table, the number of forest fire zones by area is greater than according to state statistics. This fact can be explained not only by the advantages of the accuracy of the proposed methodology, but also the possibility of making wrong decisions. As shown by numerical tests in practice in GIS GEE agricultural areas are similar to forest fire zones. Therefore, a false-positive result is possible. (Fig. 9 and Fig. 10a,b,c).

CONCLUSION AND PROSPECTS FOR FURTHER INVESTIGATION

Thus, in this work a method of analysis and visualization of geodata on forest fires and their consequences was developed, the implementation of which in the form of specialized GEE GEE increased the efficiency of their detection by more than 2.5 times, according to expert estimates.

In the development of the method, the peculiarities of multi-channel data of satellite images and the existing possibilities for their processing are analyzed. The capabilities of the American FIRMS system and the complex European EFFIS system, algorithms and methods of processing medium resolution satellite imagery (MODIS) on board the Terra and Aqua satellites, namely Land MOD14 / MYD14 for the detection of active fires and MCD45 for burned areas, are considered. The results of a comparative analysis of the best known services MCD45A1, MCD64A1 and MCD14ML are presented. It also addresses the ability of ESA's Fire_CCMCD45 from MCD45 to monitor burned areas.

The benefits and capabilities of the Google Earth Engine cloud service (GEE) for receiving and processing satellite data on wildfires and their consequences are analyzed. The use of GEE makes it possible to obtain geodata of forest fire areas and their consequences determined by date, region, type of multichannel satellite and its channels (layers of pollution). Based on this information, a method for processing, analyzing and visualizing geodata of forest fires and their consequences was developed.

The method consists of five steps, namely: obtaining input data from publicly available geographic information web services, pre-processing (filtering) of multi-channel satellite images, calculation of indexed images, their thresholding, storage of original data in cloud storage. Recommendations for the selection of spectral indices, construction and use of radiometric correction masks, cloud cover and water masks were developed.

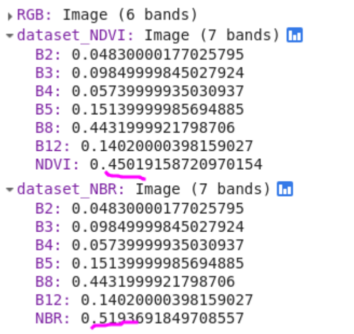
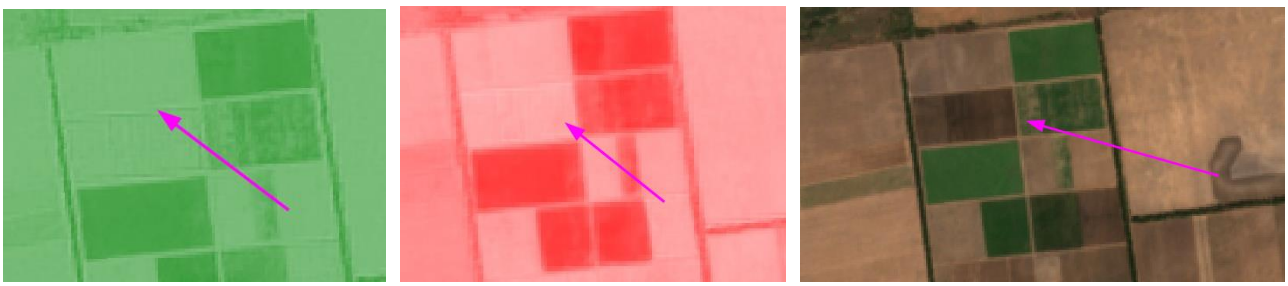


Fig. 9. **Estimated values of indices NDVI / NBR**
Source: **compiled by the authors**



a b c

Fig. 10. **An example of a false-positive solution according to the proposed method NDVI image (a), NBR image (b), RGB image (c)**
Source: **compiled by the authors**

The developed methodology is implemented in the form of GIS on the Google Earth Engine (GEE) platform. In a specialized GIS interface for interaction with the operator is implemented in the form of scripts written in the JavaScript programming language

This study demonstrates the ability of specialized GEE GIS, to detect forest fires and their consequences. Comparisons are made between the number and area of forest fires detected by the proposed method and general statistics.

The GIS capabilities of GEE are used to obtain geospatial data for the Kherson region area, which is considered the most fire-prone area in Ukraine. Positive results were obtained in terms of efficiency and accuracy of observations.

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Методика аналізу та візуалізації геопросторових данних про лісові пожежі та їх наслідки

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АНОТАЦІЯ

У роботі розглянуто особливості систем дистанційного зондування землі для виявлення лісових пожеж, а також аналізу їх наслідків у вигляді згорілих областей. Розглянуто можливості американської системи FIRMS та комплексної європейської системи EFFIS. Проаналізовано алгоритми та методики систем обробки супутникових зображень середньої роздільної здатності (MODIS) на борту супутників Terra і Aqua, а саме алгоритми множини Land MOD14/MYD14для виявлення активних пожеж і множини MCD45 для згорілих територій. Наведено результати порівняльного аналізу найбільш відомих сервісів - MCD45A1, MCD64A1, MCD14ML ESA’s Fire_CCMCD45 від MCD45 - щодо їх можливостей стосовно моніторингу згорілих територій. Показано, що в умовах відсутності загальної державної системи дистанційного зондування в України виникає необхідність використовувати можливості сучасних загальнодоступних геоінформаційних систем, наприклад хмарного сервісу Google Earth Engine (GEE) щодо отримання та обробки даних супутників про лісові пожежі та їх наслідки. Використання сервісу GEE дозволяє отримати геоданні зон лісових пожеж та їх наслідків, які визначаються за датою, регіоном, типом багатоканального супутника та його каналами (шарами зображень). На основі такої інформації розроблено методику обробки аналізу та візуалізації геопросторових даних про лісові пожежі та їх наслідки. Методика складається із п’яти етапів а саме: отримання вхідних даних із загально доступних геоінформаційних веб сервісів, попередня обробка (фільтрація) багатоканальних супутникових зображень, розрахунок індексованих зображень, їх порогова обробка, збереження вихідних даних у хмарному сховищі. Розроблені рекомендації по вибору спектральних індексів, побудови та використання масок радіометричної корекції, хмарності, а також водної маски. Методику реалізовано мовою JavaScript на платформі GEE у вигляді спеціалізованої геоінформаційної системи (ГІС GEE). Проведено дослідження можливостей розробленої ГІС GEE щодо виявлення лісових пожеж та їх наслідків .Наведено порівняльні характеристики щодо кількості та площі небезпечних зон, які отримані за запропонованою методикою та відповідними відомостями із загально статистичних даних. На думку експертів-екологів впровадження запропонованої методики дозволило підвищити оперативність виявлення небезпечних зон.

Ключові слова: геоінформаційні системи; ГІС; MODIS пожежі; MCD45 вигоріли ділянки; активні пожежі та виявлення вигорілих ділянок

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