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Andriy BABUSHKA[1], Lyubov BABIY[2], Borys CHETVERIKOV[3], Andriy SEVRUK[4]

Department of Photogrammetry and Geoinformatics, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine, e-mail: liubov.v.babii@lpnu.ua, [1] https://orcid.org/0000-0002-2025-8733, [2]https://orcid.org/0000-0002-5772-4865, [3]https://orcid.org/ 0000-0001-8677-1735

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RESEARCH OF FOREST FIRES USING REMOTE SENSING DATA (ON THE EXAMPLE OF THE CHORNOBYL EXCLUSION ZONE)

Earth remote sensing and using the satellite images play an important role when monitoring the effects of forest fires and assessing damage. Applying different methods of multispectral space images processing, we can determine the risk of fire distribution, define hot spots and determine thermal parameters, mapping the damaged areas and assess the consequences of fire. The purpose of the work is the severity assessment connected with the post-fire period on the example of the forests in the Chornobyl Exclusion Zone. The tasks of the study are to define the area of burned zones using space images of different time which were obtained from the Sentinel-2 satellite applying the method of a normalized burn ratio (NBR) and method of supervised classification. Space images taken from the Sentinel-2 satellite before and after the fire were the input data for the study. Copernicus Open Access Hub service is a source of images and its spatial resolution is 10 m for visible and near infrared bands of images, and 20 m for medium infrared bands of images. We used method of Normalized Burn Ratio (NBR) and automatically calculated the area damaged with fire. Using this index we were able to identify areas of zones after active combustion. This index uses near and middle infrared bands for the calculations. In addition, a supervised classification was performed on the study area, and signature files were created for each class. According to the results of the classification, the areas of the territories damaged by the fire were also calculated. The scientific novelty relies upon the application of a method of using the normalized combustion coefficient (NBR) and supervised classification for space images obtained before and after the fire in the Chernobyl Exclusion Zone. The practical significance lies in the fact that the studied methods of GIS technologies can be used to identify territories and calculate the areas of vegetation damaged by fires. These results can be used by local organizations, local governments and the Ministry of Emergency Situations to monitor the condition and to plan reforestation. The normalized burned ratio (NBR) gives possibility efficiently and operatively to define and calculate the area which were damaged by fires, that gives possibility operatively assess the consequences of such fires and estimate the damage. The normalized burned ratio allows to calculate the area of burned forest almost 2 times more accurately than the supervised classification. The calculation process itself also takes less time and does not require additional procedures (set of signatures). Supervised classification in this case gives worse accuracy, the process itself is longer, but allows to determine the area of several different classes.

Key words: Sentinel-2; Remote Sensing Data; NBR; burned area; Chernobyl Exclusion Zone; different time images.

Introduction

Fires are the most significant causes of disruption in plant areas, especially such as forests and meadows. Fires are a large problem for ecosystem as they can be beneficial and harmful in different cases. Thus, current estimates of the spreading and consequences of fires vegetation still remain a problem around the world, that requires effective solutions. Earth remote sensing and using the satellite images play an important role when monitoring the effects of forest fires and assessing damage. Applying different methods of multispectral space images processing, we can determine the risk of fire distribution, define hot spots and determine thermal parameters, mapping the damaged areas and assess the consequences of fire.

A lot of scientists in Ukraine and in many countries around the world are researching new methods for determining the consequences of fire impact using remote sensing data. Let's analyze the most important, in our opinion, works on this topic in recent years.

In [Burshtynska, et al., 2018] work, there was a research of Arizona state forest fire in the USA. Space images of Landsat 5 for the period (May 30, 2011; June 15, 2011) and Landsat 7 for the period (June 7, 2011) were used in the study. In order to define the area of fire during the period from 30.05. 2011 till 15.06.2011, methods of unsupervised and supervised image classification were applied.

The works [Hall, et al., 2021; Boschetti, et al., 2019; Ramo, et al., 2021] describe the problem of identifying small areas of fires. The use of free Landsat or Sentinel medium-resolution satellite imagery is not suitable for this type of research. The authors propose an alternative approach to identifying damaged areas by fires, which allows to test two widely available products to find a common burn zone – MCD64A1 and FireCCI51. It is noted that these resources also give quite large research errors.

In the works [Rasul, et al., 2021; Ertugrul, et al., 2019; Lasko, 2019], the authors determine the dynamics of increasing the large burned areas of forest over certain periods of time using remote sensing data from the resource MCD64A1 500m. The main factors causing the increase of fires in the studied regions are analyzed. However, the obtained quantitative characteristics of the burned areas are not analyzed in the works.

Studies [Ling, et al., 2015; Padilla, et al., 2015] are based on the identification of damaged areas using the MODIS satellite. Two different approaches of burned areas determination are compared and evaluated: MCD45 and SPM. Based on the obtained results, it is noted that the SPM approach is more effective for reducing the impact of low resolution MODIS images when mapping the burned area.

The articles [DaCamara, et al., 2018; Bowman, 2018; Giglio, et al., 2018] describe the methodology for delimiting burned areas using a fire-sensitive (V, W) index system defined in the near / middle IR range. These studies provide a clearer definition of the group of pixels of the burned areas in the images.

The works [Lasaponara and Tucci, 2019; Lanorte, et al., 2015; Stroppiana, et al., 2015] describe a method for determining burned areas using vegetation indices from optical images and radar space images of the Sentinel-1 satellite. The proposed here approach noted that: the time-averaged polarization ratio of VH Sentinel-1 is good to use when mapping the burned area, which gives a fairly accurate result; the use of Gettys-Horde spatial statistics in combination with ISODATA (classification without training) appropriately covers various levels of classification of the severity of damaged areas.

Studies [Pereira, et al., 2018; Kumar, & Roy, 2018; Pleniou, & Koutsias, 2013] are dedicated to the processing of spectral indices for identification of burned area using OLI/Landsat-8 space images. The various indices (NDVI, MSAVI, SAVI and GEMI) were obtained using the red and near infrared bands, and (NBR, BAIMmod and MIRBImod) using the near and short wave infrared bands. Such method was applied for images before and after the fire. The difference between the index before and after the fire was also calculated: dNDVI, dMSAVI, dSAVI, dGEMI, dNBR, dBAIMmod and dMIRBImod. From these indexes, the authors created six different compositions (RGB), which were later segmented and classified in an unsupervised manner, and then the area of interest was identified. The results of this classification were confirmed by control data obtained by visual interpretation of the image. The methods showed good classification quality, the best results show dNBR, NBRpost-fire and dMIRBImod indices in RGB composite.

Studies [Filipponi, 2018; Quintano, et al., 2018] are devoted to the determination of burned areas using the Sentinel-2 satellite. Previously, optical images with high spatial resolution were mainly used for mapping burned areas. The new MSI sensor on board the Sentinel-2 satellites carries more spectral information recorded in the spectral region of the red edge, which opens the way for the development of new indices for mapping the burned area. These researches present the currently developed burned area index (BAIS2) applied on spectral bands of Sentinel-2 for detecting burnt areas. Spatial resolution of image is 20 m and there is a processor designed to implement post-fire mapping based on Sentinel-2 data. The images of fire of 2017 in Italy were used to test new index in various studies. The results show positive estimation of the index and underline critical issues of the Sentinel-2 data processing.

The Chornobyl Exclusion Zone is the object of our research. In 2020, powerful fires occurred on this territory. (Fig. 1).

Fig. 1. A fragment of the space image obtained by the Sentinel-2 system, presented in natural colors. Date: 12/04/202

The Chornobyl Exclusion Zone is a restricted area that has been heavily contaminated with long-lived radionuclides as a result of the Chernobyl accident. The zone was established in 1986, after the people evacuation from the 30-kilometer zone around the station (Fig. 2).

Fig. 2. The Chornobyl Exclusion Zone

The exclusion zone is not suitable for human activity or activity in the economic sector.

The purpose and tasks of the study

The purpose of the work is assessment the severity connected with the post-fire period on the example of the forests in the Chornobyl Exclusion Zone. The tasks of the study are to define the area of burned zones using space images of different time which were obtained from the Sentinel-2 satellite applying the method of a normalized burn ratio (NBR) and method of supervised classification.

Methods

Space images taken from the Sentinel-2 satellite before and after the fire were the input data for the study. Copernicus Open Access Hub service is a source of images and its spatial resolution is 10 m for visible and near infrared bands of images, and 20 m for medium infrared bands of images. We used method of Normalized Burn Ratio (NBR) and automatically calculated the area which were damaged with fire. Using this index, we were able to identify areas of zones after active combustion. The space images of the Chornobyl Exclusion Zone before the fires on April 7, 2020 and after the fires on June 26, 2020 were composited in natural colors and are presented, in Fig. 3 and Fig. 4 respectively.

Fig. 3. Sentinel-2 space image 07/04/2020 composited in natural colours

Fig. 4. Sentinel-2 space image 26/06/2020 composited in natural colours

The part of area of Chornobyl zone, where the forest was actively burning in 2020 was chosen for the study. Space spectral images, composited in natural colours can be used for visual assessment of the consequences. However, in order to get quantitative analyse and to calculate the area of burned forest we need to digitize the damaged areas. If the territory of the fires is significant, then this method requires a large amount of time. If the fires occurred in several sites, they should be digitized separately and the process of vectorization become more complicated. Therefore, we need an automated approach for rapid and reliable assessment of fire consequences. This will reduce the time of area determination and allows results be without significant loss of accuracy.

Results

In this research, the digitization of sites damaged with fire in order to obtain template values of areas has been performed. To implement this process, we apply band composition for images with 10m resolution (Fig. 5). After counting total areas of all digitized sites, it was defined that the area of the zones devastated by fires is 1223 hectares.

Calculation of the area using the normalized Burn Ratio

To automatically calculate the areas damaged with fire, the Normalized Burn Ratio (NBR) was applied. This index provides the possibility efficiently and operatively to define and calculate the area damaged by fires, that gives possibility operatively assess the consequences of such fires and estimate the damage and it is calculated by the formula:

$$NBR = (NIR-SWIR)/(NIR+SWIR), \quad (1),$$

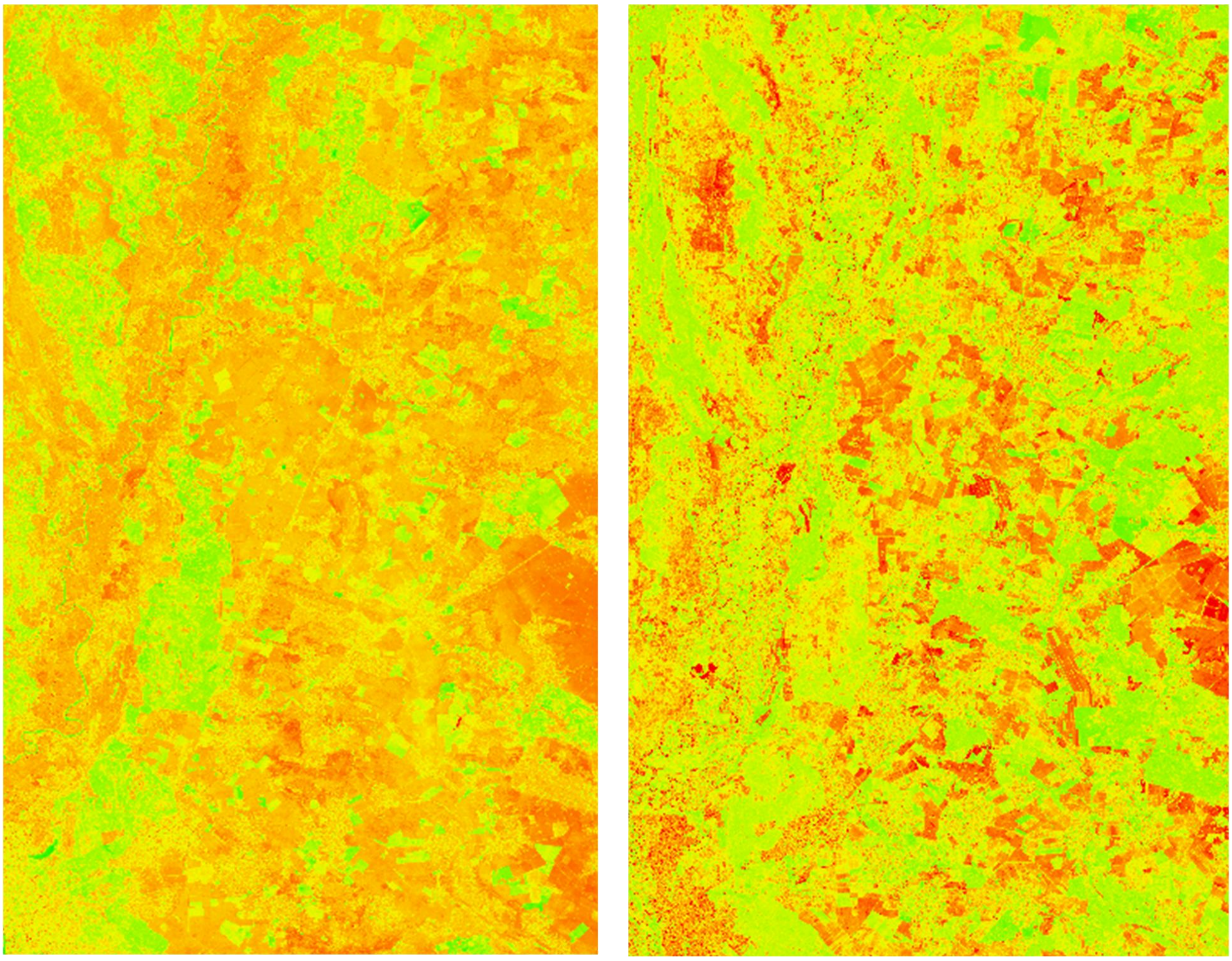
where *NIR* – the brightness value of the near infrared spectral band; *SWIR* – the brightness value of the middle infrared spectral band.

Fig. 5. Digitized areas damaged after fires in the study region

This index uses near infrared and the middle infrared spectral bands for calculations. Figure 6 shows the indices calculated for two images: before fires (a) and after fires (b), accordingly.

Modern GIS tools give possibility to calculate the difference between two resulting images of NBR for the data before and after fires. It is called the dNBR (difference of NBR), and can be used for estimation of the areas of different severity of burn. Then we reclassified obtained image of dNBR according to Table 1 and calculate the resulting areas.

The areas of classes were calculated from low to high levels for all severity levels. That is, the classes were combined to obtain a single value of the area of the fire-damaged areas. The total area of burnt area is 1141 hectares and includes all degrees of severity. Then we calculated the difference between the calculated area and template area. The value is 82 ha that is 6.7 % of template area.



a *b*

Fig. 6. Image fragment with calculated normalized burn ratio indexes before (a) and after (b) fire in the study region

Table 1

Levels of burning severity used for reclassification of the dNBR image

	Severity level	dNBR range (scaled to 10^3)	dNBR range (not scaled)
	Enhanced regrowth, high (postfire)	-500 to -251	-0,500 to -0,251
	Enhanced regrowth, low (postfire)	-250 to -101	-0,250 to -0,101
	Unburned	-100 to +99	-0,100 to +0,99
	Low severity	+100 to +269	+0,100 to +0,269
	Moderate low severity	+270 to +439	+0,270 to +0,439
	Moderate high severity	+440 to +659	+0,440 to 0,659
	High severity	+660 to +1300	+0,660 to +1,300

Calculation of the area using the method of supervised classification

In addition, a supervised classification was performed on the study area. This method is considered as one of the best automated methods for obtaining areas, but it is not without drawbacks. In particular, there is a strong relationship between the number, size and location of signatures and the resulting areas. In addition, post-processing of results is often used to improve classification results. All these procedures complicate the classification process, which leads to spend more time to complete the task. The advantage is that this approach is universal and allows you to determine the area of different types of objects.

To implement classification, one must create signature files for each class. Given that the study area is dominated by forest with separate open areas of meadow vegetation, signatures were chosen for three classes – burnt forest, roads (which are present in the picture) and other objects. The last class consists of both healthy (undamaged) forest and meadow vegetation. Since the main purpose of the classification was to obtain the area of burned forest, it was impractical to classify these groups separately. Such a division should not significantly affect the accuracy of the classification.

Signatures were selected in several places to obtain the best classification results. The size of the signatures was at least 10 × 10 pixels. An example of signature selection for a burnt forest class is given in Fig. 7.

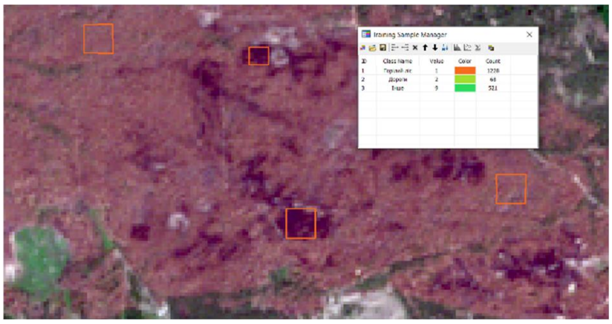


Fig. 7. Example of signature selection for a burnt forest class

Similar steps were performed for road classes and other objects. After saving the signature files, a supervised classification of the image of the study area was performed. The classification results are presented in Fig.8.

Comparing the results of the classification with digitized sections, we can conclude that there is some pixel flow between the class “roads” and other “objects”, which was not significant for our research. The area of burned forest according to the classification is 1076 hectares.

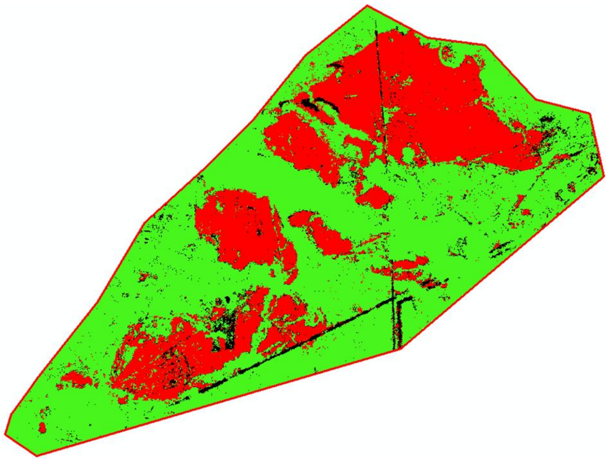


Fig. 8. Classified image of the study area

The classification results can be slightly improved by using the MajorityFilter tool. It allows to get rid of individual pixels of one class inside another. The processed image is presented in Fig.9. The area of burned forest after such processing is 1082 hectares.

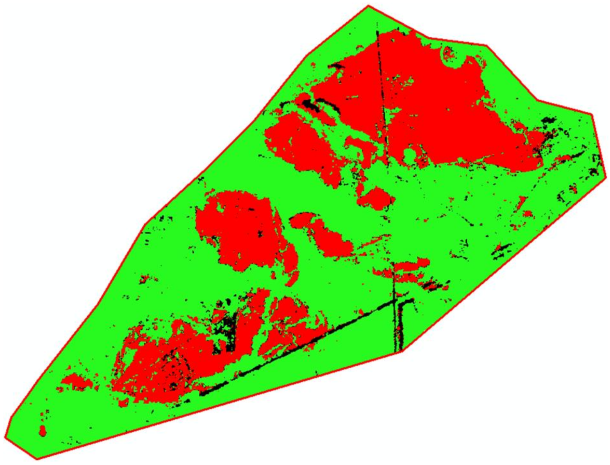


Fig. 9. Classified image of the study area after applying the MajorityFilter tool

Table 2 shows the area of burned forest, calculated according to the normalized combustion index and supervised classification. Their differences with the template area are also given.

From table 2 we can conclude that the normalized burned ratio allows to calculate the area of burned forest almost 2 times more accurately than the supervised classification. The calculation process itself also takes less time and does not require additional procedures (set of signatures). The results of supervised classification may change slightly if we classify images with a different set of bands. The classification results can be improved by post-processing data. Also, when using this method, information can be obtained about several classes at once, not just about the burned forest.

Table 2

Final table of differences in burned forest area, calculated according to the normalized burned ratio and supervised classification

	Calculated area, ha	Template area, ha	Difference, ha	Difference, %
Normalized burned ratio	*1141*	1223	*82*	*6,7*
Supervised classification	*1082*	1223	*141*	*11,5*

Scientific novelty and practical significance

The scientific novelty relies upon the application of a method of using the normalized combustion coefficient (NBR) and supervised classification for space images obtained before and after the fire in the Chernobyl Exclusion Zone. The practical significance lies in the fact that the studied methods of GIS technologies can be used to identify territories and calculate the areas of vegetation damaged by fires. These results can be used by local organizations, local governments and the Ministry of Emergency Situations to monitor the condition and to plan reforestation.

Conclusions

The use of remote sensing data with high periodicity and multispectral images with additional bands significantly expands the number of tasks that we can solve.

The normalized burned ratio (NBR) gives possibility efficiently and operatively define and calculate the area damaged by fires, that gives possibility operatively assess the consequences of such fires and estimate the damage.

It is deduced that in the researched area the accuracy of calculation area with the application of the normalized burned ratio is 6.7 % comparing with the template area. That is sufficient to solve such a problem.

Supervised classification in this case gives the worst accuracy (11.5 %), the process itself is longer, but allows to determine the area of several different classes.

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Андрій БАБУШКА[1], Любов БАБІЙ[2], Борис ЧЕТВЕРІКОВ[3], Андрій СЕВРУК

Кафедра фотограмметрії та геоінформатики, Національний університет “Львівська політехніка”, вул. С. Бандери 12, Львів, 79013, Україна, ел. пошта liubov.v.babii@lpnu.ua, [1] https://orcid.org/0000-0002-2025-8733, [2]https://orcid.org/0000-0002-5772-4865, [3]https://orcid.org/0000-0001-8677-1735

ДОСЛІДЖЕННЯ ЛІСОВИХ ПОЖЕЖ ЗА ДАНИМИ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ ЗЕМЛІ (НА ПРИКЛАДІ ЧОРНОБИЛЬСЬКИЇ ЗОНИ ВІДЧУЖЕННЯ)

Дистанційне зондування Землі відіграє важливу роль у моніторингу та оцінюванні наслідків лісових пожеж. За допомогою різних методик опрацювання багатоспектральних космічних знімків можна визначати ризик поширення пожежі, виявляти гарячі точки та встановлювати теплові параметри, картографувати уражені території та оцінювати наслідки. Метою роботи є оцінка ступеня тяжкості, пов’язаного з післяпожежною фазою на прикладі лісів Чорнобильської зони відчуження. Задачами є визначення площ спалених територій за різночасовими космічними знімками, отриманими з супутника Sentinel-2 за допомогою нормалізованого коефіцієнта горіння (NBR) та методики контрольованої класифікації. Вхідними даними для дослідження слугували різночасові космічні знімки, отримані з супутника Sentinel-2 до та після пожежі. Знімки отримані з сервісу Copernicus Open Access Hub, і їхня просторова розрізненість становить 10 м для видимих та близького інфрачервоного каналів, та 20 м – для середніх інфрачервоних. Для автоматизованого підрахунку площі територій, пошкоджених пожежею, використано нормалізований індекс горіння (Normalized Burn Ratio (NBR)). Цей індекс призначений для ідентифікації ділянок, де відбувалось активне горіння. Для розрахунків цей індекс використовує близький та середній інфрачервоні канали. Додатково на досліджувану територію здійснено контрольовану класифікацію, при цьому були створені файли сигнатур для кожного класу. За результатами класифікації також обраховані площі територій, пошкоджених пожежею. Наукова новизна полягає в опрацюванні методики використання нормалізованого коефіцієнта горіння (NBR) та контрольованої класифікації для космічних знімків, отриманих до і після пожежі у Чорнобильській Зоні Відчуження. Практична значущість полягає у тому, що досліджені методи ГІС-технологій можуть бути застосовані для виявлення зон та обрахунку площ пошкодженої пожежами рослинності. Ці результати можуть бути використані місцевими організаціями, органами самоврядування та МНС для моніторингу стану та планування відновлення лісових насаджень. Нормалізований індекс горіння дає можливість швидко та ефективно виявити та обчислити площі територій, пошкоджених пожежами, що дозволяє оперативно оцінити наслідки таких пожеж та оцінити завдані збитки. Нормалізований індекс горіння дозволяє обчислити площу горілого лісу майже в 2 рази точніше, ніж контрольована класифікація. Сам процес обчислення також займає менше часу і не вимагає додаткових процедур (набору сигнатур). Контрольована класифікація в цьому випадку дає гіршу точність, сам процес є тривалішим, але дозволяє визначити площі декількох різних класів.

Ключові слова: Sentinel-2; дані дистанційного зондування; нормалізований індекс горіння; території; пошкоджені пожежею; Чорнобильська зона відчуження; різночасові знімки.

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