ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ
Satbayev University

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Satbayev University

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

6 (450)

NOVEMBER – DECEMBER 2021

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

Clarivate Analytics

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).

The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.

Thematic scope: geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.

Periodicity: 6 times a year.

Circulation: 300 copies.

Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19

http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 450 (2021), 125-132 https://doi.org/10.32014/2021.2518-170X.128

UDC 674; 662
IRSTI 86.01; 61.51.29

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LANDSCAPE FIRE SAFETY MANAGEMENT: THE EXPERIENCE OF UKRAINE AND THE EU

Abstract. Landscape safety management is an important tool of European spatial planning.The aim of the work is to assess the effectiveness of managing the risks of environmental disasters and eliminating the consequences of forest fires using modern geographic information systems and space technologies for remote sensing of the Earth's surface.Trends in fire hazard in the past have been analyzed by processing a series of meteorological indicators that are commonly used to assess fire potential due to climatic conditions. ESRI's ArcGis GIS tools were used.It has been substantiated that climate change along with modern specifics of land use and forestry activities lead to an increase in the fire hazard of landscapes. It is proved that the situation is especially critical in the areas contaminated by the Chornobyl accident, where the large areas with dead trees bear a significant risk of catastrophic forest fires. The paper investigates the possibilities of managing the risks of environmental disasters and liquidation of consequences of forest fires using modern geoinformation systems and space technologies for remote sensing a surface of the Earth. It is proposed to introduce a modern information system for decision-making during the detection and elimination of forest fires and to create a specialised Center for Forest Protection and Safety to coordinate actions in case of fires and other emergencies in the landscapes of northern regions of Ukraine. Based on the study of the European experience in landscape fire safety management, it is proposed to use an integrated system of prevention and elimination of forest fires, which is based on the calculation of factors of fire hazard. When developing a method for identifying fire-hazardous periods using remote sensing data, it was proposed to additionally take into account wind characteristics and anthropogenic factors.

Key words: monitoring, remote sensing of the Earth, ecological safety, anthropogenic factors, fires.

Introduction. In April 2020, a wave of forest fires swept across Europe. Ukraine was no exception and suffered significant environmental, social, and economic losses from forest fires, the largest of which occurred in the area of radioactive contamination in the northern regions of Ukraine. Although forest fires occurred in all years and around the world, for Europe, the area of burnout in recent decades has declined over the years since 1980, with the exception of Portugal [1-6]. However, even during the last 20-year period, there has been a variation in the areas of landscape burnout in Europe, which in turn is due to seasonal meteorological conditions. Large areas, for example, were burned in 2017 due to unprecedented forest fires in Portugal, while the area burned in 2018 was the lowest. At the same time, more European countries were affected by major forest fires in 2018 and 2020 than ever before, including in Central and Northern Europe [7]. Both fire seasons coincided with record droughts and heat waves in the spring and summer of those years in the worst-hit regions. For example, in Sweden, international aid was used to overcome the consequences of forest fires in 2018 [8], while in Ukraine more areas burned out in 2020. Some authors argue that global warming has increased the risk of such extreme forest fires in Europe, but the lack of a plausible climate change scenario forces to view fires as a potential threat to landscape safety worldwide [9].

In 2020, a critical lack of soil moisture caused another wave of forest fires that swept through European countries, for example, in Poland in April 2020, fires engulfed 6 hectares of Bebzhan National Park [10], but these areas many times less than the areas affected by fires in Ukraine in 2020, especially in the Chornobyl Exclusion Zone. Currently, three main types of models are used to successfully predict the occurrence and spread of fires: empirical (statistical), semi-empirical, and physical [11-14]. In this study, we compared the systems of prevention and monitoring of landscape safety in leading European countries and Ukraine and analysed the main groups of safety management models, as well as substantiated the most appropriate for use in the northern regions of Ukraine. The need to study the European experience of landscape fire safety management is due to Ukraine's declared intentions to integrate into the EU, and therefore the need to agree on many approaches and mechanisms, participation in cross-border cooperation, joining the European ecological network [15], ratification and implementation of international conventions. Given all the above, the purpose of this work was to assess the effectiveness of risk management of environmental disasters and forest fires using modern geographic information systems and space technologies for remote sensing of the Earth's surface.

Materials and methods. Trends in fire hazard in the past have been analysed by processing a series of meteorological indicators that are commonly used to assess fire potential due to climatic conditions. The ArcGis GIS tools manufactured by ESRI were used. To solve the problems of applying GIS technologies for landscape safety using remote sensing data of the Earth's surface, materials from the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) toolkits (Table 1) installed on the Landsat-8 satellite (Geological Survey (U.S.)) were used [13]. The satellite information used in this study was taken from the United States Geological Survey [16] geoportal, in the Fire Information Resource Management System (FIRMS) [17]. This method of data processing was already used by O.V. Zhukov, O.M. Kunah, V.O. Taran, M.M. Lebedinska, T.P. Fedonyuk, O.M. Galushchenko et al. [18] to determine the electrical conductivity of the soil in the Dniprovsko Orilskyi Nature Reserve and Chornobyl Radiation-Ecological Biosphere Reserve.

Table 1.The main characteristics of the spectral ranges of OLI and TIRS sensors

Spectral channel	**Wavelength, μm**	**Resolution, m**	**Spectral channel**	**Wavelength, μm**	**Resolution, m**
Landsat-8			**Sentinel-2**		
Operational Land Imager (OLI)			**MultiSpectral Instrument (MSI)**		
Band 1 (coastal /aerosol)	0.43-0.45	30	B1 (blue)	0.43-0.45	60
Band 2 (blue)	0.45-0.52	30	B2 (blue)	0.46-0.52	10
Band 3 (green)	0.52-0.60	30	B3 (green)	0.54-0.58	10
Band 4 (red)	0.63-0.68	30	B4 (red)	0.65-0.68	10
			B5 (red edge)	0.70-0.71	20
			B6 (red edge)	0.73-0.75	20
			B7 (red edge)	0.77-0.79	20
			B8 (NIR)	0.78-0.90	10
Band 5 (near infrared, NIR)	0.84-0.87	30	B8a (NIR)	0.86-0.88	20
			B9 (water vapor)	0.93-0.95	60
Band 6 (near infrared, SWIR1)	1.56-1.66	30	B11 (SWIR1)	1.57-1.66	20
Band 7 (near infrared, SWIR2)	2.10-2.30	30	B12 (SWRIR2)	2.10-2.28	20
Band 8 (panchromatic, PAN)	0.50-0.68	15			
Band 9 (cirrus clouds, cirrus)	1.36-1.38	30	B10 (cirrus)	1.37-1.39	60
Thermal Infrared Sensor (TIRS)					
10 (far infrared, TIR1)	10.3-11.3	100			
11 (far infrared, TIR2)	11.5-12.5	100			

To monitor the safety of landscapes, the following indices were used, which are derived from the spectral channels of sensors installed on Landsat-8 or Sentinel-2 satellites (ratio of spectral bands) [19]. In general, the resolution of the Sentinel-2 spectral channels is higher than that of Landsat-8. But it should be noted that the Sentinel-2 satellite has been in orbit since June 23, 2015. Therefore, if it is necessary to obtain retrospective information about ecosystems, it is possible to use information from the Landsat-8 satellite (or earlier Landsat satellites). Information from the Sentinel-2 satellite is preferred for ongoing monitoring. In addition, combining information from both sources can produce data with higher time resolution, or it is possible to obtain scenes without a high level of cloudiness.

For Sentinel-2 (Eq. 1): (1)

Normalised Difference Tillage Index (NDTI) also known as the Vegetation Index (VI), takes into account the variation of biomass and the peculiarities of vegetation types (true for both satellites, STI is calculated by the equation for the corresponding satellite) [20; 21] (Eq. 2): (2)

Normalised Difference Vegetation Index (NDVI) for Landsat-8 [19] (Eq. 3): (3)

For Sentinel-2 (Eq. 4): (4)

Modified Normalised Difference Water index (MNDW) – sensitive to water content in green biomass for Landsat-8 (Eq. 5) [22]: (5)

For Sentinel-2 (Eq. 6): (6)

Land Surface Water Index, Normalised Difference Infrared Index (LSWI)
for Landsat-8 (Eq. 7) [16]: (7)

For Sentinel-2 (Eq. 8): (8)

Normalised Burn Ratio (NBR) for Landsat-8 (Eq. 9) [17]: (9)

Depending on applied research tasks, time series based on one of the indices of interest can be studied. Analysis of the temporal dynamics of the normalised fire index can be the basis for establishing the areas of ecosystems affected by the pyrogenic factor and monitor the dynamics of ecosystem restoration after fires. Of particular importance is the multidimensional statistical analysis of a set of indices on a single date. For example, an analysis of the main components of the set of presented indices for the date corresponding to the highest vegetation activity will provide information on the diversity of habitats and on the state of the biotic potential. Ultimately, tensor analysis of the dynamics of a set of indices over time is a tool for understanding the complex dynamics of ecological and landscape systems.

Results and discussion. Climate change, frequent outbreaks of forest diseases and pests, together with limited forestry activities, increase the fire hazard in forest landscapes and surrounding areas. Rising temperatures during the fire season, prolonged droughts, heavy rainfall, and frequent gusts of wind contribute to the formation of high fire hazard classes. The combination of these factors with high reserves of combustible materials, forest clutter in the northern regions of Ukraine, in particular areas contaminated by the Chornobyl accident with large areas with dead trees, increases the risk of catastrophic forest fires. In particular, these were recorded in 1992, 2015, when fires covered 16 and 17 thousand hectares of forests, respectively, and in 2020, when the total area of forests covered by fire was about 67 thousand hectares. Large forest fires have significant environmental consequences, which are manifested in the transport of radionuclides with smoke, secondary pollution of adjacent areas, and the loss of barrier function due to deforestation and burning of living soil. Moreover, weather conditions and the accumulation of combustible materials in forest contribute to large fires. Burned areas that occur after fires require the study of their restoration, including changes in biodiversity, natural and artificial reforestation in order to determine the duration of restoration of barrier functions and other properties of forest areas [23-30].

In Ukraine and other post-Soviet countries, GOST R 22.1.09-99 «Safety in emergencies. Monitoring and forecasting forest fires. General requirements» [31] was introduced to determine the fire hazard factors, which provides for the use of V. Nesterov's fire hazard factors (FHF). FHF is defined as the sum of the product of air temperature and the difference between air temperature and the dew point, which is calculated for a particular point and a specific time. This indicator is calculated exclusively on the basis of meteorological data registered at a specific weather station (Eq.10).

$$FHF_n = FHF_{n-1} * K_{pr} + [t(t-t_d)]_n \quad (10)$$

FHF_n – the value of the fire hazard factor calculated for the current day, ºC;

FHF – Nesterov fire hazard factor

FHF_{n-1} – the value of the fire hazard factor calculated for the next day, ºC;

K_{pr} – precipitation correction factor (equal to one if the amount of precipitation is less than 3 mm, and zero – if more than or equal to 3 mm).

t – air temperature at the time from 12 to 15 hours or at a time close to synchronous meteorological observations, t_d – ew point at the same time, $(t-t_d)$ – dew point deficit.

An example of actual data on fire danger in forests in the northern regions of Ukraine as of April 5, 2020 is presented in Figure 7. Thus, as of April 5, according to the FHF, the level of fire danger in Polesia was low and medium, so the informativeness of this factor raises doubts.

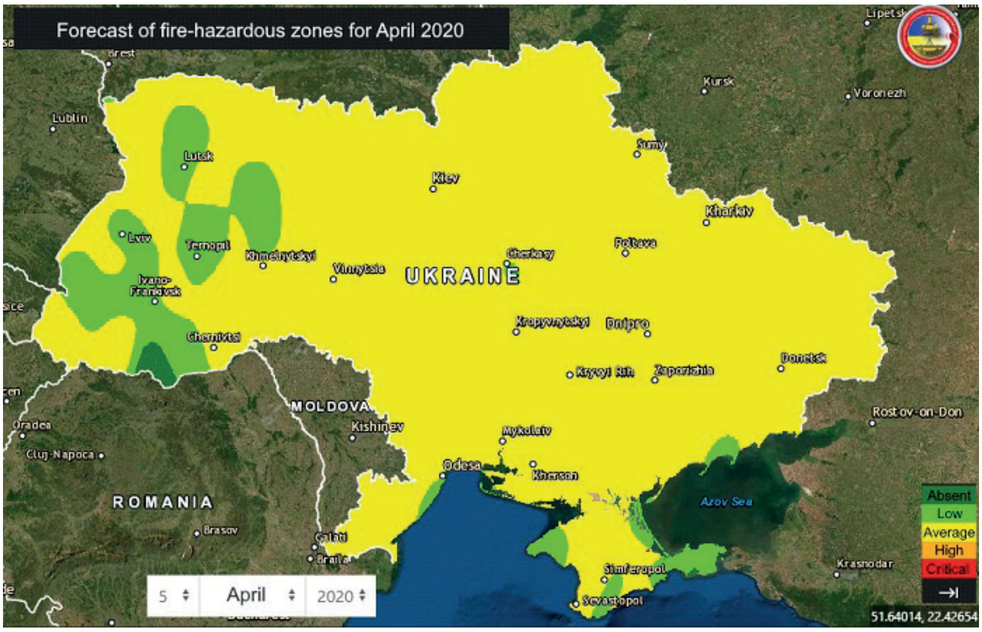

Figure 7. Forecast of fire-hazardous zones on the territory of Ukraine using the Nesterov fire hazard factor.

The main disadvantage of the Nesterov fire hazard factor should be considered a rather gross error in precipitation. Untimely operation of this factor was established in 2020. Such shortcomings in the reflection of fire hazard were once fixed by various scientists, and an amendment to precipitation was added to the general formula – K_{pr} (Eq.11):

$$FHF_n = FHF_{n-1} * K_{pr} + [t(t-t_d)]_n * (K_{pr})_n \qquad (11)$$

However, the inflow of water in the form of precipitation is not always an appropriate indicator for an adequate assessment of the fire hazard of the landscape. Certain moisture content is characteristic of healthy vegetation, which grows faster and is more resistant to fires. For example, many plant materials can accumulate moisture and retain it for a long time, for example, mosses and lichens have a certain hygroscopicity, so when calculating fire factors, a hygroscopicity correction should be added. Such a modified assessment system is currently used by the Portuguese Meteorological Institute as the main indicator of forest fire risk [32; 33]. In the US National Rating System, which is a model of combining two groups of parameters (basic and intermediate), this is also taken into account. This model introduces intermediate moisture indices of living and dead forest combustible materials, which are the basis for further calculations. In addition, the main parameters include the speed of fire and the amount of heat released during a fire. The main initial parameters are combined into a single combustion index.

The importance of using remote sensing data increases, as well as the need for urgent changes in existing methods of detecting fire-hazardous periods, by combining drought and moisture indices with their traditional definition according to the V.G. Nesterov method. Considering the dynamics of one of the forest fires in Zhytomyr region, it can be concluded that if such a system worked, 26 thousand hectares of forest would be preserved, as the time between the initial stage of forest fire to the active stage was 10 hours.

One of the factors for the renewal of fires in April 2020 was wind. During the day from 3 to 4 April 2020, a south-westerly wind with gusts up to 13 m/s was observed, which caused a rapid spread of fire in the northern direction. During the day there was a very low humidity, not typical for this time of year (21-24% during the day, up to 69% at night). It contributed to the intensive burning of forests and fallows in the northern regions of Ukraine and made it difficult to supress the fire. Until April 13, the fires continued to move north. The fire in the south-western part of the Chornobyl Reserve due to the wind of 3-5 m/s with gusts up to 11-13 m/s, continued the rapid spread to the north. There is a threat of fires in areas with high conservation status. In particular, the ecosystems of the Ilyinsky Hydrological Nature Reserve of national importance were damaged. The fire in the central part of the exclusion zone approached the Chornobyl industrial site, where it was stopped. A third large fire broke out in the southern part of the Reserve near the villages of Rozsokha and Ilovnytsia.

On April 16, the wind with a speed of 5-7 m/s and gusts up to 18 m/s, led to the burning of decaying foci and the resumption of fires in the exclusion zone. There was a big fire in the eastern part of the Reserve near Kyiva Hora village. The fire in the central part of the exclusion zone spread to the territory of the Reserve near the Korogod and Rozyizhdzhe villages (Figure 8).

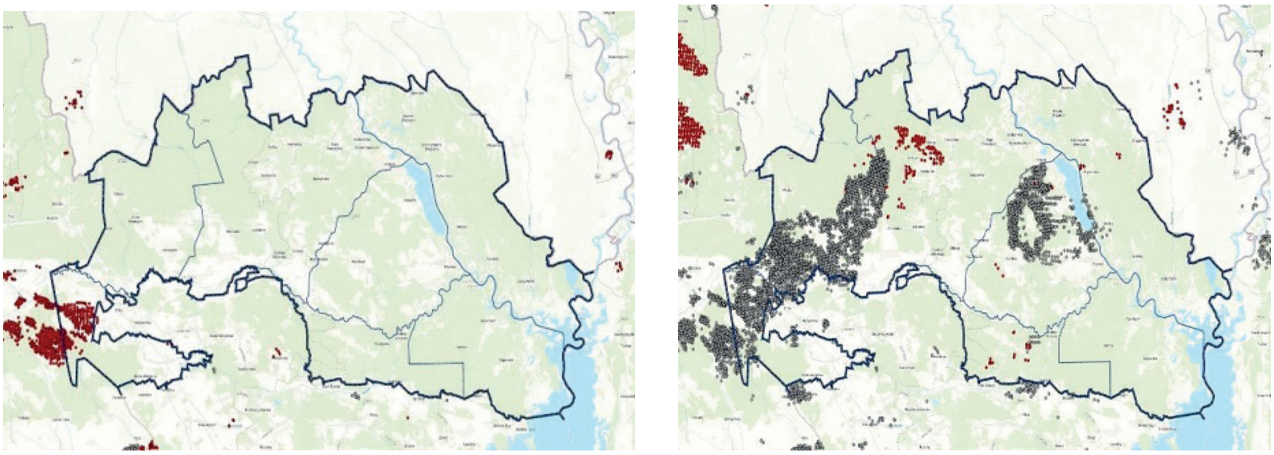

Figure 8. Coverage of the reserve territory by fire as of April 4 and 16, 2020 [17]

Unfortunately, the forest fire prevention systems existing in Ukraine do not include wind characteristics, but they are provided by forest fire prevention systems in many countries, such as Australia. This country uses the Forest Fire Danger Meter (FFDM) proposed by McArthur. It takes into account relative humidity, maximum air temperature, average wind speed and humidity. On this basis, a system for assessing the fire hazard of landscapes was built [34; 35]. The SiroFire computer system is now operating on the basis of FFDM – an application that provides decision-making for ensuring fire safety of landscapes.

$$FFDM_n = 2e^{(-0.45+0.987\cdot \ln(FMC)-0,0345\cdot AH+0,0338\cdot tn+0.0234\cdot WS)} \quad (12)$$

$FFDM_n$ – indicator calculated for the current day; FMC – Forest fuel moisture content, AH – Daily minimum relative air humidity, %, ºC; WS – Daily average wind speed, km/h.

It is the Australian system adopted as a basis for assessing the fire hazard of landscapes in European countries. Despite the optimal set of key parameters that are decisive for the spread of fires in the northern regions of Ukraine, the fire hazard monitoring system should be rebuilt similarly to the systems for assessing the fire hazard of landscapes in most European countries.

Conclusions. The main causes of forest fires in the northern regions of Ukraine and European countries were abnormal weather conditions in 2019 and early 2020, including a warm snowless winter, which provoked a decrease in the water content of rivers and other bodies of water. An additional factor in the deterioration of the situation can be considered anthropogenic, because a significant proportion of fires occur due to the burning of dry grass by the inhabitants of settlements. Deterioration of the fire elimination situation is also caused by the imperfection of the system of fire-fighting measures in Ukraine. In order to reduce the risk of recurrence of fires that occurred in April 2020, it is necessary to introduce a modern information system for decision-making in the detection and elimination of forest fires and create a specialized Center for Forest Protection and Safety to perform a number of functions to coordinate fires and other emergencies in the landscapes of the northern regions of Ukraine, a significant proportion of which are in the zone of radioactive contamination.

In accordance with European practice, a modern integrated system of forest fire prevention and elimination should be introduced, which will be based on the use of Forest Fire Danger Meter (FFDM). It is also necessary to develop a new method of using Earth remote sensing data to detect fire-hazardous periods. This technique should provide a combination of the use of drought and moisture content indices, along with their traditional definition of fire risk indices according to the method of V.G. Nesterova; taking into account wind characteristics and anthropogenic factors. International cooperation in the field of landscape fire safety management is relevant for Ukraine in the future. International organisations and national governments of active countries actively cooperate in the direction of coordination of actions in case of emergency fires, sign agreements on mutual assistance. One of the most influential and active international organisations in the field of forest fire protection is the Global Fire Monitoring Center (GFMC), based in Freiburg, Germany, which is mandated by the UN to coordinate the implementation of the UN International Strategy for Disaster Reduction (UN ISDR). forest protection from fires.

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ЛАНДШАФТЫ ӨРТ ҚАУІПСІЗДІГІН БАСҚАРУ: УКРАИНА МЕН ЕО ТӘЖІРИБЕСІ

Аннотация. Ландшафттық қауіпсіздікті басқару еуропалық кеңістікті жоспарлаудың маңызды құралы болып табылады.Жұмыстың мақсаты – жер бетін қашықтықтан зондтау үшін заманауи географиялық ақпараттық жүйелер мен ғарыштық технологияларды пайдалана отырып, экологиялық апаттардың тәуекелдерін басқару және орман өрттерінің зардаптарын жоюдың тиімділігін бағалау. Бұрынғы өрт қауіпті тенденциялары климаттық жағдайларға байланысты өрттің ықтималдығын бағалау үшін әдетте қолданылатын бірқатар метеорологиялық көрсеткіштерді өңдеу арқылы талданды. Олар ESRI ArcGis GIS құралдар жинағын пайдаланды. Климаттың өзгеруі жерді пайдалану мен орман шаруашылығының қазіргі ерекшеліктерімен қатар ландшафтардың өрт қаупінің артуына әкелетіні дәлелденді. Жағдай әсіресе Чорнобыль апатымен ластанған аудандарда өте маңызды екені дәлелденді, онда ағаштары қураған үлкен аумақтарда орман өртінің апатты қаупі бар. Мақалада жер бетін қашықтықтан зондтаудың заманауи геоақпараттық жүйелері мен ғарыштық технологияларды қолдана отырып, экологиялық апаттар мен орман өрттерінің салдарын жоюды басқару мүмкіндіктері зерттеледі. Украинаның солтүстік облыстарының ландшафттарындағы өрттер мен басқа да төтенше жағдайлар кезіндегі әрекеттерді үйлестіру үшін орман өрттерін анықтау мен жою кезінде шешім қабылдауға арналған заманауи ақпараттық жүйені енгізу және орманды қорғау мен қауіпсіздіктің мамандандырылған орталығын құру ұсынылады. Ландшафты өрт қауіпсіздігін басқарудағы еуропалық тәжірибені зерделеу негізінде орман өртінің алдын алу мен жоюдың интеграцияланған жүйесін қолдану ұсынылады, ол өрт қаупі факторларын есептеуге негізделген. Қашықтықтан зондтау деректерін қолдана отырып, өрт қауіпті кезеңдерді анықтау әдісін әзірлеу кезінде желдің сипаттамасы мен антропогендік факторларды қосымша ескеру ұсынылды.

Түйінді сөздер: қатты биоотын, өңдеу технологиялары, экологиялық қауіптер, инженерлік және экологиялық критерийлер, технология.

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УПРАВЛЕНИЕ ПОЖАРНОЙ БЕЗОПАСНОСТЬЮ ЛАНДШАФТОВ: ОПЫТ УКРАИНЫ И ЕС

Аннотация. Управление безопасностью ландшафтов является важным инструментом европейского пространственного планирования. Целью работы является оценка эффективности управления рисками экологических катастроф и ликвидации последствий лесных пожаров с использованием современных геоинформационных систем и космических технологий дистанционного зондирования поверхности Земли. Тенденции пожарной опасности в прошлом были проанализированы путем обработки серии метеорологических показателей, обычно используемых для оценки потенциала пожара вследствие климатических условий. При этом использовали ГИС-инструментарий ArcGis компании ESRI. Обосновано, что изменение климата наряду с современной спецификой землепользования и лесохозяйственной деятельности приводит к увеличению пожарной опасности ландшафтов. Доказано, что ситуация особенно критическая на территориях, загрязненных в результате Чернобыльской аварии, где большие площади с мертвыми деревьями несут значительный риск катастрофических лесных пожаров. В статье исследуются возможности управления рисками экологических катастроф и ликвидации последствий лесных пожаров с использованием современных геоинформационных систем и космических технологий дистанционного зондирования поверхности Земли. Предлагается внедрить современную информационную систему для принятия решений при обнаружении и ликвидации лесных пожаров и создать специализированный Центр охраны и безопасности лесов для координации действий при пожарах и других чрезвычайных ситуациях на ландшафтах северных регионов Украины. На основе изучения европейского опыта управления ландшафтной пожарной безопасностью предлагается использовать комплексную систему предупреждения и ликвидации лесных пожаров, которая основана на расчете факторов пожарной опасности. При разработке метода определения пожароопасных периодов по данным дистанционного зондирования было предложено дополнительно учитывать ветровые характеристики и антропогенные факторы.

Ключевые слова: твердое биотопливо, технологии переработки, экологические опасности, инженерные и экологические критерии, технологии.

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Редакторы: *М.С. Ахметова, А. Ботанқызы, Д.С. Аленов, Р.Ж. Мрзабаева*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.12.2021.
Формат 60x881/8. Бумага офсетная. Печать – ризограф.
4,6 п.л. Тираж 300. Заказ 6.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19