



UDC 528.94

GEOINFORMATION WILDFIRE MAPPING OF UKRAINE: ANALYZING FIRMS DATA FOR EFFECTIVE FIRE MANAGEMENT

Olha TOMCHENKO¹, Dmytro LIASHENKO², Mariia YAKOVENKO^{2✉}, Iryna STAKHIV²

¹State Institution "Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine", Olesia Honchara St., 55-b, 01054 Kyiv, Ukraine

²Kyiv National University of Taras Shevchenko, Vasylykivska St., 90, 03022 Kyiv, Ukraine

Article History:

- received 12 April 2024
- accepted 09 September 2025

Abstract. Sustainable growth in Earth remote sensing data necessitates the advancement of interpretation methods to address a wide array of economic challenges. This research paper proposes the development of a methodology to automate the assessment of fire-affected areas using GIS software such as ArcGIS and QGIS. Data on fire localization from NASA/NOAA Suomi NPP and NOAA-20 and MODIS (M6) satellites, sourced from NASA's Fire Information for Resource Management System (FIRMS), as well as annual land use/land cover data from ESA WorldCover 2021, are utilized for this study. The series of maps obtained from the aggregation and generalization of fire distribution data for individual years across the administrative regions of Ukraine from 2021 to 2023 allows for the assessment of fire density, their correlation with different land cover types, and spatio-temporal changes. Graphs showing the distribution of fires based on land cover types in Ukraine for 2021–2023 have been generated. Additionally, the dynamics of fire occurrences in 2023 compared to 2022 are presented.

Keywords: land use, land cover (global land cover), maps, mapping, fires, remote sensing, algorithm, data aggregation, automation, GIS.

✉Corresponding author. E-mail: yakovenkomaria12@gmail.com

1. Introduction

Fires pose a significant global challenge, impacting nearly every inhabitant of our planet directly or indirectly. While each country implements its own mechanisms and tools to address this issue, the occurrence of fires remains a pressing concern worldwide. Forest fires are recognized as a major contributor to environmental degradation, with a noticeable increase in their frequency worldwide in recent years. Wildfire risk assessment and hazard mapping are critical to fire risk reduction, fire recovery, and effective wildfire management.

In environmental settings, fires induce landscape alterations, biodiversity loss, and the disruption of sustainable development, with approximately one in three fires transpiring in open spaces. Ukraine, like many other regions, is not immune to this phenomenon. The country's climate is undergoing rapid transformations, characterized by escalating temperatures, heatwaves, and prolonged dry spells, rendering vegetation highly susceptible to ignition and amplifying the occurrence of intense and uncontrollable fires. Among the array of natural and anthropogenic catastrophes, fires, including those of natural origin, stand out as recurrent occurrences.

Anthropogenic activities often serve as catalysts for fires, which, under certain conditions, escalate into large-scale conflagrations. Peculiar weather phenomena, such as prolonged droughts, soaring temperatures, and strong gusty winds, exacerbate the situation. Notably, research by Balabukh and Zibtsev (2016) investigated the influence of climatic factors on forest fire incidence and extent in the Northern Black Sea region of Ukraine, highlighting the predominant impact of air temperature on fire area compared to fire occurrence.

According to the State Statistics Service of Ukraine (2024), referencing data from the State Emergency Service of Ukraine, there were 1,278 forest fires in 2023. This number is 21.5% higher than in 2022 and 93.6% higher than in 2021. For comparison, there were 1,052 forest fires in 2022 and 660 in 2021. In 2023, the area of forest land affected by fires amounted to 51,000 hectares. This is 3.2 times more than in 2022 and 170 times more than in 2021. For comparison, in 2022, it was 15,800 hectares, and in 2021, it was 300 hectares.

In addition to forest fires, natural fire events encompass peat fires, steppe fires, and fires on agricultural land, each exhibiting distinct characteristics influenced by fire

conditions, vegetation types, and soil cover. Key natural factors, including topography, vegetation, and climatic conditions, collectively shape landscape structures and contribute to fire occurrence probabilities.

According to Serhii Zibtsev, director of the Regional Eastern European Fire Monitoring Center, Ukraine stands as a leader in agricultural land fires within Eastern Europe (Drozdova et al., 2021). Notably, research by Drozdova et al. (2021) identifies two peak periods for fire outbreaks: March–April and July–October. In spring, fires predominantly ignite in uncultivated areas rich in dry vegetation, occurring across most regions except the south. Conversely, during summer and autumn, fields become the focal point of fire occurrences. Furthermore, the authors emphasize the adverse consequences of field burning, including the degradation of black soil and the emission of health-hazardous dust and greenhouse gasses, notably carbon dioxide (CO₂). In recent years, the incidence of fires has surged, particularly in regions of eastern and southern Ukraine, largely attributed to the ongoing Russian armed aggression against the country (Tomchenko et al., 2023; Yakovenko et al., 2023).

The effectiveness of Earth remote sensing methods for fire detection has been significantly enhanced through various studies, including those by Sevruk et al. (2021), Matsala et al. (2024), Tian et al. (2013), and Giglio et al. (2016).

A scientific team (Tian et al., 2013) conducted an analysis of fire distribution characteristics in China from 2008 to 2012, utilizing Aqua, Terra, NOAA-12 satellite data, and statistical data. Their findings revealed that agricultural burning primarily caused local fires, while large-scale fires were prevalent in regions with large forest areas in north-east and southwest China.

Giglio et al. (2016) focused on global fire data from the Terra MODIS satellite, proposing an enhanced MODIS Collection 6 (C6) fire detection algorithm. This algorithm classified each MODIS band pixel into categories such as missing data, cloudy, missing fire, fire, and unknown. By comparing Collection 5 and Collection 6 Terra MODIS products using fire control maps derived from 2,500 high-resolution ASTER images, they demonstrated the superiority of Collection 6. Notably, Collection 6 exhibited a reduction in omission errors for identifying large fires and a decrease in false alarms in tropical ecosystems. The MOD14 Collection 6 commission measurement error was significantly lower at 1.2%, compared to 2.4% in Collection 5.

A statistical model of the risk of forest fires was developed using GIS in the work by Eugenio et al. (2016). The model included two classes of data: physical site factors and climatic factors.

In Çolak and Sunar (2020), the authors showed the effectiveness and veracity of using NASA FIRMS data on active fires by comparing it with actual fire information provided by the Turkish General Directorate of Forestry. Thus, 72% and 50% of NASA FIRMS data on active fires were confirmed in Menderes and Marmaris regions, respectively. The authors also emphasized the importance

of using crowdsourced data. Since social media data easily transmits and collects information on natural disaster risk assessment, incorporating social media data into wildfire risk assessment helps to manage wildfires in a timely and effective manner.

Giglio et al. (2006) analyzed the global distribution of fire activity over a period of 5 years using Terra MODIS CMG data. It was found out that the peak values of fires are observed in July, August, and September. The duration of the annual fire season ranges from 2 to 6 months. The authors also examined fire radiative power (FRP) and found that low FRP was observed in arable land in boreal areas, as well as in forests in the tropics and most of the subtropics. The high radiation power of fires was recorded in areas with grassy vegetation. In the boreal regions, this trend was the opposite: high PVP values were observed in areas covered by forests, and low PVP values were observed in areas with grassy vegetation.

Important research results were obtained by Osadchyi et al. (2023), after conducting satellite monitoring of fires in Ukraine. They found out that most heat emissions recorded by satellite observations are caused by agricultural production, fires in forest areas and meadows, and to a lesser extent by industrial enterprises or “recreational” human activities. Heat emissions are recorded both in forested areas and fields. This means that the factors that lead to the occurrence and spread of fires are primarily anthropogenic, not natural. The time of appearance of thermal anomalies and fires has a clearly defined seasonal nature and depends on the level of fire danger, which is determined by temperature and amount of precipitation, the schedule of seasonal works (waste burning in spring, late summer and autumn), as well as on the activation of human activity (outdoor recreation) on warm days, illegal logging, etc.

The authors (Kelm, 2023) used data from Fire Information for Resource Management System (FIRMS) to compare the number of fires in the fields in Ukraine for two periods: March–April 2021 and March–April 2023 and concluded that the number of fires in Ukraine has decreased. However, fires can also occur because of hostilities, such results are given in works by Ordway (2015), Shevchuk et al. (2022), Witmer (2015), and Garzón and Valánszki (2020). The work by Oreshchenko (2022) identifies key criteria for recognizing fires caused by military actions, particularly those resulting from missile strikes. These fires can emerge suddenly and may affect large areas, often leading to multiple ignition points. have irregular fire contours, and cover the territory with different types of land use.

In contrast to the ones discussed above, the presented work introduces a semi-automated algorithm aimed at evaluating the dynamics of fire spread, with a unique focus on considering the underlying surface type. This approach involves categorizing ignition centers into different land cover classes, enabling concurrent analysis of vulnerabilities and losses across forested, agricultural, and anthropogenic landscapes and resources.

The objective of this study is to analyze fires in Ukraine, including their frequency, localization, and distribution relative to various surface types such as rural fields, grasslands, forests, and populated areas. Additionally, the research aims to assess changes in environmental conditions over the period spanning from 2021 to 2023 using map series.

2. Method

Ukraine is a European country bordering Romania and Moldova in the southwest, Hungary, Slovakia, and Poland in the west, Belarus in the north, and Russia in the east and northeast. It is bordered to the south by the Black Sea and the Sea of Azov. The area is 603,700 km². It is the largest country in terms of area among those located entirely in Europe (Figure 1). Ukraine occupies one of the first places in the world considering the area of agricultural lands which occupy 70% of the area of the territory of Ukraine (42 million hectares). Forest coverage of the country is 15.9%. The research area covered the entire territory of Ukraine and involved a comparison of the number of fires in each of the 25 administrative units (24 regions and the Autonomous Republic of Crimea).

One of the research methods involved the collection and analysis of data related to fires in Ukraine from 2021 to 2023. Original data on the location of fires from January 2021 to December 2023 was obtained from the FIRMS archive (Figure 2). In Figure 2, the stages of the research are presented, specifically the upper block combines three types of input data. ESA WorldCover 2021 (<https://worldcover2021.esa.int/>) is a classification map of land cover (Earth's surface) as of 2021, created by the European Space Agency with a spatial resolution of 10 meters, resulting from the processing of radar and optical images from Sentinel-1 and Sentinel-2, divided into 11 classes of land cover

(tree cover, shrubland, grassland, cropland, built-up, bare/sparse vegetation, snow and ice, permanent water bodies, herbaceous wetland, mangroves, moss and lichen). Additionally, land cover information was sourced from the ESA WorldCover 2021 dataset, which is based on data from Sentinel-1 and Sentinel-2 satellites and provides a global overview of annual land use and land cover. For further detailed study of fire distribution in Ukraine, the dominant land cover classes were selected, namely tree cover, grassland, cropland, built-up areas, and wetland.

The administrative boundaries of European countries in Figure 1 are presented based on materials from Wikimedia Commons. Administrative boundary polygons for Ukraine were acquired from the Humanitarian Data Exchange managed by the UN Office for the Coordination of Humanitarian Affairs (Humanitarian Data Exchange, 2021), allowing for the identification of fire incidents within specific regions of the country. And directly the data on fire hotspots based on satellite data. The Fire Information System for Resource Management (FIRMS) disseminates near-real-time (NRT) active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua and Terra satellites and the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard S-NPP and NOAA 20 (officially known as JPSS-1). The Fire Information for Resource Management System (FIRMS) distributes Near Real-Time (NRT) active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua and Terra satellites, and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard S-NPP and NOAA 20 (formally known as JPSS-1) (<https://firms.modaps.eosdis.nasa.gov/>). Data are available from the following periods of MODIS Collection 6.1: Temporal Coverage: 11 November 2000 – present, VIIRS S-NPP 375 m: Temporal Coverage: 20 January 2012 – present, VIIRS NOAA-20 375 m: Temporal Coverage: 1 January 2020 – present. The Visible Infrared

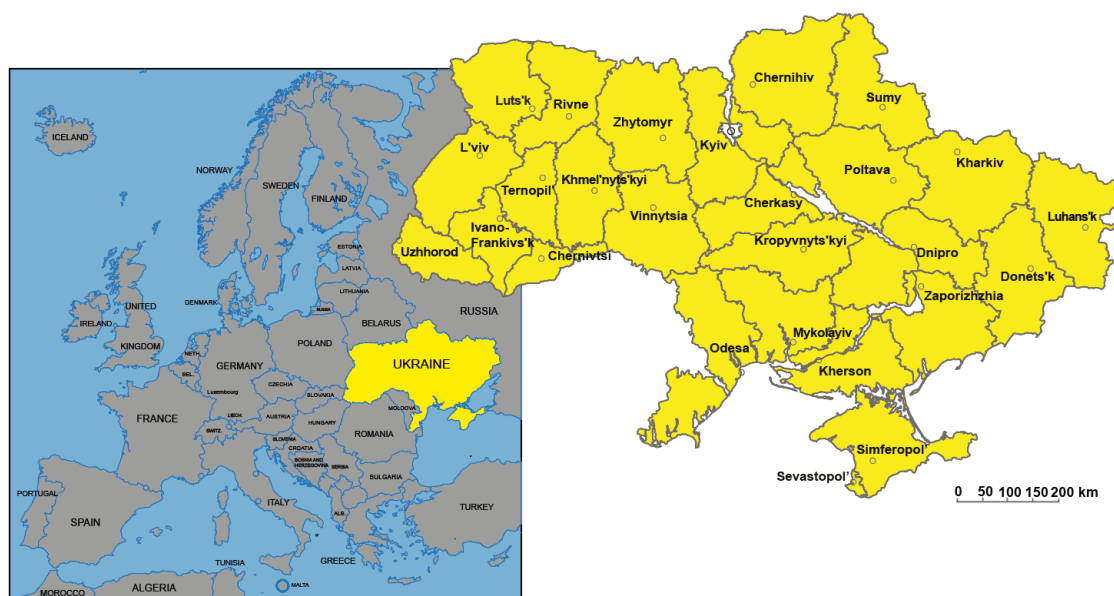


Figure 1. Overview map of the research area location

Imaging Radiometer Suite, utilizing data from the Suomi NPP and NOAA-20 satellites, was chosen as the source for fire detection.

The second block in Figure 2 illustrates the processing and interpretation of input data, specifically the division of ESA WorldCover 2021 data and FIRMS materials into 25 separate fragments to summarize the number of fires by land cover types in each of Ukraine's administrative units. The resulting block displays the final database, which served as the foundation for GIS modeling and the cartographic representation of the obtained results (fire density maps) and statistical analysis, including the construction of histograms and graphs depicting the number of fires by land cover types over the years and across administrative regions.

The intermediate data were processed using ArcGIS software, which included a shapefile of fire points, raster data representing land use, and a shapefile of administrative division polygons. The procedure consists of two models based on the ModelBuilder utility in ArcGIS. The resulting output extends the FIRMS data set with an identifier of the land use class and attributes of a region of Ukraine to which the fire point belongs. The workflow of Model 1 based on the ModelBuilder utility is described in Figure 3. Model 1 enhances the FIRMS dataset by adding land cover classifications to the fire points using the "Extract Values to Points" tool. Here's a clearer breakdown of the process: data extraction; selection of points; filtering out undefined points; output. This process results in a more informative dataset that links fire occurrences to

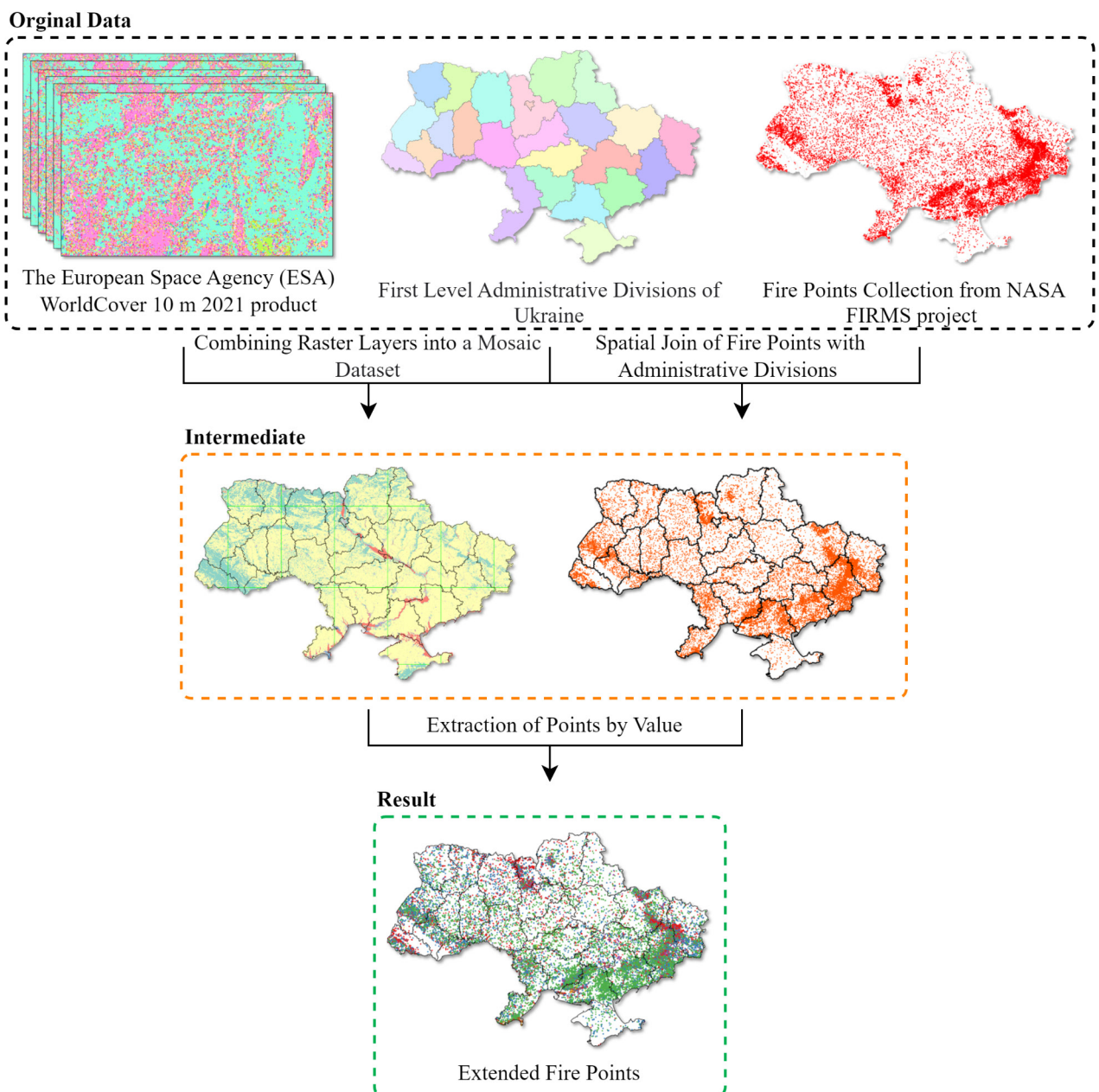


Figure 2. Research flowchart on the fire distribution on the territory of Ukraine

specific land cover types, facilitating better analysis and understanding of fire impacts in different environments.

Model 2 implements a complete algorithm of extension of the FIRMS data set with additional attributes (Figure 4). Model 1 runs as a smaller part of a larger process to update the fire data table by adding information from each land cover layer one at a time. After processing all

the layers, it combines the results into a single table. At this stage, the fire data is now enriched with land cover information. Finally, Model 2 adds details about each administrative region in Ukraine, including the name and area, to complete the dataset. The obtained final shape file is then available for analysis with both ArcGIS tools and external utilities.

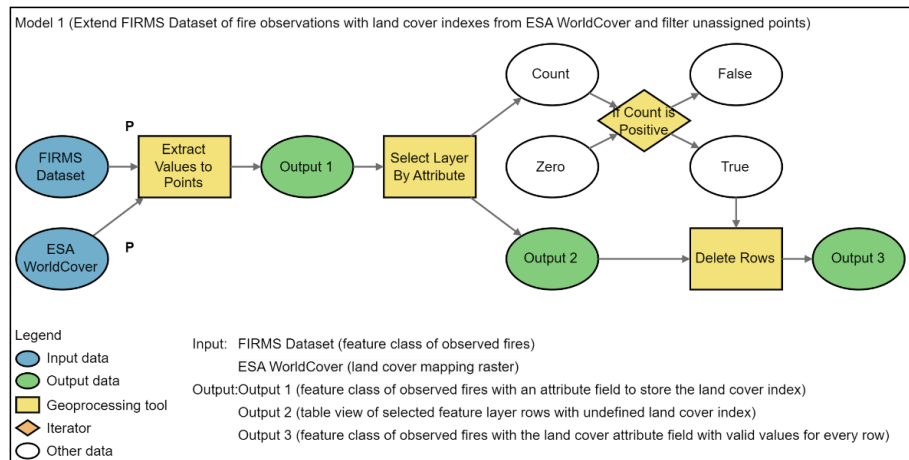


Figure 3. Workflow of Model 1

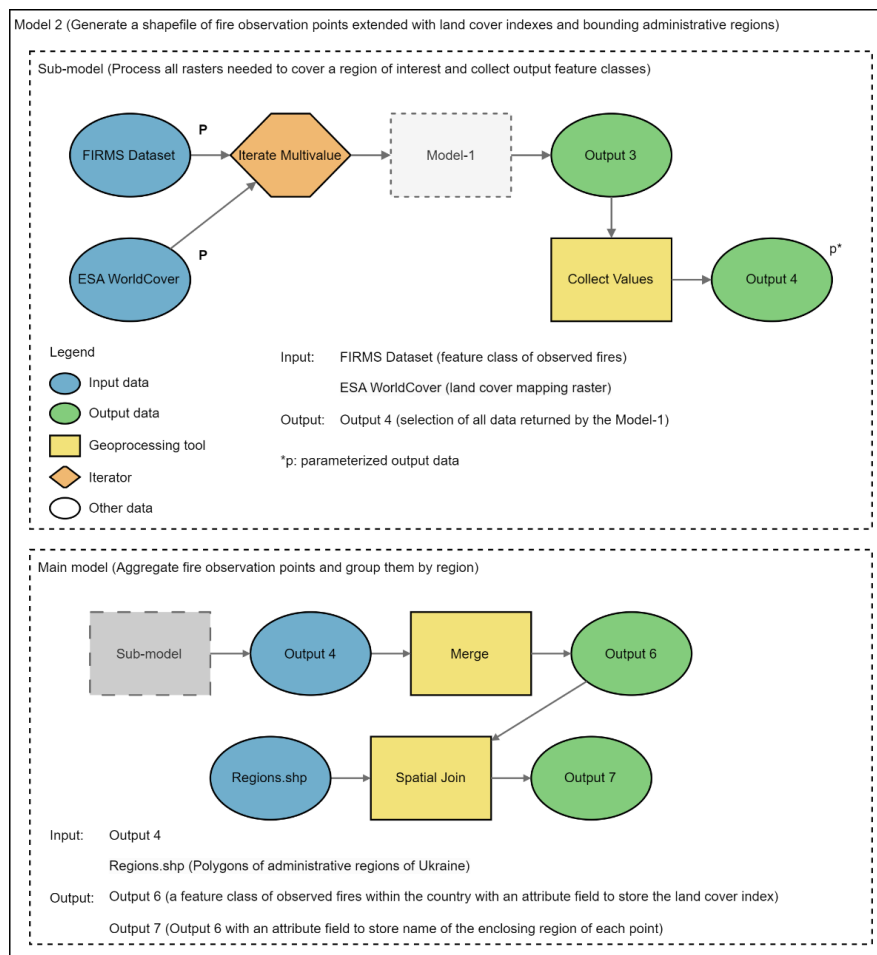


Figure 4. Workflow of Model 2

3. The results and discussion

After downloading the available data on active fires in the territory of Ukraine from all three types of satellites, it was found out that despite different settings of sensors and differences in equipment, the same trend of the overall dynamics of the number of fires is preserved when converting their intensity into percentage values (Figure 5).

According to MODIS data, the longest schedule of the dynamics of the number of fires in Ukraine was constructed from 2003–2023. The maximum number of fires was recorded in 2008, 2014, 2015, 2020, the main reason being climatic conditions. Minimum indicators are observed in 2003, 2013, 2021 and 2023.

However, the years 2021 to 2023 were chosen for a detailed study of the distribution of fires by administrative regions of Ukraine and land cover types. This period was selected for several reasons. The developed methodology for analyzing fire distribution can be effectively tested using data from these three recent years. By focusing on the 2021–2023 period, the study will provide insights into the most current patterns and trends in fire occurrence across Ukraine. In 2022, a large-scale Russian military invasion of Ukraine took place. Examining fire data during this period is crucial for understanding the potential impact of the war on fire distribution and frequency.

By concentrating on these three years, the research will offer a comprehensive and up-to-date analysis of fire patterns in Ukraine, taking into account both methodological considerations and the significant geopolitical events that

occurred during this time frame. The findings are shedding light on the current state of fire distribution and help inform future prevention and mitigation strategies.

An important result was the comparison of fire frequency over the years (2021, 2022, 2023). Figure 6 shows the general distribution of fires depending on the type of land cover surface in Ukraine for 2021–2023. The largest number of fires occurred on agricultural land in 2023 (49%) and 2021 (46%). The maximum number of fires on land covered by buildings was observed in 2021 – 29%, in 2022 and 2023 the number of fires decreased by 2.6 and 2 times, respectively. An increase in the number of fires on lands covered with grassy vegetation is observed in 2022 and 2023 by 2 and 1.7 times, compared to 2021. The number of fires in wetlands in 2021–2023 is unchanged and remains within 2–4%, respectively. On lands covered with forests, the distribution of fires changed as follows: the maximum number of fires was observed in 2022 (22%), in 2021 and 2023 there was a decline of 2 and 1.7 times, respectively.

Noteworthy is the leading analysis of fire occurrence frequency in different regions of Ukraine and the identification of peak periods of fire activity. Figure 7 shows the distribution of the number of fire densities per 1 square kilometer by land cover surface types by regions and months for the period 2021–2023. The maximum values of the distribution of the fire number densities are highlighted in red. According to this distribution, the maximum number of fires on forest land in 2021 was recorded in Kyiv region in March, August, and October; in Donetsk

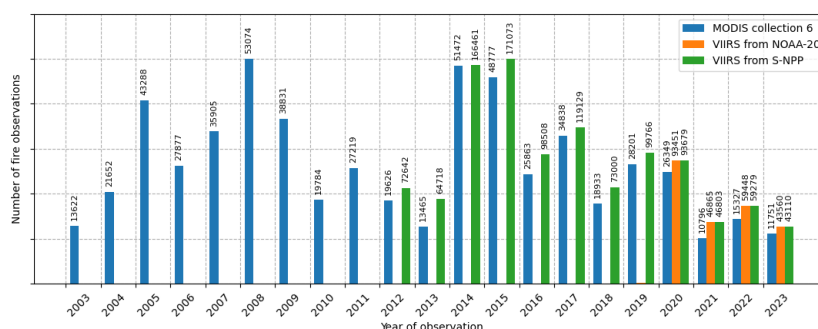


Figure 5. Dynamics of the fires number in Ukraine from 2003 to 2023 according to data from MODIS Collection 6, VIIRS 375 m from S-NPP, VIIRS 375 m from NOAA-20 (JPSS-1)

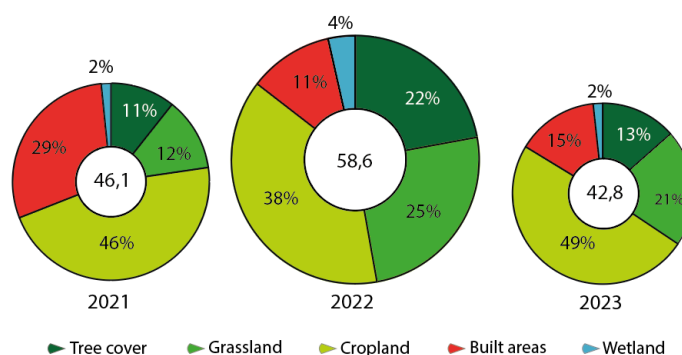


Figure 6. General distribution of fires depending on the type of land cover surface in Ukraine for 2021–2023

region from July to October, and in 2022–2023 – in Kyiv, Donetsk, Luhansk and Kharkiv regions in May, June, July, and August. The maximum values of the distribution of the number of fire densities in 2021–2022 were observed on lands covered with a grassy plant complex in the Kyiv region in the spring months and October, in the Donetsk and Luhansk regions in August and October. In 2023 the situation changed somewhat – fires seized several more regions: among which Kyiv, Kherson, Donetsk, and Luhansk were dominant, the main months being August, September, October and March.

Agricultural lands have been the most affected by fires due to several factors: in areas where the Line of Combat occurs, agricultural lands dominate the structure of land use; there is a high concentration of dry plant residues, stubble, and cut grass that easily ignite under high temperatures; and agricultural fields often have large open spaces that facilitate the rapid spread of fire. Agricultural lands were the most disturbed by fires among the four types of surface land cover, in almost all regions from July to October. As for the situation on land covered by buildings, the maximum values of the distribution of the number of fire densities were recorded in 2021 in Donetsk, Zaporizhia and Kyiv regions during the year. In 2022 the

number of fires drastically decreased, and in 2023 – slightly increased in Donetsk, Luhansk, Zaporizhia and Kyiv region, in the period from May to October.

The analysis of the data array on the spatial location of fire outbreaks indicates their significant density on the territory of Ukraine. An attempt to display all fires at once on the map of Ukraine cannot be considered successful. Only when the scale is increased, the territorial distribution of fire foci by types of land begins to be well displayed. The analysis of the fire data array requires building queries to the geodatabase (by types of underlying surface (trees, grass, fields, buildings, liquid vegetation, water surfaces, marshes), by time intervals (year, month, week), territorial coverage (region, district, community, regular grids).

As a result of such requests, maps were created and analyzed. The figures below (Figures 8–10) show the territorial distribution of fires generalized within administrative regions in 2021–2023.

Hot fire spots are typically found in the eastern region, where the Line of Combat is active and shelling occurs. Map analysis indicates a significant increase in the fire density in 2022 and the movement of the largest number of fire centers to the Donetsk, Zaporizhzhia, and Kherson regions. In the fires structure a significant share of built-up

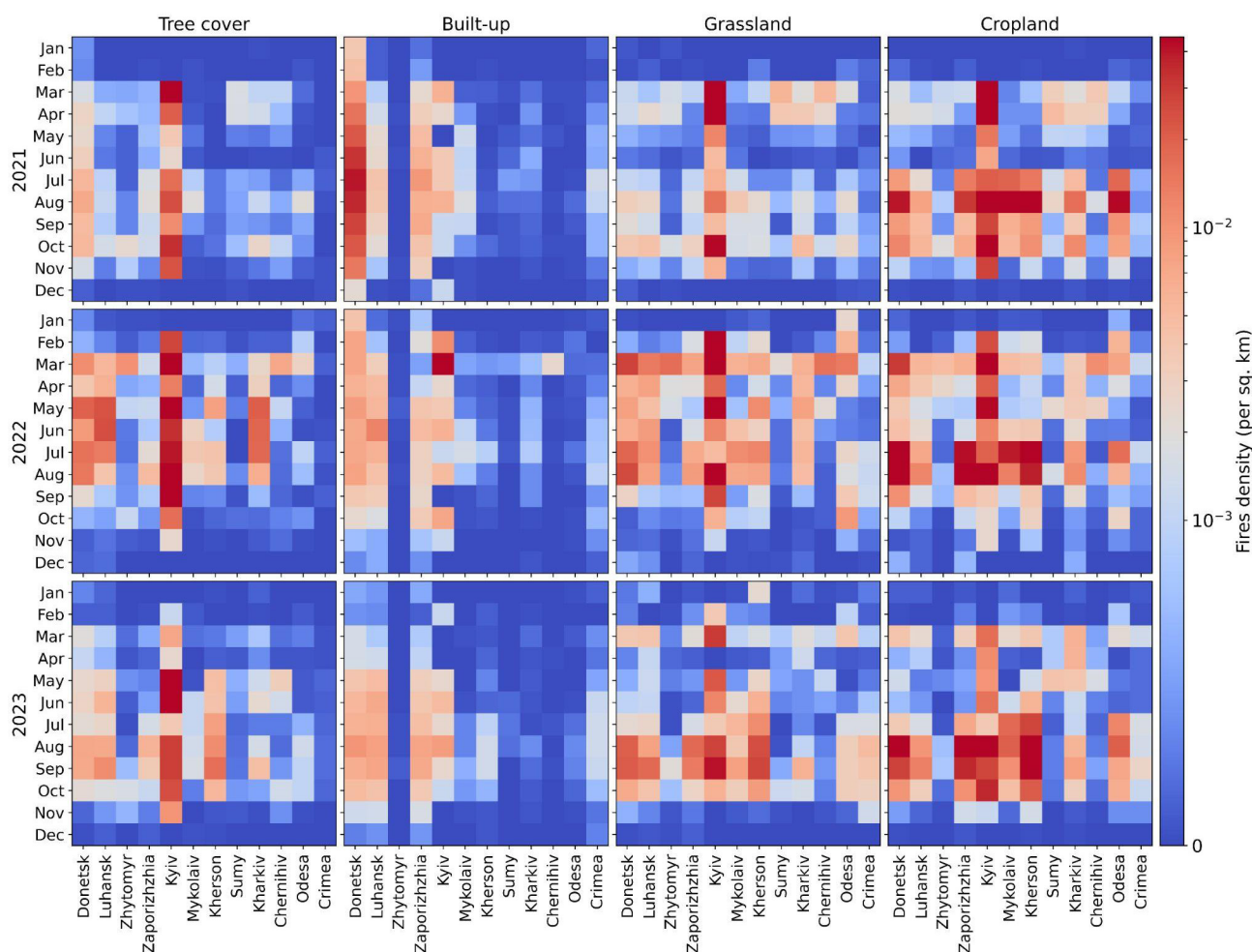


Figure 7. Distribution of the fire density on the territory of Ukraine per 1 sq. km by land cover surface types by regions and months

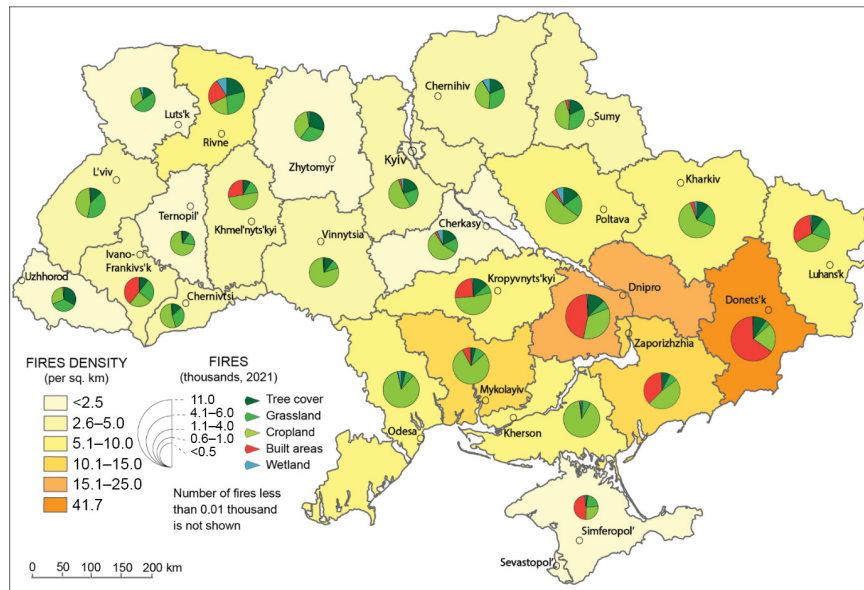


Figure 8. Fires distribution on the territory of Ukraine according to FIRMS data, for 2021

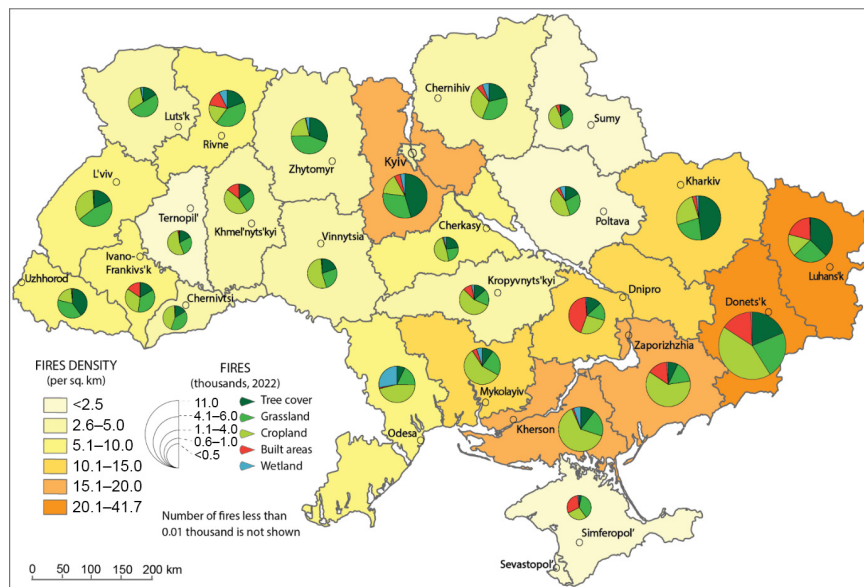


Figure 9. Fires distribution on the territory of Ukraine according to FIRMS data, for 2022

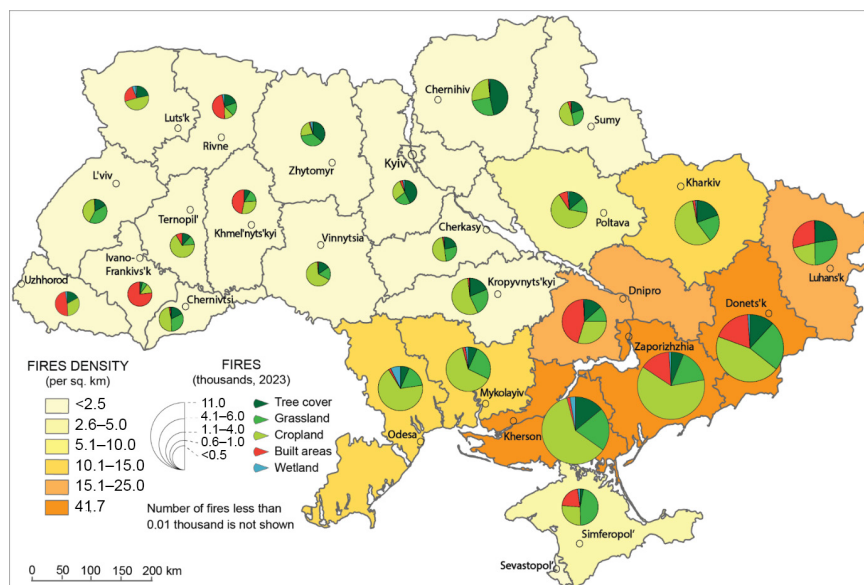


Figure 10. Fires distribution on the territory of Ukraine according to FIRMS data, for 2023

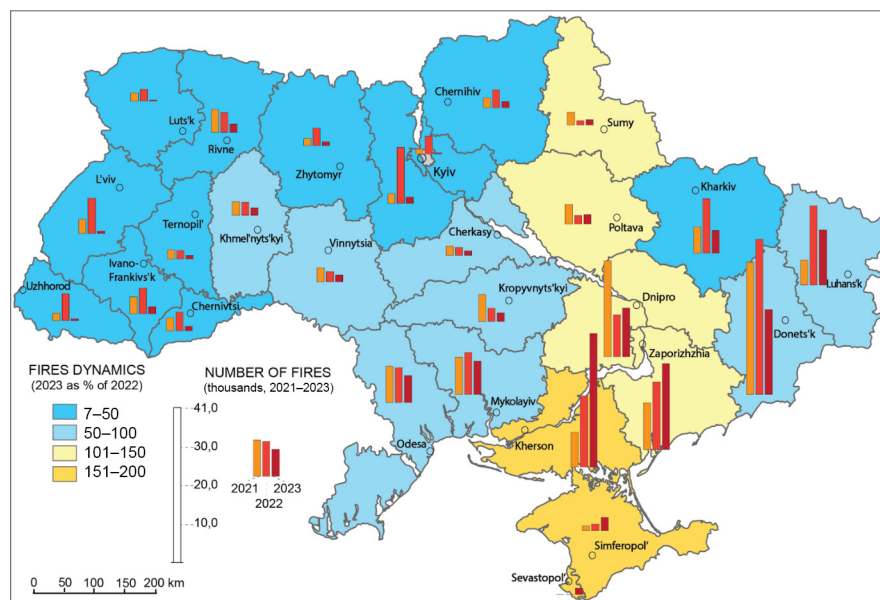


Figure 11. Dynamics of the number of fires in 2023 compared to 2022

land in the regions through which the front-line passes are clearly visible.

The dynamics of the fires number for 2022–2023 (Figure 11) reflects a rather interesting picture: in some regions the fires number has decreased, but in areas where active hostilities are taking place, the fires number is increasing. Also, the fire number in the Autonomous Republic of Crimea increased due to shelling of military facilities by the occupation army of the Russian Federation.

The map uses blue shades to represent areas with a decrease in the number of fires and warm shades for those with an increase. The use of bar charts allowed for the demonstration of peaks in the detected number of fires in 2022 in Kyiv, Kyiv, Chernihiv, Kharkiv, Donetsk, and Luhansk regions, which may be related to the high intensity of combat activities during that period. In contrast, in 2023, military actions in southern Ukraine manifested as an increase in the number of fires in Zaporizhzhia, Kherson regions, and the Autonomous Republic of Crimea and the city of Sevastopol.

Data on fires in Ukraine for the period 2021–2023 obtained from FIRMS and their cartographic modeling indicate significant changes in the intensity and distribution of fires, which can be compared to the results of previous studies. The data show that the frequency of fire occurrences in 2022, especially during the summer, was significantly higher compared to 2021. This aligns with studies indicating that extreme weather conditions, such as high temperatures and droughts, contribute to an increased risk of fires (Jain et al., 2022). It is important to note that military actions on Ukrainian territory in 2022 may have also influenced the increase in fire frequency due to explosions from munitions, particularly in eastern and southern regions. The reduction in the number of fires in 2023 may have occurred due to a higher-than-usual level of soil moisture during

the summer across Ukraine (Toreti et al., 2023) and a decrease in forest visitation by the population due to displacement beyond Ukraine's borders as a result of military actions.

The obtained results demonstrate clear seasonal fluctuations in fire occurrences, with peaks during the summer months. This is consistent with previous studies indicating that most fires occur under conditions of high temperatures and low humidity (Pausas & Keeley, 2021). It is crucial to consider these seasonal characteristics when planning fire prevention measures in Ukraine.

4. Conclusions

The use of remote sensing data from satellites capable of detecting infrared radiation from fires significantly simplifies the process of assessing the scale and dynamics of fires. Currently, there are several satellites with varying resolutions, in addition to those used in this article, that capture thermal anomalies. These can be widely applied for various types of fire monitoring. Open access to these images enables operational monitoring of forest and other areas worldwide at a lower cost compared to patrolling and expedition detection methods.

The research has allowed for a better interpretation of FIRMS data through the application of geoinformation modeling. The resulting maps provide a visual representation of fire distribution across the administrative regions of Ukraine and land cover types. This offers valuable information for understanding current trends in fire occurrences in Ukraine. Comparing this data with previous studies enables a more accurate assessment of the impact of anthropogenic factors (particularly combat activities) on fire dynamics and emphasizes the need for developing effective fire suppression strategies and addressing their consequences.

The applied geoinformation modeling methodology has broad prospects for further use. The experience of comprehensive analysis, during which it was possible to integrate fire data with land use data, is considered successful. The proposed methodology can be applied to study fires in Ukraine over longer periods, such as the last 10 years. This will help identify long-term trends, cyclicity in fire occurrences, and the contribution of combat activities, which is important for forecasting and planning response measures. The developed approach can be adapted for analyzing fires in other countries, especially those with similar climatic conditions and landscapes. This will allow for the identification of new patterns and factors influencing the occurrence and spread of fires. Unfortunately, the accumulated data and identified patterns can only be used to develop predictive models on a limited scale, as the intensity and duration of the current armed conflict in the war between Ukraine and Russia cannot be predicted.

References

- Balabukh, V. O., & Zibtsev, S. V. (2016). Impact of climate change on quantity and area of forest fires in the northern part of the Black Sea Region of Ukraine. *Ukrainian Hydrometeorological Journal*, (18), 60–71. <https://doi.org/10.31481/uhmj.18.2016.07>
- Çolak, E., & Sunar, F. (2020). The importance of ground-truth and crowdsourcing data for the statistical and spatial analyses of the NASA FIRMS active fires in the Mediterranean Turkish forests. *Remote Sensing Applications: Society and Environment*, 19, Article 100327. <https://doi.org/10.1016/j.rsase.2020.100327>
- Drozdova, Y., Harasym, A., Bondarenko, A., & Kelm, N., (2021). *In Ukraine, there are about 20,000 fires on arable land yearly.* <https://texty.org.ua/projects/105282/ukraine-there-are-about-20000-fires-arable-land-yearly/>
- Eugenio, F. C., dos Santos, A. R., Fiedler, N. C., Ribeiro, G. A., da Silva, A. G., dos Santos, Á. B., Paneto, G. G., & Schettino, V. R. (2016). Applying GIS to develop a model for forest fire risk: A case study in Espirito Santo, Brazil. *Journal of Environmental Management*, 173, 65–71. <https://doi.org/10.1016/j.jenvman.2016.02.021>
- Garzón, F. A. M., & Valánszki, I. (2020). Environmental armed conflict assessment using satellite imagery. *Journal of Environmental Geography*, 13(3–4) 1–14. <https://doi.org/10.2478/jengeo-2020-0007>
- Giglio, L., Csiszar, I., & Justice, C. O. (2006). Global distribution and seasonality of active fires as observed with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. *Journal of Geophysical Research*, 111, Article G02016. <https://doi.org/10.1029/2005JG000142>
- Giglio, L., Schroeder, W., & Justice, C. O. (2016). The collection 6 MODIS active fire detection algorithm and fire products. *Remote Sensing of Environment*, 178, 31–41. <https://doi.org/10.1016/j.rse.2016.02.054>
- Humanitarian Data Exchange. (2021). *Ukraine – subnational administrative boundaries.* <https://data.humdata.org/dataset/cod-ab-ukr>
- Jain, P., Castellanos-Acuna, D., Coogan, S. C., Abatzoglou, J. T., & Flannigan, M. D. (2022). Observed increases in extreme fire weather driven by atmospheric humidity and temperature. *Nature Climate Change*, 12(1), 63–70. <https://doi.org/10.1038/s41558-021-01224-1>
- Kelm, N. (2023). *There have been many times less fires in the fields in Ukraine.* <https://texty.org.ua/fragments/109429/v-ukrayini-stalo-v-razy-menshe-pozhezh-na-polyah/>
- Matsala, M., Odruzhenko, A., Hinchuk, T., Drobyshev, I., Sydorenko, S., Zibtsev, S., Milakovsky, B., Schepaschenko, D., Kraxner, F., & Bilous, A. (2024). War drives forest fire risks and highlights the need for more ecologically-sound forest management in post-war Ukraine. *Scientific Reports*, 14, Article 4131. <https://doi.org/10.1038/s41598-024-54811-5>
- Ordway, E. M. (2015). Political shifts and changing forests: Effects of armed conflict on forest conservation in Rwanda. *Global Ecology and Conservation*, 3, 448–460. <https://doi.org/10.1016/j.gecco.2015.01.013>
- Oreshchenko, A. (2022, November 15–18). Monitoring of wildfires caused by hostilities using satellite thermal sensors. In *XVI International Scientific Conference “Monitoring of Geological Processes and Ecological Condition of the Environment”* (Vol. 2022, pp. 1–5), Kyiv, Ukraine. <https://doi.org/10.3997/2214-4609.2022580171>
- Osadchyi, V. I., Oreshchenko, A. V., & Savenets, M. V. (2023). *Satellite monitoring of fires and air pollution.* Ukrainian Hydrometeorological Institute. https://doi.org/10.15407/uhmi.2023_1
- Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment*, 19(7), 387–395. <https://doi.org/10.1002/fee.2359>
- Sevruck, A., Babi, L., Babushka, A., & Chetverikov, B. (2021, October). Study of forest fires according to remote sensing data (on the example of the Chornobyl exclusion zone). In *International Conference of Young Professionals “GeoTerrace-2021”* (Vol. 2021, pp. 1–5). European Association of Geoscientists & Engineers. <https://doi.org/10.3997/2214-4609.20215K3010>
- Shevchuk, S. A., Vyshnevskiy, V. I., & Bilous, O. P. (2022). The use of remote sensing data for investigation of environmental consequences of Russia-Ukraine war. *Journal of Landscape Ecology*, 15(3), 36–53. <https://doi.org/10.2478/jlecol-2022-0017>
- Tian, X., Zhao, F., Shu, L., & Wang, M. (2013). Distribution characteristics and the influence factors of forest fires in China. *Forest Ecology and Management*, 310, 460–467. <https://doi.org/10.1016/j.foreco.2013.08.025>
- Tomchenko, O. V., Khyzhniak, A. V., Sheviakina, N. A., Zagorodnia, S. A., Yelistratova, L. A., Yakovenko, M. I., & Stakhiv, I. R. (2023). Assessment and monitoring of fires caused by the War in Ukraine on Landscape scale. *Journal of Landscape Ecology*, 16(2), 76–97. <https://doi.org/10.2478/jlecol-2023-0011>
- Toreti, A., Bavera, D., Acosta Navarro, J., Cammalleri, C., de Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magini, D., Masante, D., Mazzeschi, M., Niemeyer, S., & Spinoni, J. (2023). *Drought in Europe August 2023.* Publications Office of the European Union.
- Witmer, F. D. W. (2015). Remote sensing of violent conflict: Eyes from above. *International Journal of Remote Sensing*, 36(9), 2326–2352. <https://doi.org/10.1080/01431161.2015.1035412>
- Yakovenko, M., Tomchenko, O., Stakhiv, I., & Liaschenko, D. (2023, October 4–6). Assessment of the quality loss, damage of forestry lands affected by military operations in 2021–2023. In *International Conference of Young Professionals “GeoTerrace-2023”* (Vol. 2023, pp. 1–5). European Association of Geoscientists & Engineers. <https://doi.org/10.3997/2214-4609.2023510041>