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FOREST FIRE DATABASE ON THE TERRITORY OF BULGARIA FOR THE PERIOD 2020–2024 BASED ON SATELLITE DATA

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Abstract

This study presents the development and analysis of a geospatial database of forest fire events across the territory of Bulgaria for the period 2020–2024. The database was compiled from satellite-derived active fire detections, incorporating geographic coordinates, acquisition date and time, signal intensity, and satellite platform of origin (Terra or Aqua). Organised in shapefile format, it enables direct integration into Geographic Information Systems (GIS) for spatial analysis, visualisation, and correlation with other geospatial datasets. The results include both spatial and temporal assessments, with statistical summaries revealing interannual variability and a notable increase in recorded events in 2024. Kernel Density estimation was applied to identify high-density clusters of fire occurrences, providing insights into spatial patterns and potential hotspots. The dataset offers a robust foundation for risk assessment, supports targeted forest fire prevention and mitigation strategies, and contributes to data-driven decision-making for sustainable forest management in Bulgaria.

Introduction

Forest fires represent a significant global challenge with profound implications for the sustainable management of forest resources. This issue is of particular relevance to Bulgaria, where approximately one-third of the national territory is covered by forests, making the integrity of forest ecosystems a matter of strategic environmental concern.

In recent years, the wildfire situation in Bulgaria has become increasingly severe, particularly during the summer months of July and August. A substantial portion of these fires occur in agricultural landscapes and are often caused by the accidental or deliberate burning of stubble. Such practices are a major driver of forest fires, accounting for an estimated 40% to 60% of cases and frequently leading to the spread of fire into adjacent areas, including pastures, meadows, firebreaks, and field margins. Beyond vegetation loss, these fires often result in the destruction of entire habitats and their associated biodiversity, many of which fall within the Natura 2000 ecological network [1].

Over the past 15 years (2010–2024), more than 7,000 forest fires have been recorded in Bulgaria, according to data from the Executive Forest Agency and the Ministry of Interior [2], covering over 110,000 ha (over 1.1 million decares) of territory. The year 2024 marked a particularly critical point, with Bulgaria ranking second among European countries in terms of the number of forest fires, with the regions of the Rhodopes, Strandzha, Pirin, and Sakar being among the most severely affected. These incidents are not only increasing in frequency and intensity, but the ecological damage they cause is becoming more severe and widespread, posing a growing threat to biodiversity and forest sustainability at the national and European level.

Given the increasing frequency and severity of forest fires, there is a growing need for accurate, timely, and spatially comprehensive monitoring tools. Aerospace remote sensing methods represent an advanced technological approach for monitoring natural disasters [3–7], including forest fires [8, 9]. These methods provide the foundation for building a reliable and large-scale forest fire database, which supports the effective tracking of post-fire recovery processes in forest ecosystems [10].

Several studies have demonstrated the effectiveness of satellite-based approaches in compiling large-scale forest fire datasets, such as the MODIS burned area product [11] and the Landsat-derived global burn severity dataset [12], which have significantly contributed to fire monitoring and post-fire assessment at regional and global scales. While global forest fire datasets based on MODIS [11] and Landsat imagery [12] provide valuable insights, there remains a need for high-resolution, country-specific databases that reflect local fire dynamics and landscape characteristics.

In response to this need, the present research aimed to develop a comprehensive forest fire database for the territory of Bulgaria, covering a five-year period from 2020 to 2024. The database is based on satellite data and is intended to serve as a reliable tool for analysing fire dynamics, identifying high-risk areas, and supporting forest management and conservation efforts. Its development contributes to the implementation of data-driven strategies for mitigating the impact of forest fires and enhancing the resilience of forest ecosystems in Bulgaria.

Data and methods

For the purpose of developing the database, the following steps were undertaken: thermal anomaly data were selected for the entire territory of Bulgaria over a five-year period; areas covered by forest vegetation were filtered in order to exclude agricultural and grassland fires from the dataset; and all thermal anomalies were systematically verified (Fig. 1).

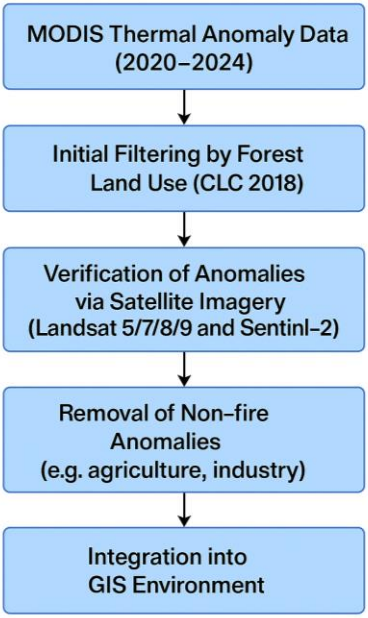

Fig. 1. Workflow diagram of the methodological framework for Forest Fire Database development (2020–2024)

Thermal anomaly data selection

Thermal anomaly data were selected for the entire territory of Bulgaria over a five-year period (2020–2024). For this purpose, data were extracted from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor [13], mounted on the Terra and Aqua satellites, which provide regular observations with moderate spatial resolution and a broad spectral range. These characteristics make MODIS highly suitable for the detection and monitoring of thermal anomalies associated with forest and field fires.

In the first stage of database development, thermal anomalies were retrieved from the official archive of NASA's Fire Information for Resource Management System (FIRMS) [14], which offers access to pre-processed, geospatially referenced fire hotspots detected by MODIS. FIRMS automatically aggregates, filters, and publishes high-temporal-resolution data, enabling near real-time fire activity monitoring with high detection reliability.

The extracted data were structured and adapted to meet the requirements of the forest fire database being developed for the territory of Bulgaria for the period 2020–2024. Key attributes included the geographic coordinates of the thermal anomaly, date and time of detection, signal intensity, and the satellite platform of origin (Terra or Aqua). The downloaded data were integrated into a Geographic Information System (GIS) environment for further processing and analysis.

Filtering the forest vegetation

Areas covered by forest vegetation were filtered in order to exclude agricultural and grassland fires from the database. To further refine the dataset and eliminate irrelevant thermal anomalies such as those caused by field fires or industrial heat sources, the Corine Land Cover 2018 (CLC 2018) classification [15] was applied. CLC 2018 is a homogeneous pan-European land cover database developed under a unified methodology by the European Environment Agency (EEA). The classification includes more than 40 land cover categories and provides a reliable geospatial framework for ecological and territorial analysis at both national and regional levels.

At the time of the analysis, CLC 2018 represented the most recent officially available land cover classification for Bulgaria, offering standardised and comparable data for the entire national territory. Through spatial overlay of thermal anomalies with the updated land cover layers, areas classified as forest, namely broadleaved, coniferous, and mixed forests, were extracted. This step enabled the analysis to focus exclusively on forest ecosystems, in alignment with the research objectives.

Following this filtering and verification process, the resulting data were incorporated into the Forest Fire Database for Bulgaria (2020–2024) under development.

Verification of the thermal anomalies

Each thermal anomaly was individually examined to determine whether it was caused by a forest fire or by another source. The selected MODIS-detected hotspots may originate from active fires, fire-related smoke plumes, agricultural activity, or other heat sources. To verify the nature of each anomaly, optical satellite imageries were utilized from the following sources: Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, and Landsat 9 OLI-2 sensors, obtained via the USGS Earth Resources Observation and Science Center (USGS-EROS) [16], as well as data from the European Space Agency’s Sentinel missions (ESA) [17], made available through Bulgaria’s status as a cooperating state since 2015.

The satellite images from Landsat and Sentinel were used to visually inspect each hotspot and validate whether it was the result of a forest fire. If no evidence of fire was present in the corresponding Landsat or Sentinel-2 imagery, the thermal anomaly was excluded from the database. This verification process effectively filtered out false positives, thermal anomalies not associated with wildfires.

Although labour-intensive, this approach significantly enhanced the accuracy of the forest fire database by ensuring a high level of reliability in identifying true fire events. The combined use of high-resolution multispectral satellite imagery and thermal anomaly data from MODIS enabled an efficient mechanism for filtering out false detections. As a result, a consistent and reliable geospatial dataset was created, suitable for spatial analysis, risk assessment, and the formulation of forest fire management policies.

Upon completion of the thermal anomaly verification process, the forest fire database has been finalised and is ready for further analysis and application.

Results and discussion

In the following section, the results derived from the database are presented, including its visualisation within a GIS environment (Fig. 2), the structure of the attribute table (Fig. 3), and the key spatial and descriptive parameters associated with each recorded forest fire event.

The database is organised in a shapefile format (Fig. 2), which enables its direct use and visualisation within GIS, facilitating spatial analysis and integration with other geospatial datasets. This format ensures broad compatibility across GIS platforms and allows for efficient querying, layer integration, and spatial analysis, making it a practical tool for researchers, policymakers, and forest management authorities.

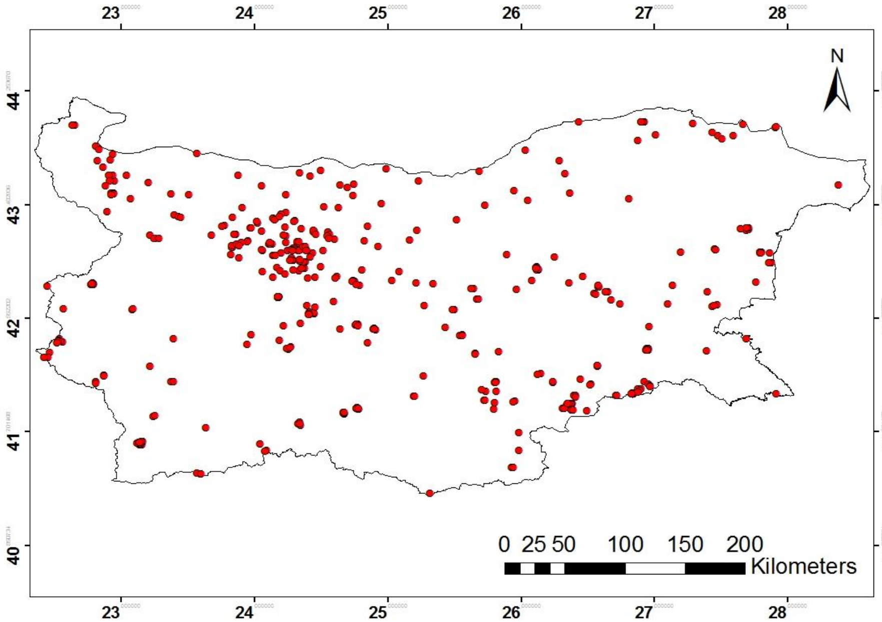

Fig. 2. Forest Fire Database in Bulgaria (2020–2024) organised as a shapefile format

FID	LATITUDE	LONGITUDE	BRIGHTNESS	ACQ_DATE	ACQ_TIME	SATELLITE
0	42.7166	24.1776	300.5	4.1.2020 г.	0920	Terra
1	43.5883	22.9505	301.4	23.1.2020 г.	1133	Aqua
2	43.6425	26.3309	304.6	25.1.2020 г.	0939	Terra
3	41.877	25.7948	303.4	1.2.2020 г.	1126	Aqua
4	42.3056	25.8349	303.4	1.2.2020 г.	1126	Aqua
5	43.2189	25.2204	316.2	1.2.2020 г.	1127	Aqua
6	43.6591	25.6878	300.8	1.2.2020 г.	1127	Aqua
7	43.6883	22.865	308.5	1.2.2020 г.	1127	Aqua
8	42.6823	24.5977	302.6	3.2.2020 г.	1114	Aqua
9	43.0481	24.4408	309.7	3.2.2020 г.	1114	Aqua
10	43.0817	24.33	312.5	18.2.2020 г.	1210	Aqua
11	43.4971	22.9269	300.7	18.2.2020 г.	1210	Aqua
12	43.4955	22.9441	311.3	24.2.2020 г.	1133	Aqua
13	42.9758	27.8753	307.1	11.3.2020 г.	1133	Aqua
14	42.9741	27.8584	308.2	11.3.2020 г.	1133	Aqua
15	42.7178	24.1786	306.7	12.3.2020 г.	0857	Terra
16	43.6313	22.9399	317.9	13.3.2020 г.	1121	Aqua
17	42.7173	24.1801	308	17.3.2020 г.	0915	Terra
18	42.9414	24.5003	308	20.3.2020 г.	1127	Aqua
19	42.9296	24.3786	304.1	21.3.2020 г.	0850	Terra
20	42.8391	24.7386	306	21.3.2020 г.	0850	Terra
21	42.8343	24.7538	307.1	21.3.2020 г.	0850	Terra

Fig. 3. The attribute data: geographic coordinates, acquisition date, acquisition time, signal intensity, and the satellite platform of origin (Terra or Aqua) for the Forest Fire Database in Bulgaria (2020–2024)

In addition to the spatial representation of the data, the database enables the extraction of statistical summaries that provide insights into the temporal distribution of forest fire events. Such analyses help identify interannual variability and potential trends within the study period. Fig. 4 presents the total number of recorded forest fires for each year from 2020 to 2024, providing a quantitative overview of the temporal dynamics in the dataset.

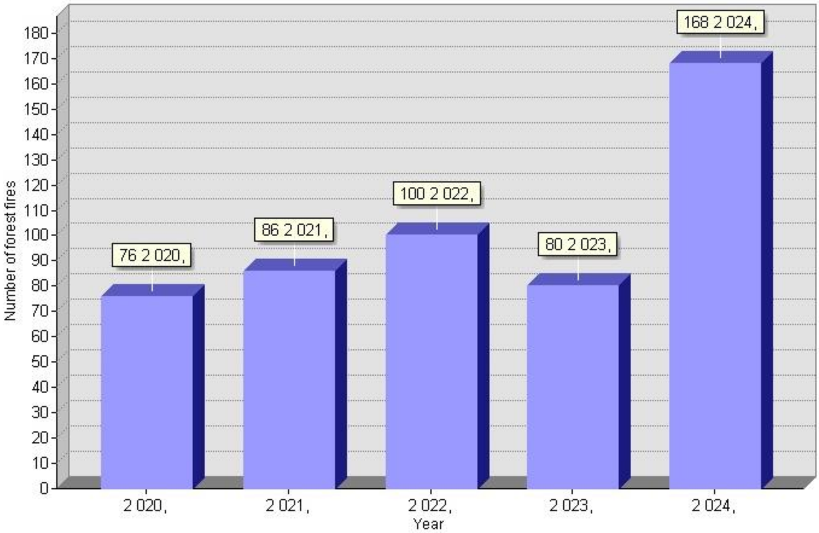

Fig. 4. The total number of recorded forest fire events in Bulgaria for the period 2020–2024

The temporal dynamics of recorded forest fire events across the study period indicate distinct fluctuations that merit detailed examination. In 2020, a total of 76 events were documented, representing the baseline for subsequent comparisons. The following year, 2021, shows a moderate increase to 86 events, which may be associated with variations in meteorological conditions or shifts in land use and vegetation patterns. In 2022, the number of forest fires rose further to 100, marking the highest value observed up to that point in the study period, and possibly reflecting a combination of prolonged dry spells and elevated summer temperatures.

A decline is registered in 2023, with 80 events, suggesting either more favourable climatic conditions for fire prevention, the effectiveness of fire management strategies, or natural variability in ignition sources. However, 2024 exhibits an exceptional surge to 168 events – more than double the previous year’s figure – which may be indicative of extreme weather phenomena, such as heatwaves and droughts, compounded by human activities. This substantial increase underscores the necessity for targeted investigation into the underlying drivers and for the implementation of adaptive management measures to mitigate future risks.

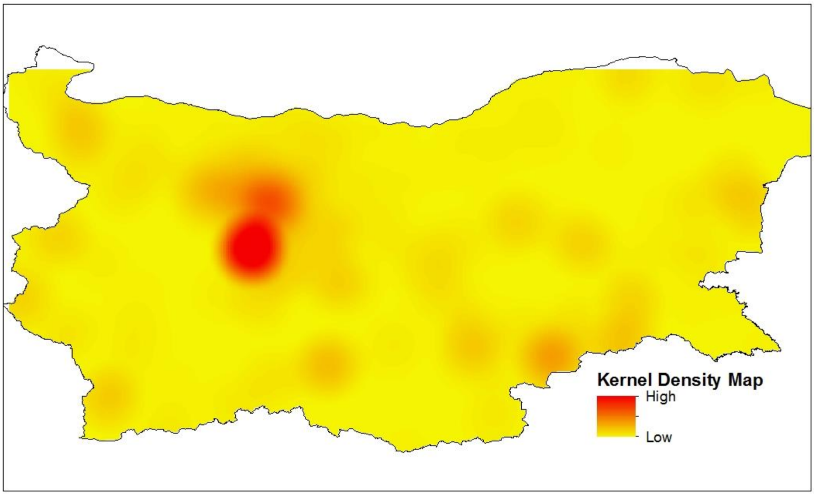

Fig. 5. Kernel Density estimation of forest fire events for the period 2020–2024, displayed using a stretched yellow-to-red colour ramp to indicate a continuous increase in density values (events/km²)

To further explore the spatial distribution patterns of the recorded forest fire events, a Kernel Density estimation was applied to the dataset. This method generates a continuous surface representing the concentration of events per unit area, allowing for the identification of high-density clusters and spatial trends that may not be evident from raw point data alone. The Kernel Density map (Fig. 5), visualised using a stretched colour ramp from low to high density values, highlights several distinct hotspots of fire occurrence. These spatial clusters provide a valuable basis for examining potential correlations with environmental variables, land cover characteristics, and proximity to anthropogenic features, thereby supporting more targeted prevention and mitigation strategies.

The finalised database provides a consistent, high-confidence dataset of forest fire events across Bulgaria for the period 2020–2024. This structured geospatial resource serves as a solid foundation for subsequent spatial analyses, risk assessments, and the development of data-driven forest fire management strategies.

By integrating both spatial and temporal dimensions, the dataset facilitates the identification of patterns, trends, and high-risk zones, thereby supporting more targeted and effective prevention measures. The methodological framework applied in this study ensures broad compatibility of the database with other geospatial resources, enabling its use in multidisciplinary research and operational contexts. Ultimately, the presented resource has the potential to contribute significantly to evidence-based policy-making, enhance preparedness, and strengthen adaptive management in the face of evolving forest fire dynamics.

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БАЗА ДАННИ ГОРСКИ ПОЖАРИ НА ТЕРИТОРИЯТА НА БЪЛГАРИЯ ЗА ПЕРИОДА 2020–2024 Г. ПО СПЪТНИКОВИ ДАННИ

Н. Станкова, Д. Аветисян

Резюме

Настоящото изследване представя разработването и анализа на геопространствена база данни за горски пожари на територията на България за периода 2020–2024 г. Базата данни е съставена от спътникови наблюдения за активни огнища, като включва географски координати, дата и час на регистриране, интензитет на сигнала и изходна спътникова платформа (Terra или Aqua). Организирана във формат Shapefile, тя позволява директна интеграция в Географски Информационни Системи (ГИС) за пространствен анализ, визуализация и корелация с други геопространствени набори от данни. Резултатите включват пространствени и времеви оценки, като статистическите обобщения показват междугодишна изменчивост и значително увеличение на регистрираните събития през 2024 г. За идентифициране на зони с висока плътност на пожарите е приложен методът Kernel Density, което позволява откриването на пространствени модели и потенциални горещи точки. Базата данни предоставя надеждна основа за оценка на риска, подпомага целенасочените стратегии за превенция и ограничаване на горските пожари и допринася за вземането на решения, основани на данни, в подкрепа на устойчивото управление на горите в България.