

Introduction

Kyiv Polissia is a physical and geographical region, a part of Ukrainian Polissia, located in the central part of Northern Ukraine, between Zhytomyr Polissia and Chernihiv Polissia. Covers the northern part of Kyiv and the eastern part of Zhytomyr regions. In the east, it is limited by the Dnipro River with the Kyiv Reservoir. In the zone of Kyiv Polissia, the forest cover is 44% (Zibtsev, et al., 2019).

The climate in the region is temperate continental with the average annual temperature was $8.2\pm 0.8^{\circ}\text{C}$ and the annual amount of precipitation was 620 ± 62 mm per year (The Climate of Ukraine, (2003); Boychenko & Maidanovych, 2024). The climate change in the region was marked by a tendency to increase the average annual temperature by $+0.60^{\circ}\text{C}/10$ years for the period 1991-2020 and the annual amount of precipitation decrease of 2–4% (Karamushka, et al., (2022); Karamushka, et al., (2023). Also, these changes are accompanied by a decrease in the severity of winter, a decrease in the amount of precipitation in the warm period of the year, and an increase in the number of days with extreme fire danger. An increase in the recurrence frequency of droughts in the zone of excessive and sufficient moisture, to which Polissya belongs occurs (Boychenko & Maidanovych, 2024; Semenova, et al., 2022). In the Polissia zone, there is a risk of desertification, which will lead to the spread and increase in the number and frequency of fires in coniferous forests (Melnyk & Voron, 2021).

According to the data of the Hydrometeorological Center of Ukraine, the temperature regime and the precipitation regime are important as a precondition for the occurrence and spread of fires in the environment, because the less energy a fire emits into the air, the more it can transfer to the fuel material, at sub-zero temperatures, if a fire occurs, it almost does not spread. The average temperature during the period of hostilities from February 24 to April 2, 2022 was 2.7 degrees Celsius. For the first 4 weeks, it fluctuated from -4 to 4 degrees and on March 21 it began to rise to the level of 7 C. The highest temperature reached 18.7 degrees and the lowest -8.6 C. The decrease in temperature in this case did not significantly affect the fires because in most cases their occurrence was not related to spontaneous combustion, but to the conduct of hostilities, during which a large number of ignitions occur from explosions. Atmospheric precipitation in the form of rain and snow was observed in March, with the amount of rainfall from 0.3 to 2 mm per day, and snow from 10 to 50 mm, that is, at a rather low level, and rains were observed on April 1 and 2 in the amount of 6.6 mm and 4.1 mm. Therefore, the ecosystems received relatively little moisture, which could increase their resistance to fire.

During the period from February 24 to April 7, 2022, significant cloudiness was observed over Kyiv Polissya with the number of cloudy days being 28-37 days and only 9 days were clear. The significant proportion of cloudy days during the observation period is a limitation of the study and affects the ability to describe fires on a day-to-day basis, as well as the total number of fires that can be detected, as well as the ability of the FIRMS system to detect areas of flame initiation.

Method and/or Theory

FIRMS system data were used to analyze occurrence of fires day by day in period of battle for Kyiv region from February 24, 2022 to April 2, 2022 (FIRMS, 2022). To further clarify the area of fires, the Sentinel-2 satellite images were used, in the spectrum of short-wave infrared radiation (SWIR) (Sentinel-2 MSI, 2022). Geodata on the administrative boundaries of Ukraine at the level of oblast, district and united territorial community are taken from the open data portal of the UN Office for the Coordination of Humanitarian Affairs. Obtaining data on the land cover and analysis of the land covers within the territories occupied by fires was performed using the map "ESRI 2020 Global Land Use Land Cover from Sentinel-2". All fires that occurred outside the boundaries of forest areas are classified as surface-level fires. Burned areas can be differentiated on the basis of the delta of the normalized burn index (NBR), which allows you to determine the strength of the burn, according to which the average and severe degrees of burn serving as markers of crown fires (infrared (NIR) and short-wave infrared (SWIR) ranges are used). For the analysis, Sentinel-2 satellite images of L2A level, which are linked to the WGS-84 coordinate system, were used. Bands 8 and 12 are used to calculate the NBR index and the NBR delta (Sentinel-2 MSI, 2022).

The calculation of fire areas was carried out in the ArcGIS PRO program, the calculation was carried out in the geodetic coordinate system WGS 1984 UTM ZONE 36n (EPSG:32636), and the acquisition

and processing of images was carried out using the Google Earth Engine platform (Earth Engine Data Catalog, 2022).

Results

Spatial distribution of the studied fires. The spatial distribution of fires that occurred during the study period is not homogeneous, they can be divided into two large clusters, the first to the north and northwest of Kyiv, where 263 fires with a total area of 28,400 hectares of fires were recorded, and the second cluster of fires - along in the western part of the region between highway E 40 and the Grezlya River, where 118 fires were recorded, the area of which was 29,834 ha.

These two zones could be divided on 4 sites with high density of fires:

1) the territory of the suburban agglomeration of the city of Kyiv from along the Irpin river from the city of Irpin to the city of Dyer, as well as near Stary Petrivtsi, where 101 fires occurred with an area of 10,493 hectares;

2) the territory along the Zdvizh River and the territory of settlements west of Zdvizh in the Triangle of Makariv, Zagaytsi, Sosnivka - 156 fires occurred here, with an area of 17,597 hectares;

3) the territory between the Teteriv and Zhereva rivers to the villages of Rasky to Rakhvalivka, there were 51 fires with an area of 9,581 hectares;

4) the area along highway P02 from Ivankov to the village of Tarasiv and the village of Grezlya and the southern bank of the Grezlya River, there were 80 fires with an area of 21,345 hectares, of the seven largest fires in terms of area, 6 occurred in this area, of which 3 were on the territory Chernobyl radiation-ecological biosphere reserve (32 fires in total).

The first category fire occurred the most in the first agglomeration - 77 out of 101 recorded in total. Other categories of fires are relatively evenly distributed in the study area.

These areas with a large number of fires are comparable to the main advances of the troops of the Russian Federation and places of combat. Thus, the march of the enemy's main forces towards Kyiv took place along the P02 route, and the retreat took place along this route at the end of the month. In the zone of the Kyiv agglomeration, the main battles in the Kyiv polissia took place during the attempt to seize the capital, this zone also had the largest number of damaged civil infrastructure objects, which indicates the intensity of the battle there. Advancing along the Zdvizh River in the direction of Makarov, attempts were made to encircle the city of Kyiv, cut the M06 route and advance towards Zhytomyr, so on March 6, the route was crossed and the enemy advanced to the city of Byshiv and along the route to the border of Kyiv and Zhytomyr regions. From there it was knocked out only on March 14, it was pushed to the border of the M06 route only on March 28, and only in the first days of April the territory along the Zdvizh was liberated, intensive combat operations were conducted throughout the month. The southern territory from the Teteriv River and along the P02 route was the flank of the Russian occupation army, which was constantly under pressure from the Armed Forces of Ukraine, which explains the significant number of fires in this location.

Distribution of fires within the administrative subjects of Kyiv Polissia in 2022. As a result of the research, 234 fires with a total area of 2,305 hectares, which is 9.5% of the area of the district, were found within the Buchansky District for the period from February 24 to April 2, 2022 (see Table 1). In the Vyshgorod district, it was possible to detect 180 fires with a total area of 27,192 hectares during the same period, which is 6.1% of the total area of the district. Quantitatively, the territories of these districts were affected approximately equally, but in percentage terms, the fires took up a little more territory in the Buchansky district, where military actions were more intensive.

In the Vyshgorod district, the Ivankivska OTG has the largest area of fires, which also makes up a significant part of the total area of the community, however, according to relative indicators, the largest share of the territory burned in the Poliska territorial community. In the Buchansk District of the Makariv OTG, the fires occupied the largest area in terms of absolute indicators, while the Gostomel OTG has the largest relative indicator of the area of fires to the total territory of the community. In the Chernobyl Exclusion Zone, the area of fires was 13,000 ha, which is 5% of the Zone's territory.

Crown fires in the forests of the Kyiv Polissia as a consequence of hostilities in 2022. Most of the fires that took place in Kyiv Polissia during the hostilities were surface fires, based on the cover on which they occurred: in cities, fields, meadows, floodplains, and bushes. Due to the impossibility of

conducting additional field studies, to clarify these data, additional studies can be conducted using LiDAR, which allows determining the change in the height of tree crowns [11]. The total area of these surface fires was 46,293 hectares.

Table 1. Area of fires according to coverage in hromadas of Kyiv Polissia February 24 - April 2, 2022 (% - percentage of the total area of fires in hromada)

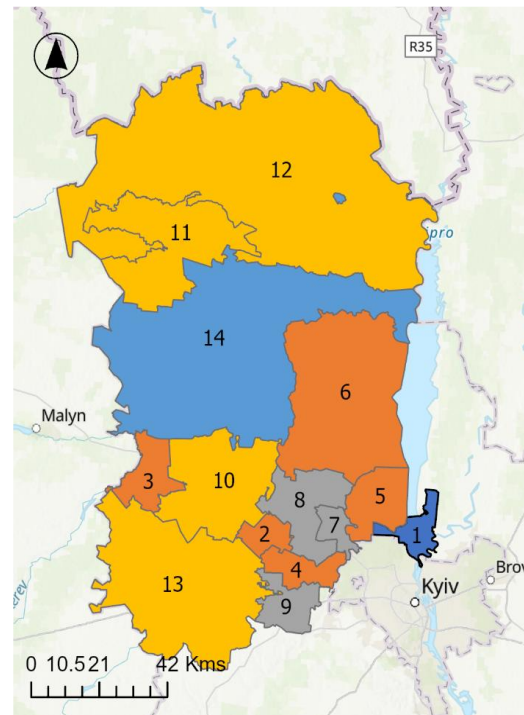
Administrative unit	Type of burned areas											
	Built area		Crops		Flooded Vegetation		Grass		Shrub		Trees	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Chernobyl Exclusion Zone	1	0.0	124	1.0	6	0.1	1056	8.1	6541	50.3	4253	32.7
Vyshhorod Raion												
Irpinska hromada	108	5.9	1011	55.1		0.0	163	8.9	466	25.4	86	4.7
Borodianska hromada	705	9.6	1819	24.7		0.0	997	13.5	2213	30.0	1625	22.0
Buchanska hromada	257	6.7	1441	37.3		0.0	385	10.0	1339	34.7	414	10.7
Dmytrivska hromada	34	3.7	283	30.5		0.0	167	18.0	182	19.6	263	28.3
Makarivska hromada	662	8.5	2195	28.1	15	0.2	519	6.6	2649	33.9	1746	22.3
Hostomelska hromada	332	24.3	290	21.2		0.0	73	5.3	544	39.8	110	8.0
Nemishaievska hromada	3	0.8	94	23.6		0.0	26	6.5	222	55.6	54	13.5
Piskivska hromada	11	0.9	16	1.4	0	0.0	100	8.5	388	32.9	665	56.3
Bucha Raion												
Dymerska hromada	102	4.4	595	25.6	25	1.1	204	8.8	1074	46.3	315	13.6
Poliska hromada	404	6.6	1567	25.7	1	0.0	485	8.0	1351	22.1	2282	37.4
Ivankivska hromada	800	4.7	2045	12.0	286	1.7	1713	10.0	7180	42.1	4811	28.2
Petrivska hromada	63	4.2	190	12.7		0.0	105	7.0	611	40.9	526	35.2
Vyshhorodska hromada	10	16.4	10	16.4		0.0	1	1.6	34	55.7	6	9.8
Total:	3492	6.9	11680	22.5	333	0.2	5994	8.6	24794	37.8	17156	23.1

The sum of the territories of forest fires was 17,156 hectares, using delta of the burnout index, the possible area of crown fires was calculated, and total area of fires with an medium and high value of indicator of the delta of the burnout index was 1628 hectares, so the area of crown fires is 9.48% of the total area of fires (see Table 2 and Figure 1). Most of these areas were smaller than 1 hectare (20,000), the other 2,400 areas varied in size from 1 to 37 hectares.

Table 2. The share of crown fires from the total area of forest fires within hromadas of the Kyiv agglomeration

Hromada	Total area, ha	Crown fires, %
Ivankivska	508.8	11
Makarivska	273.8	16
Chernobyl Zone	193.0	5
Poliska	140.5	9
Borodianska	140.5;	9
Dmytrivska	72.1	27
Buchanska	65.9	15
Hostomelska	61.8	56
Dymerska	39	12
Petrivska	34.5	6
Irpinska	24.2	28
Piskivska	20.0	2
Nemishaievska	7.2	13
Vyshhorodska	0.2	3

Fig. 1. Areas (ha) of crown forest fires within the territories of the hromadas of Kyiv Polissia



The largest part of crown fires was recorded within the boundaries of Dmitrivska, Buchanska, Irpinska and Gostomelska hromadas. In peacetime, the share of crown fires for this territory usually reaches 20%, in the case of these communities, the area of crown fires exceeded this indicator, for the Gostomel community by more than two times. This is due to the fact that the longest and fiercest battles were fought on the territory of these communities.

Conclusion

So, within the boundaries of Kyiv Polissia during the period of hostilities from February 24, 2022 to April 2, 2022, 440 fires with a total area of 64,913 hectares were detected using the analysis of satellite images, and the geographical distribution of fires within administrative units was also analyzed. As a result of the analysis of spatial data, the following distribution of the received areas of fires according to land cover was obtained: 17,156 hectares in trees, 24,794 hectares in shrubs, 5,995 hectares in grasses, 333 hectares fell in flooded areas, 11,680 hectares in fields and within the boundaries of buildings the area of the fires was 3,492 hectares. Due to the impossibility of conducting additional field research, LiDAR was used to clarify the data on the areas of crown fires, which allowed to determine the change in the height of tree crowns. Due to military operations, the number of crown forest fires increased by an average of 9.5% of the total area of fires, which cause more damage to the forest and forestry in March-April 2022. Among all territorial communities, the highest percentage of crown fires was in the Dmitrivska, Gostomelska and Irpin communities, located within the Kyiv agglomeration.

Referents

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