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Influence of War on the Forest Plantations of the Left Bank Kherson Region

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Abstract

Mapping burnt areas of forest plantations is needed to understand the scale of the violation and plan the post-fire activities to save the biggest artificially made forest in the world. The military actions due to the ongoing war in Ukraine complicate the monitoring by traditional and standard methods. Given the complexities of military actions, our study during this period is heavily reliant on remote sensing, marking a significant shift from traditional methods. The article is dedicated to the impact of hostilities resulting from Russian armed aggression against Ukraine on the state of forest plantations and shelterbelts of the left bank Kherson region. The research was conducted using images of Sentinel-2 L2A satellite, focusing on the study of forest burnt areas from the beginning of hostilities on the territory of the occupied Kherson region in February 2022 to March 2024. The pre-war year 2021 was used as a benchmark for comparing the state of forest plantations. Satellite images were used to generate the Normalized Difference Vegetation Index (NDVI) and Normalized Burn ratio (NBR) index to determine and monitor forest cover changes and burnt areas in forest plantations as a result of hostilities on the research territory using ArcGIS Pro. The area of study is 44 657 hectares, and the burnt area of Oleshky forest in March 2024 was 7 833 hectares (17.5 %). The conducted studies have proved the critical situation with forest plantations on the left bank of the Dnipro River within the Kherson region. This situation necessitates immediate and collaborative intervention to save the ecosystem of Oleshky forest.

Keywords: Forest cover, Burnt area, Remote sensing, Sentinel-2 L2A, NDVI, NBR.

1. Introduction

A forest is an ecologically complicated system with a number of components, such as trees, shrubs, lichens, grasses, mosses, mushrooms, animals, and various microorganisms. Every plant or living thing is an integral part of the forest zone and is a part of the food chain. A large share of the world's forests contains conifers. Since coniferous trees are the source of oxygen and volatile antimicrobial substances, such forests are rightfully called the lungs and green shield of our planet. One of their greatest enemies is fire. Forest fires worldwide are one of the most significant disruptions of forest ecosystems, along with climate change, drought, deforestation, habitat fragmentation, and pollution. Forest fires belong to the category of natural disaster because they are uncontrolled fires that occur in a wild area, with or without anthropogenic intervention, and causes damage to natural resources and humans. Forest fires have a significant impact on several factors on our planet, such as, black carbon emissions, adverse effects on soil, threats to wildlife, increased possibility of landslides, the occurrence of uncontrolled soil movement due to the effects of wind erosion, and the loss of old growth forests (Navarro et al., 2017).

The Oleshky forest is located on the left bank of the river Dnipro in the Kherson region of Ukraine, which has been under the occupation of the troops of the Russian Federation since the first days of the full-scale invasion and remains under their control. This forest has a unique history of its origin; it was artificially planted. The first trees were planted in the 70-80s of the 19th century. The forest consisted of undemanding drought and barren soil Crimean pine (*Pinus nigra ssp. pallasian*) and Scots pine (*Pinus sylvestris L.*). The primary task of this forest was to save Oleshky City from the sand coming from the side of the desert – the "Oleshky Sands". However, further, the task of the forest became the preservation of the largest and unique European desert in its historical and natural form. For this purpose, the National Natural Park (NNP) "Oleshky Sands" was created. This NNP represents one of the most amazing landscapes of Ukraine. Its territory has quite a few features that distinguish it from those territories that, at first glance, seem similar. Even though "Oleshky Sands" are called a desert, according to the temperature regime and the precipitation amount, it can be classified as semi-desert. In the summer, the sand heats up to 70 degrees Celsius,

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and the hot vertical currents from the sand disperse rain clouds, so precipitation rarely occurs here. Often, there are sandstorms during which neither the sky nor the sun can be seen. The sand, in general, is characterized by a high degree of natural diversity; various natural landscapes are presented here – from water bodies to sandy areas of desert and semi-desert types (Boiko et al., 2018).

Since the beginning of the full-scale invasion of Russian forces on February 24, 2022, Russian military aggression has caused excessive ecological losses in Ukraine, and the negative impact on forest resources continues. This makes it necessary to review the goals and priorities of forest and ecological policies and directions for achieving sustainable development of Ukraine. The destruction of forest areas will make it difficult for Ukraine to implement plans and measures for adaptation to climate change.

From the beginning of the full-scale Russian invasion, about 34% of Ukraine's territory has been affected by military aggression, including 32 % of forested areas. By the beginning of 2024, according to the estimation of various experts, forests area that remain under occupation or is located in the active war zone range from 450,000 to 500,000 hectares. The relevant ministries of the country have already begun to assess the damage caused by the Russian armed aggression to the forestry of Ukraine. However, the final sum of the damage caused will be possible to calculate only after the end of hostilities on the territory of the country (Breus et al., 2021).

Damage to forests consists of destruction and damage of stands and stocks of wood and other components of forest ecosystems due to result of fires and explosions. Also, occupation and mining cause a lack of access to wood harvesting, reforestation, other forestry activities, and non-wood forest products, such as berries and mushroom harvesting, tourism, and recreation. In addition, damage to the forest causes a complete or partial loss of its valuable properties, including absorption of greenhouse gases from the atmosphere, air purification, protection against erosion and landslides, water purification and replenishment, life support and reproduction of hunting and other animals (Issa et al., 2022).

Military operations are destroying the forests of Ukraine, which is also affecting the food security of the world. Combat action is currently taking place in the Eastern and Southern regions of Ukraine; these regions are characterized by low forest coverage, which is primarily of artificial origin. Here, forests perform protective functions. Their destruction and damage will affect the local climate, lead to erosion processes, and threaten significant crop losses of agricultural plants in these regions. In particular, in the south of Ukraine, the consequences may be wind erosion and desertification, an increase in extreme summer temperatures, atmospheric drought, and a drop in soil moisture reserves. It, of course, will affect agriculture (Dudiak et al., 2020). Hence, the aim of the article is to study the condition of forest plantations using remote sensing technologies, and to present spatial models of the distribution of burnt forest cover on the territory of active hostilities on the left bank Kherson region. For this study, the freely available satellite images were deciphered to identify burnt forests. Hence, this study assesses the changes in forest vegetation cover from 2021 to 2024 using NDVI and NBR classification methods.

2. Materials and Methods

2.1. Study Area

The forest fund of the Kherson region is 146,700 hectares, including the forested area – 116,300 hectares with a stock of trees of approximately 11,550 thousand m^3. The total forest coverage of the region is 4.1 %. By administrative district, forest coverage varies from 0.8 % (Novotroitsk district) to 20.4 % (Oleshky district). A fluctuation in forest coverage across administrative regions depends on the heterogeneity of the distribution of forest massifs. For the study, two districts of the Kherson region with the largest forested territory out of the total district area were chosen: Oleshky and Hola Prystan districts in Ukraine.

Figure 1. Location of the study area

2.2. Data

For the conduction of research, the Sentinel-2 L2A satellite images of the territory of the Kherson region of Ukraine were used; all these images refer to level 2A (with atmospheric, radiometric, and geometric correction). The uploaded images will cover the territories with forest cover of Oleshky and Hola Prystan districts of the Kherson region clear of clouds during March 2021 (pre-war period) and March 2023-2024 (the war period). The spatial and spectral resolution of the bands used in this study is presented in Table 1.

Table 1. Sentinel-2 L2A bands with their corresponding central wavelengths and spatial resolutions

Number of bands	Name	Central wavelength (nm)	Spatial resolution (m)
4	Red	665	10
8	NIR	842	10
12	SWIR 2	2190	20

2.3. Method

Spatio-temporal differentiation and condition of the forest vegetation during pre-war and war periods were determined by calculating Normalized Difference Vegetation Index (NDVI) using satellite images (Rouse et al., 1973; Akay et al., 2019).

The NDVI value for the study area was calculated using the following formula:

$$NDVI = \frac{NIR-Red}{NIR+Red} \quad (1)$$

According to this formula, the density of vegetation (NDVI) at a certain point of the image equals the difference in the intensities of reflected light in the visible and near-infrared range, divided by the sum of their intensities. The calculation of NDVI is based on the two most stable (independent of other factors) sections of the spectral curve of the display of vascular plants. In the visible spectrum (0.4-0.7 μm) lies the maximum absorption of solar radiation by chlorophyll of vascular plants, and in the near-infrared spectrum (0.7-1.0 μm), there is a maximum reflection of cellular structures of the leaf. That is, high photosynthetic activity (associated with dense vegetation) leads to a smaller reflection in the visible range of the spectrum and a larger one in the near-infrared (Chu et al., 2013).

The value of NDVI ranges from -1 to +1. In our study area, NDVI ranges from 0.02 to 1, and on the uncovered with forest territories is characterized by the values of NDVI from 0.02 to 0.24. The value of NDVI reflects the state of the forest cover, that is: < 0.24 – uncovered soil; 0.24-0.37 – thin vegetation; 0.37-0.5 – stunted vegetation; 0.5-0.62 – good state of forest; > 0.62 – very good state of forest.

Channels containing information in the near-infrared (NIR) and shortwave infrared (SWIR) spectral were used to study and distinguish burnt and non-burnt areas. These channels were chosen because there will be a decrease in the reflection coefficient of the green and NIR spectral between the images before and after the start of combat actions (disappearance of vegetation cover) and an increase in the reflection coefficient from 2200 nm (SWIR-2 channel) over time due to spectral properties of ash and charcoal as well as to a decrease in water absorption. In the case of images after full-scale invasion, the reflectivity of burnt forest areas will increase (especially in the SWIR-2 channel) due to ash formation on the trunks of affected trees (Sokolović et al., 2022).

In addition, there is a similarity between areas of healthy vegetation and images before the start of combat actions, as well as between bare areas of soil and images before the start of the invasion (burnt trees fall, and for this reason, the similarity with the ground increases). Therefore, the Normalized Burn Ratio (NBR) and the differenced NBR (ΔNBR) were chosen for the study (Miller and Thode, 2007).

$$NBR = \frac{NIR-SWIR}{NIR+SWIR} \quad (2)$$

$$\Delta NBR = NBR_{pre} - NBR_{post} \quad (3)$$

The ΔNBR index is effective for determining the state of burnt forest cover, as well as the degree of such damage, using the classification proposed by the United States Geological Survey (USGS) to interpret the burn severity of natural forests (Table 2). There is certain dependence between the degree of naturalness of the ecosystem, and its biological resistance against epiphytotic, insect pests, industrial pollution and disasters of natural and anthropogenic origin – artificial forest has a lower resistance to these factors. Hence, the recovery after fire occurs much more slowly than in natural forests. In this particular work, the goal was to determine the damage to the artificial forest as a result of fires caused by hostilities on the occupied territory and not to determine the degree of damage to the forest. Therefore, it was chosen to classify the studied territories into two categories – non-burnt area and burnt area (Lisetskii et al., 2017).

Table 2. Burn severity levels for natural forests proposed by USGS

Severity level		ΔNBR range (not scaled)
1	Enhanced regrowth, high (post-fire)	-0.50 – (-0.251)
2	Enhanced regrowth, low (post-fire)	-0.25 – (-0.101)
3	Unburned	-0.10 – 0.090
4	Low severity	0.10 – 0.269
5	Moderate-low severity	0.27 – 0.439
6	Moderate-high severity	0.44 – 0.659
7	High severity	0.66 – 1.300

According to the classification presented in Figure 2, the value of ΔNBR ranges from -0.5 to 1.3. Non-burnt areas usually have values close to zero the lower ΔNBR value below 0, the healthier vegetation. A value higher than 0 indicates bare ground and recently burnt areas. Forests on the territory of the "Oleshky sands" are of artificial origin, so their damage leads to the impossibility of their natural restoration and destruction. Therefore, two categories of the burn severity of forest areas were considered: burnt and non-burnt. Considering the spectral-reflective features of the soil-vegetation differences of the study area, we adjusted and adapted the limit of the burning rate of forest massifs. For the Steppe zone of Ukraine, 0.3 indices above this threshold value identify the burnt area, below – non-burnt area. (Pichura et al., 2019).

3. Results

The National Natural Park "Oleshky Sands" is divided into 7 sand arenas surrounded by forests. The article includes the research of a part of forested territories with a total area of 44,657 hectares. These are forests located directly around the central part of the desert – Oleshky Arena, which was divided into 3 polygons: northern, southeastern, and southwestern with a total area 17,736 hectares; forest massif close to Vynohradove village, which has a historical name in the zoning of the arenas of Oleshky sands – Chalbask Arena. Territorially, it is located 20 kilometers to the south of the floodplain of the Dnipro River valley (9,009 hectares); forested territories of Kozachi Laheri Arena were divided into three forest massifs – southern (7,161 hectares), eastern (1,802 hectares) and western (8,949 hectares). Forest polygons are presented in Figure 2. Figure 3 presents the dynamics of changes in NDVI in March 2021 (pre-war period) and on the same month of two years of war (2023 and 2024) on the territory of the forest polygon of the Chalbask Arena.

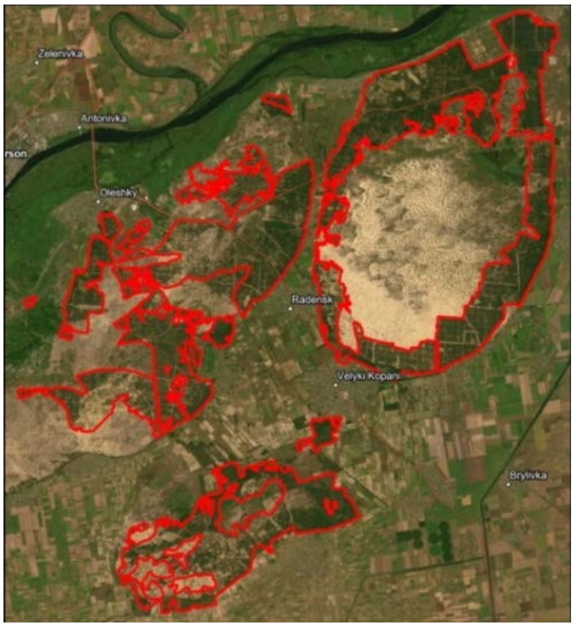

Figure 2. Location of studied forest covered territories

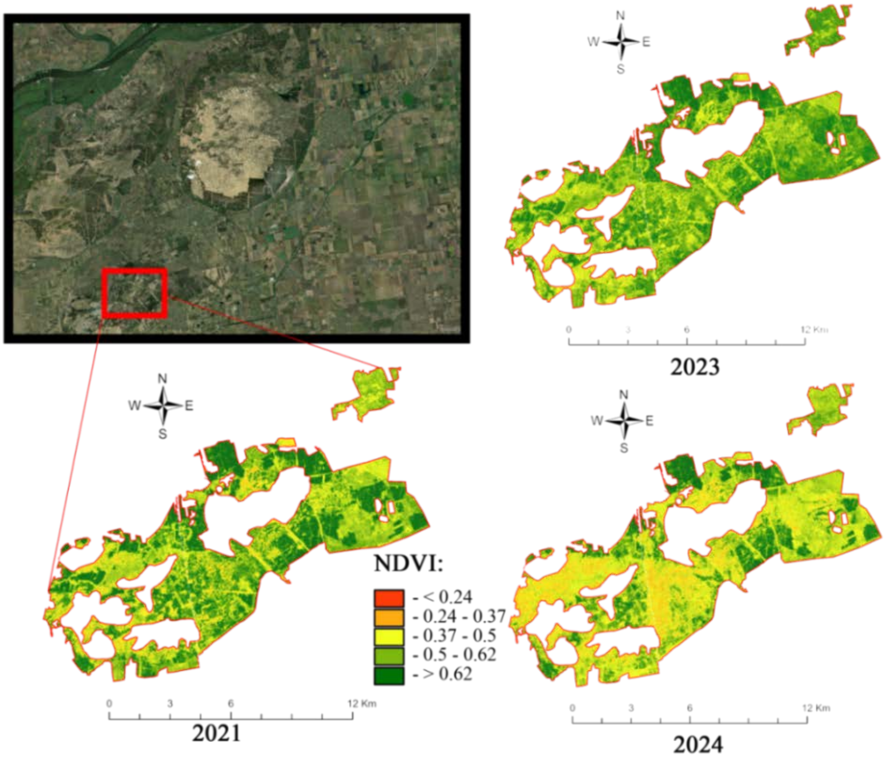

Figure 3. Value of NDVI of study area (2021-2024)

Analyzing the obtained data, it is clearly visible that in the pre-war year, a very good state of forest (NDVI – > 0.62) and stunted vegetation (NDVI – 0.37-0.50) prevailed on most of the studied polygon. However, starting from the second year of the war (2023), the index began to decline and reached its currently critical state in March 2024. Such a change depends primarily on large-scale forest fires of anthropogenic origin that arose due to hostilities on this territory.

Other factors, such as rainfall, temperature, and the evapotranspiration process, affect the vegetation state of forested areas. Therefore, the value of NDVI, but analyzing the map, it is clear that in all of the studied years there are areas with the same NDVI value (0.62-0.80), which indicates the insignificant influence of these factors on the index change. The study of NDVI in other research areas indicated that in all forest areas, there was a significant decrease in the index during the years of full-scale war, especially from the end of 2023 to the beginning of 2024. It is associated with the intensification of large-scale hostilities on these territories, which leads to mass fires and ultimately to a decrease in the index, as well as the lack of proper supervision under forest areas by the occupation authorities. Figure 4 presents the compilation maps illustrating the spatial distribution of NDVI value on the studied territories.

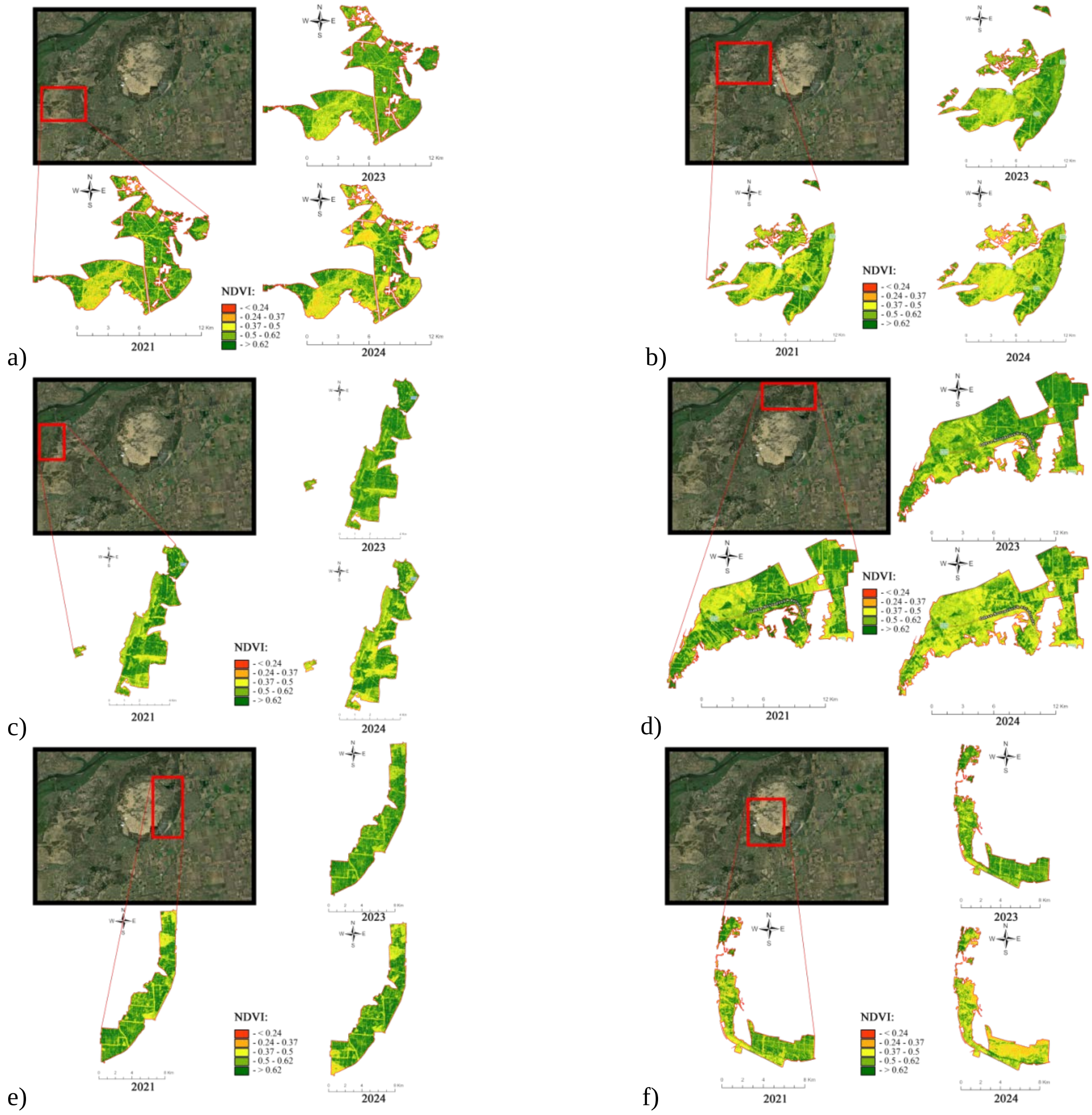

Figure 4. NDVI of a studied forest massif: a, b, c – southern, western, eastern part of Kozachi Laheri Arena; d, e, f – northern, southeastern, southwestern part of Oleshky Arena

The satellite-derived ΔNBR index was used to determine the territory affected by forest fires that occurred as a result of hostilities on the studied territory. The images of March 2021 were taken as reference images, and the March 2023 and 2024 satellite images were research ones. Based on the obtained cartograms, the burnt forest areas were calculated using the built-in functions of the ArcGIS Pro software. Figure 5 illustrates the forest massif with the most injured forest plantations by the fire as of March 2023.

The territory of this massif is 9,382 hectares, and in March 2023, the burnt forest covered 17.8 % of its territory (1,673 hectares). Calculating the area of burnt territories in 2023 showed that the forests with the most negligible impact of fires are located in the southern part (Figure 6a) and western part (Figure 6c) of Kozachi Laheri Arena. The areas of these territories are 7,161 and 1,802 hectares, respectively. The biggest burnt area of these two study parts of the forest is 21 hectares. The forest located around the Oleshky Arena has also negligible impact of fires in 2023. These territories are the southeastern part (Figure 6d) and southwestern parts (Figure 6e). The areas of these massifs are 5,140 and 3,214 hectares, respectively, and the most fire-affected territory here is 19 hectares. The territories of western part of Kozachi Laheri Arena, an area 8,949 hectares (Figure 6b), and Chalbask Arena, an area 9,009 hectares (Figure 6f) had moderate damage. The area of burnt forests here was 350 and 78 hectares, respectively.

Fire has several negative impacts on forests. It can destroy vegetation, including the loss of trees and underbrush, and damage plant species that are not adapted to fire. Wildlife habitats are often destroyed, resulting in the displacement and death of animals and reduced biodiversity. Soil erosion and degradation are expected consequences, with the loss of soil structure, increased erosion, nutrient loss, and reduced water infiltration.

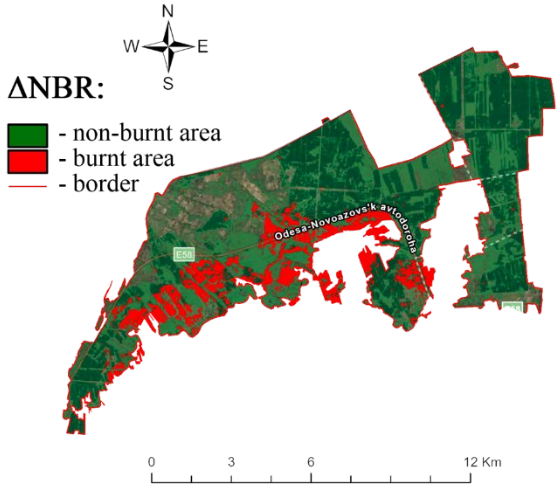

Figure 5. Burnt territory of northern part of Oleshky Arena

Table 3. Burnt area of Oleshky forest in March 2023

Name of the territory	Area studied (ha)	Area burnt (ha)	The studied territory (%)
Oleshky Arena	17,736	1,221	6.90
Chalbask Arena	9,009	78	0.87
Kozachi Laheri Arena	17,912	374	2.09
Total	44,657	1,673	3.74

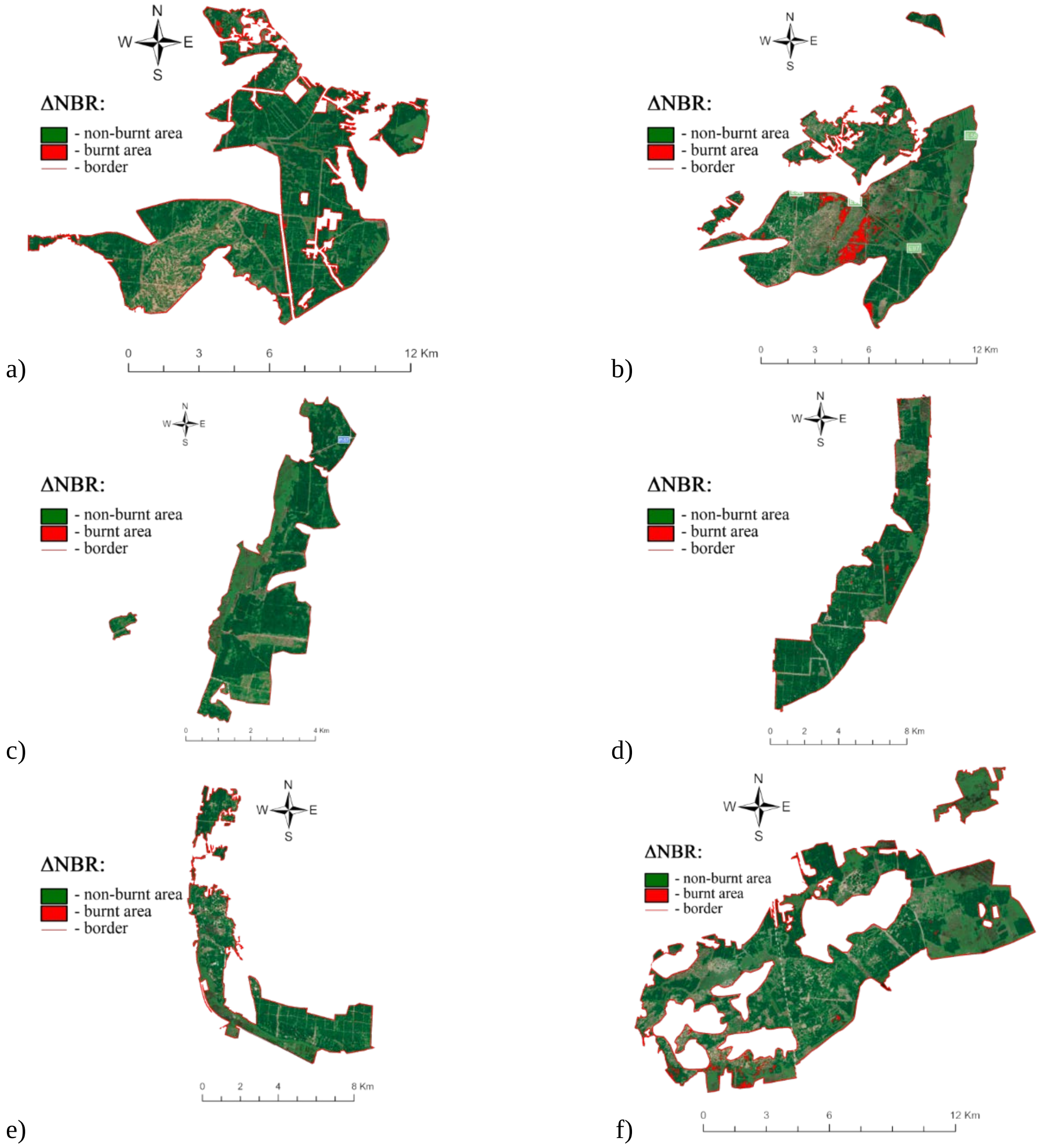

Figure 6. ΔNBR of a studied forest massifs (2023): a, b, c – southern, western, eastern part of Kozachi Laheri Arena; d, e – southeastern, southwestern part of Oleshky Arena; f – Chalbask Arena

The results of mapping the burnt territories of the rest of researched massifs as of March 2023, a crucial step in understanding the impact of fire on forests, is presented on Figure 5. The obtained data on the areas of burnt forest in the entire studied area in 2023 are summarized in Table 3. Due to the complication of the situation in the occupied territory of the Kherson region as a result of harder hostilities, the situation with the burnt forests of the studied territories has significantly worsened by March 2024. The largest area of the burnt forest relative to the total area of the forest is southwestern part of Oleshky Arena with a total area of 3,214 hectares (burnt area 932 hectares or 28.9 %), this part of forest is presented on Figure 7.

The two biggest studied forest massifs – Chalbask Arena (Figure 8f) and northern part of Oleshky Arena (Figure 8e) were significantly influenced by fire. The area of these territories is 9,009 hectares, and 9,382 hectares, and the burnt area here is 1,803 hectares (20.0 %) and 2,058 hectares (21.9 %), respectively.

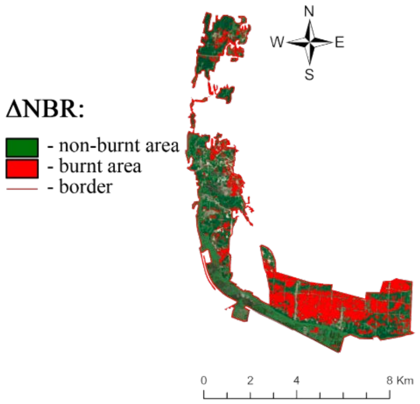

Figure 7. Burnt territory of southwestern part of Oleshky Arena

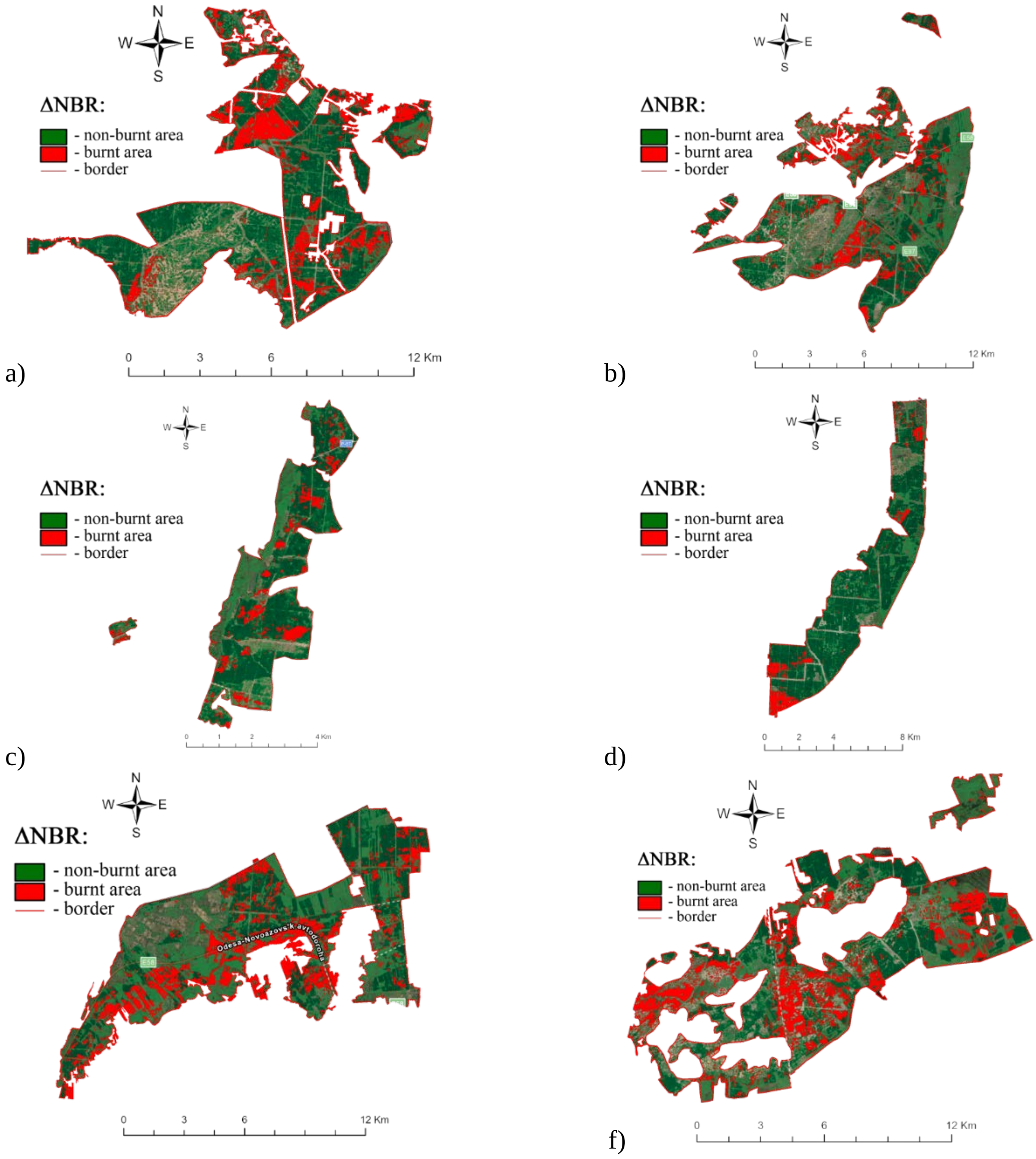

Figure 8. ΔNBR of a studied forest massifs (2023): a, b, c – southern, western, eastern part of Kozachi Laheri Arena; d, e – southeastern, northern part of Oleshky Arena; f – Chalbask Arena

A smaller percentage of burnt forest relative to the total territory of each separate polygon belongs to the southern (16.6 %), the western (14.2 %) and the eastern (11.2 %) parts of Kozachi Laheri Arena. Also, smallest percentage belongs to the southeastern polygon of Oleshky Arena, with a total area of 5 140 hectares and an area of burned forest of 381 hectares (7.4 %). However, Oleshky Arena general has 19 % of the damaged forest in its territory. The calculation of burned areas as of March 2024 is presented in Table 4. Figure 9 presents a true-color example of a fire that occurred in January 2023 on the territory of Chalbask Arena.

Table 4. Burnt area of Oleshky forest in March 2024

Name of the territory	Area studied (ha)	Area burnt (ha)	The studied territory (%)
Oleshky Arena	17,736	3,371	19.0
Chalbask Arena	9,009	1,803	20.0
Kozachi Laheri Arena	17,912	2,659	14.8
Total	44,657	7,833	17.5

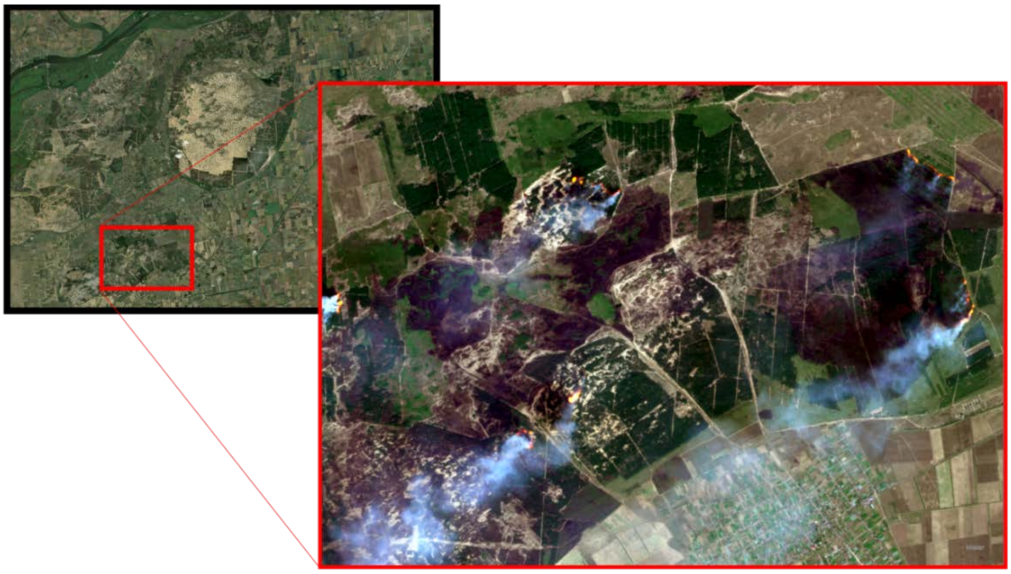

Figure 9. The fire in true color on Chalbask Arena of “Oleshky Sands”

4. Discussion

The results of the studies carried out with the help of deciphering images from the Sentinel-2 L2A satellite provide compelling evidence of the criticality of the situation with forest plantations growing on the left bank of the Kherson region, namely on the territory of the largest desert in Europe and the National Nature Park “Oleshky sands”. At the moment, it seems impossible to stop the destruction of the forest due to the continued occupation of the territory and the ongoing hostilities on it, which may lead to greater disaster and the complete loss of unique forest plantations with a long history. On the other hand, it is only a matter of time before the economic and ecological effects of such losses emerge. Although not yet visible, the environmental impacts of this war are reaching a level that could affect the region and its surroundings (Pereira et al., 2022). For example, considering the magnitude of forest losses, a significant increase in soil erosion may be observed after the war (Almohamad, 2020).

Usually, there is no need to observe and evaluate forests with satellite images at short intervals. However, this technique is frequently used in situations that cause unexpected destruction in forest areas. The devastating effects of war on forests, which result in sudden changes, remove the temporal use restriction (Othman et al., 2018). Dangerous situations (for example, war), limits research and researcher opportunities; therefore, the use of satellite images is beneficial for conducting the study (Witmer, 2015). The method of use and selection of satellite images is important according to research on the social and science subjects (Marx and Goward, 2013). This study has revealed that Sentinel satellite images, which have spatial and temporal resolution and spectral band values, can be effectively used to monitor deforestation caused by war.

5. Conclusion

The work carried out on deciphering images from the Sentinel-2 L2A satellite facilitated the remote analysis of forest plantations that belong to the territory of the “Oleshky Sands” National Nature Park and performs the function of protecting the entire region from the spread of sand from the largest desert in Europe. The left bank of the Kherson region is under the occupation of the military formations of the Russian Federation. There are also active hostilities, which cause fires and forest destruction, and on the other hand, make it impossible to monitor the state of the forest properly.

Studies have shown that since the beginning of the full-scale invasion of the territory of the Kherson region in February 2021, the condition of the forest plantations of the Oleshky forest plantations has gradually deteriorated due to constant fires that the occupying authorities cannot control. It was established that as of March 2024, the state of the forest massifs the most studied territory has a very low indicator of the vegetation state according to the NDVI. This indicator in the studied area is mainly at 0.24-0.50, corresponding to thin and stunned vegetation. There is a clear, significant decrease in the values of NDVI compared to the pre-war level.

The research conducted on the NBR index also shows a gradual increase in the areas of burnt forest starting from 2022. At this moment, the latest satellite images made it possible to determine that 17.5 % of the territory studied (total area of 44,657 hectares) was affected by fire, and considering the trend, the process of forest burning will continue in the future.

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