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Landsat-8 satellite Imagery to Assess Mediterranean Forests Fire Impact on Land Surface Temperature and Vegetation†

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Abstract: Forests are considered vital to earth and humanity, as they clean air, protect us from disasters, and enhance our well-being. However, nowadays forests are frequently exposed to different types of dangers, and fires are the major ones, as they drastically alter land surface properties, including temperature and vegetation. In this research, we aim to assess the impact of fire on surface temperature and vegetation using the Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI), respectively, In two zones of "Bou Jedyane" forest (Mediterranean region, North of Morocco), one of which was totally affected by a fire occurred in July 2022, with an area of approximately 308 Km², and the other was used as a control. Landsat-8 images from January 2021 to August 2023 were used to extract the considered indices. Then, we computed their percentage of difference between the two zones to assess how the fire changed the temperature and vegetation in the burned area compared to the intact area before, during, and after the fire. Results revealed that fire significantly affected LST and NDVI in the region, as they shifted dramatically from percentage differences ranging between 1% and 5% in 2021 to 27% and 59% for LST and NDVI, respectively, right after the fire outbreak. In the year 2023, we got a decreasing percentage of differences in both LST and NDVI, indicating that the forest is recovering over time. These results demonstrate the impact of fire on two significant elements, the land surface temperature and the vegetation, as well as the forest potential for natural regeneration.

Keywords: LST; NDVI; forest; fire severity; Landsat-8

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1. Introduction

Forests, often described as the "lungs of our planet," are an essential component of Earth's ecosystems, offering a variety of invaluable services to both the environment and humans. Among their numerous roles, forests serve as natural air purifiers, protecting us from natural disasters, and improving our overall quality of life [1,2]. However, today's forests confront an escalating number of threats, with wildfires being one of the most devastating. Wildfires have the power to bring about profound alterations in land surface properties, notably temperature and vegetation cover, thereby disrupting the intricate balance of forest ecosystems [3,4]. Many efforts are made to study forest fires and their impacts, recognizing the urgent need to understand and mitigate the destructive consequences of these events. These efforts include a spectrum of scientific disciplines, from ecology and climatology to remote sensing and land management [5,6].

In this research, we are contributing to these ongoing efforts of researchers in remote sensing field by conducting a comprehensive study of the effects of wildfires on forest ecosystems, with a particular focus on two key metrics: Land Surface Temperature (LST)

and Normalized Difference Vegetation Index (NDVI), providing a detailed and nuanced analysis of the impact dynamics. Our study takes place in the "Bou Jedyane", a Mediterranean forest located in the northern part of Morocco. Within this forest, we examine two distinct zones: one that was destroyed by a severe wildfire in July 2022, covering an area of approximately 308 square kilometers, and another that remained unaffected; we used it as a control area.

Another key aspect of our study lies in the temporal dimension. By utilizing Landsat-8 images spanning from January 2021 to August 2023, we undertake a dynamic analysis that captures the evolution of the forest's recovery over time. This temporal perspective adds depth to our understanding of the wildfire's long-term impact.

Through the integration of remote sensing technologies, specific metrics, unique study area, comparative approach, and temporal analysis, our study represents a distinctive and substantial contribution to the ongoing efforts in the field. Additionally, the relevance of this study could be extended beyond the specific case of Bou Jedyane and contributes to our broader understanding of how wildfires impact vital Mediterranean forest ecosystems.

2. Materials and methods

2.1. Study Area

For this study, we selected two distinct zones of a Mediterranean forest situated in the northern region of Morocco (35.1167° N, 5.7754° W), covering an area of approximately 600 km². The first section endured a wildfire in July 2022, scorching approximately 308 km² of the forest's total expanse. The second section remained unaffected by the fire and served as our designated control area (Figure 1). Regarding its topography, Bou Jedyane is predominantly a mountainous region, with 61% of its land being mountainous terrain, 20% consisting of hills, 18% comprising plateaus, and only 1% forming valleys or basins. The area experiences a humid continental climate, with an annual precipitation average of 657 mm3 and an average temperature of 22.3 degrees.

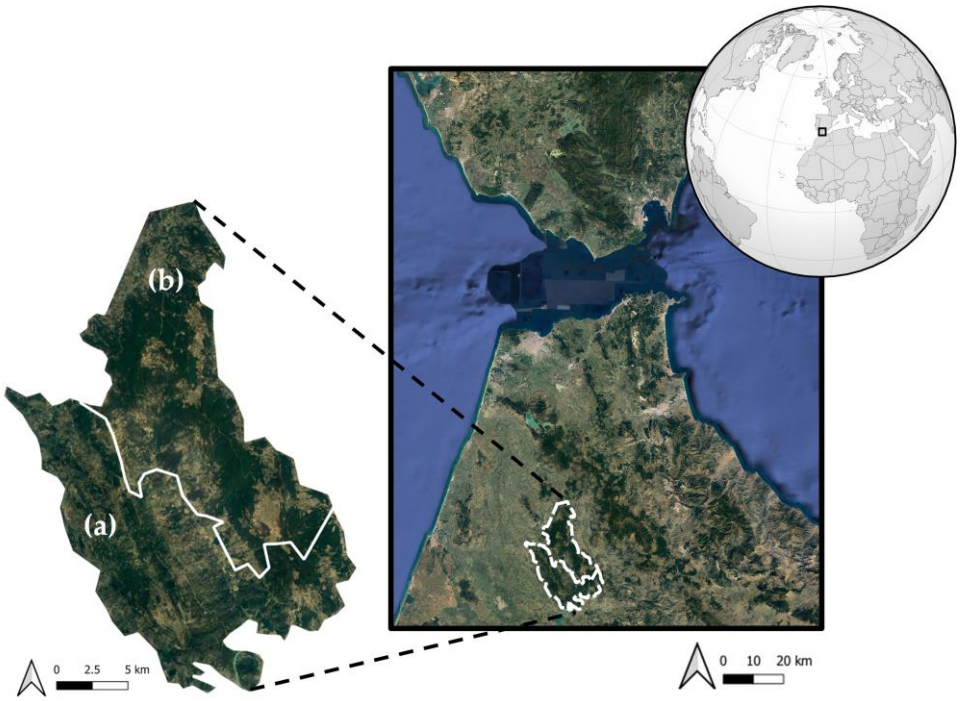

Figure 1. Study area. (**a**) Burned area; (**b**) Unburned area.

2.2. Satellite Data

Landsat-8, part of a long-running Landsat program conducted by National Aeronautics and Space Administration (NASA) and United States Geological Survey (USGS), represents a remarkable milestone in Earth observation and remote sensing. In our study, we used three images of this satellite that cover the total study area, specifically NIR, Red, and TIRS (Thermal Infrared Sensor) spectral and thermal bands to compute NDVI and LST (Table 1). Our dataset consisted of images acquired during the summers of 2021, 2022, and 2023, enabling us to track the dynamic changes in land surface properties at three different times.

Table 1. Landsat-8 bands characteristics.

Band description	Band number	Wavelength (μm)	Resolution (m)
Red	Band 4	0.64 - 0.67	30
Near-Infrared (NIR)	Band 5	0.85 - 0.88	30
TIRS 1	Band 10	10.6 - 11.19	100

Downloaded images, initially processed at level-2, calibrated and atmospherically corrected, were scaled to physical values in accordance with Landsat-8 manual [7]. Next, we unified the bands resolution to 30m using the Nearest Neighbor method. Then, images were clipped by mask layers of the two zones (i.e., burned, and unburned zones), which resulted in six images.

2.3. Normalized Difference Vegetation Index

To assess the health and vitality of the considered zones, we used NDVI, a prominent index developed by Rouse et al. in 1974 [8–10], which uses the NIR and Red spectral bands (i.e., band 4 and band 5 of Landsat-8) within a normalized equation as described in the formula below.

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4) \quad (1)$$

2.4. Land Surface Temperature

To extract LST from our images database, we utilized a detailed process [11,12]. This process involves a sequence of calculations, beginning with the determination of the proportion of vegetation (Pv) (equation 2) derived from NDVI. We then incorporated measurements of emissivity (ε) (equation 3) and TIRS band to obtain the final LST (equation 4).

$$Pv = ((NDVI - NDVImin) / (NDVImax - NDVImin))^2 \quad (2)$$

$$\varepsilon = 0.004 * Pv + 0.986 \quad (3)$$

$$LST = (Band\ 10 / (1 + (0.00115 * Band\ 10 / 1.4388) * Ln(\varepsilon))) \quad (4)$$

After computing both indices for all our images, we then computed the percentage of difference between the burned and the unburned zones in the three summers.

3. Results and discussion

The results, including the averages of LST and NDVI for both zones and their percentage of difference, are presented in Table 2, Figure 2, and Figure 3.

Table 2. Bou Jedyane forest LST and NDVI resulted values, for the burned and unburned area, and their percentage of differences.

	Burned area		Unburned area		Percentage of difference	
	LST	NDVI	LST	NDVI	LST	NDVI
2021	30.00	0.59	29.56	0.63	1.5%	5%
2022	50.20	0.23	39.38	0.58	27.5%	59.6%
2023	37.49	0.42	33.44	0.59	12%	29.5%

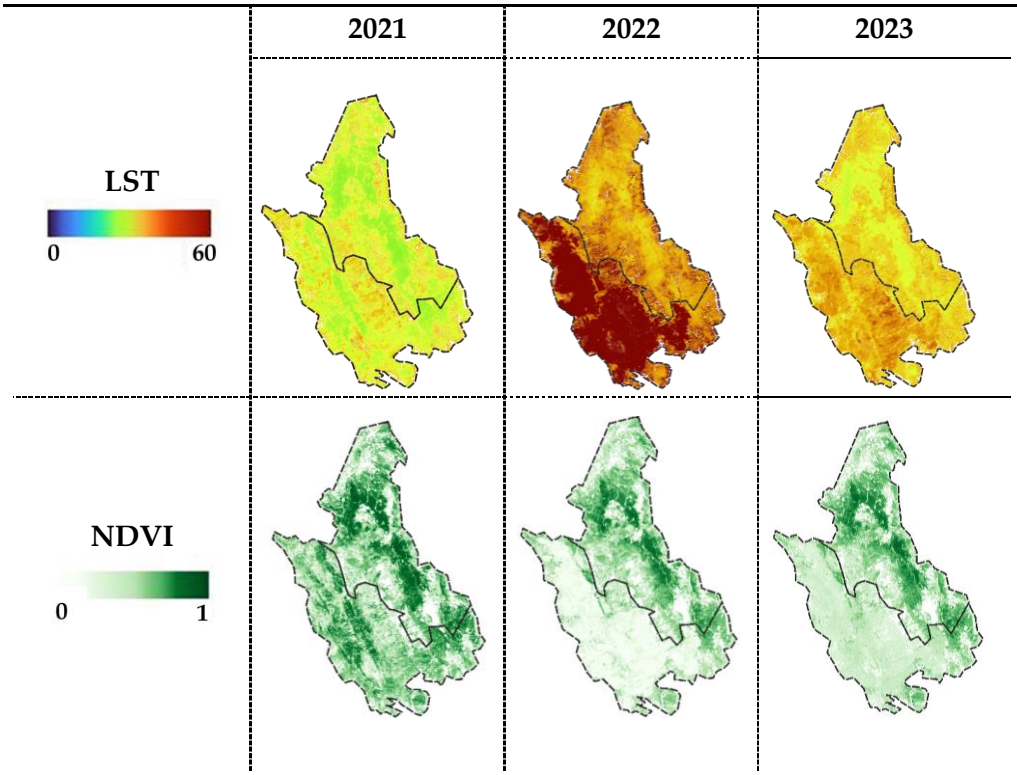

Figure 2. Bou Jedyane forest LST and NDVI of 2021, 2022, and 2023.

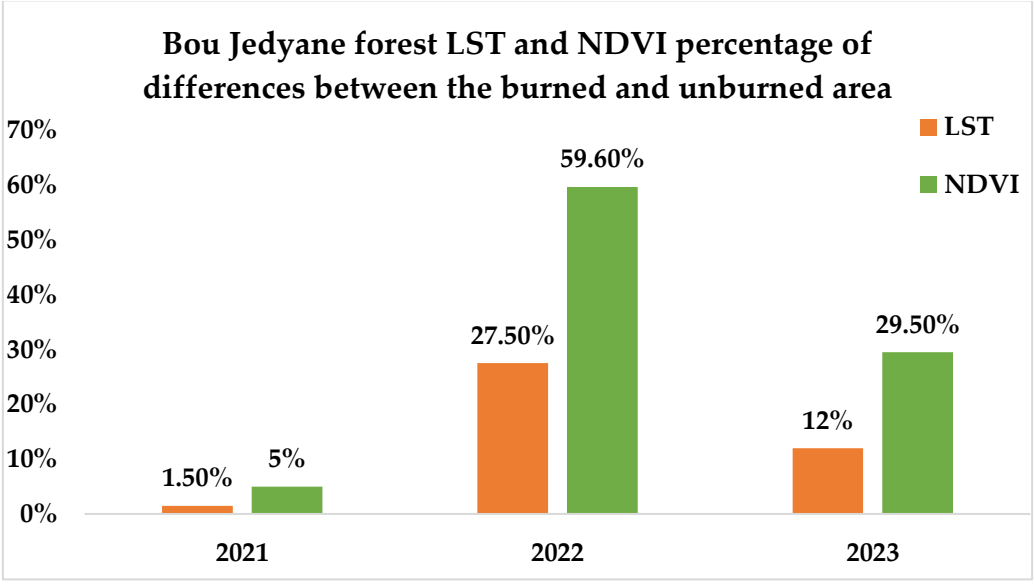

Figure 3. Bou Jedyane forest LST and NDVI percentage of differences between the burned and unburned area.

Our findings unveil a striking and undeniable impact of the wildfire on LST and NDVI in Bou Jedyane forest region. Prior to the wildfire outbreak in 2022, the percentage of differences in LST and NDVI between the two zones were relatively low (i.e., 1.5% for LST and 5% for NDVI). Whereas, in the immediate aftermath of the wildfire event, these differences surged dramatically. The percentage of differences in LST and NDVI peaked at 27% and 59%, respectively, signifying a substantial alteration in both land surface temperature and vegetation cover within the burned area compared to the control area.

For the year 2023, our analysis yielded a significant observation of a notable decrease in the percentage of differences for both LST and NDVI. This finding suggests that the forest ecosystem in Bou Jedyane is recovering over time. The diminishing differences underscore the inherent resilience of these ecosystems, offering hope for their restoration and long-term sustainability.

The utilization of Landsat-8 images and two key metrics (i.e., LST and NDVI) to conduct this multitemporal comparative approach enhanced the robustness of our study by providing a clear baseline for assessing the change's magnitude induced by wildfires in Mediterranean forest.

4. Conclusions

Forests occupy a unique and irreplaceable role in sustaining life on Earth. Thus, understanding the effects of wildfires on these ecosystems is critical for successful conservation and management. Our research conducted in Bou Jedyane forest of Morocco has revealed the profound effects of wildfires on land surface temperature and vegetation cover. Equally important, it underlines the remarkable ability of Mediterranean forests to recover and restore themselves in the wake of devastating events. In an era of changing climate patterns and increasing wildfire frequencies, it is critical deploy proactive wildfire prevention and control methods. Furthermore, our study highlights the need for continued monitoring and research to better understand the complex dynamics of forest ecosystems.

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