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Normalized Burn Ratio and Land Surface Temperature in Pre- and Post- Mediterranean Forests Fire †

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Abstract: Fire is a natural disruption that affects the structure and function of forest systems by changing the vegetation composition, climatic situation, carbon cycle, wildlife habitat, and many other major properties. The measure of these changes' degree is known as fire severity, and it can be assessed using remote sensing data (i.e., satellite images, aerial images, etc.) and various biophysical indices (such as Normalized Burn Ratio (NBR), Char Soil Index (CSI), Burn Area Index (BAI), etc.), in addition to the measurement of Land Surface Temperature (LST). This research aims to assess the response of NBR and LST in pre- and post-forest fire, taking as a study area, a Mediterranean forest located in the northern part of Morocco, which burned in the summer of 2022. We used seven Landsat-8 images spanning three years: three images from 2021 (i.e., pre-fire), one image from the summer of 2022 (i.e., fire period), and three images from 2023 (i.e., post-fire). Results demonstrated a negative correlation between LST and NBR in the pre-fire period; when the temperature rises, the NBR drops. Same for the fire period in summer 2022, LST reached its peak at 50 °C, while NBR decreased to its lowest point at −0.2. Whereas, in the recovery time (i.e., 2023), LST and NBR changed their fluctuation patterns; the first one variated normally according to seasons, dropping from the 50 °C to 12 °C in winter and reaching 37 °C in summer, and the second one increased over time, going from the −0.2 to −0.04 in winter rising to 0.03 in summer, which indicates the gradual restoration of vegetation in the study area. The study concludes that in the post-fire period when the forest is recovering, NBR is unaffected by seasonal changes in temperature and is more reflective of the vegetation it projects more the vegetation situation in the area, unlike LST. Thus, relying only on LST to measure fire severity can give biased results due to changes in seasons.

Keywords: NBR; LST; Mediterranean forest; remote sensing; correlation

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1. Introduction

Forests are considered one of Earth pillars, as they play a vital role in keeping it in balance. They act as nature's air purifiers, soaking up carbon dioxide and giving us clean, fresh air to breathe [1,2]. Yet recently, this pillar is confronting an increasing challenge, that is the menace of wildfires, which disrupts the stability of flora and fauna, altering the landscape's physical and ecological characteristics. Assessing the magnitude of these alterations, known as fire severity, constitutes a fundamental task in comprehending the ecological impacts of wildfires [3].

Fire severity can be estimated by using remote sensing data, which are images or data collected from satellites, airplanes, drones, or other platforms that observe the Earth from above. Remote sensing data can provide information about the spatial extent, intensity, and duration of a fire, as well as its effects on the forest [4–6]. One way to use remote sensing data to assess fire severity is by calculating biophysical indices, which are mathematical formulas that combine different spectral bands (such as visible, near-infrared, shortwave-infrared, etc.) of the remote sensing images to highlight certain features or characteristics of the land surface. Some examples of biophysical indices that are commonly used to measure fire severity are Normalized Burn Ratio (NBR), Char Soil Index (CSI), and Burn Area Index (BAI). In addition to the measurements of Land Surface Temperature (LST).

In this article, we use seven remote sensing images from Landsat-8 satellite to assess the response of NBR and LST to the transformative force of wildfires. Taking as a study case, on a Mediterranean forest situated in the northern reaches of Morocco, a region subjected to a significant wildfire event during the summer of 2022. The images represent a comprehensive chronicle of the forest's journey over a span of three pivotal years. Among these images, three were captured in the year 2021, offering a valuable insight into the pre-fire conditions of the forest. Another crucial image was obtained during the peak of the wildfire in 2022. Finally, three post-fire images from 2023 complete the series, enabling us to observe the gradual process of recovery and regeneration.

This research contributes to the ongoing efforts in studying Mediterranean forests, emphasizing the essential role played by NBR and LST to assess the repercussions of wildfires on these landscapes.

2. Materials and Methods

2.1. Study Area

Our research is centered on Bou Jedyane, a Mediterranean forest situated in the northern region of Morocco (35.1167° N, 5.7754° W) (Figure 1), which experienced a wildfire during the summer of 2022 scorching 308 km^2 of its total area.

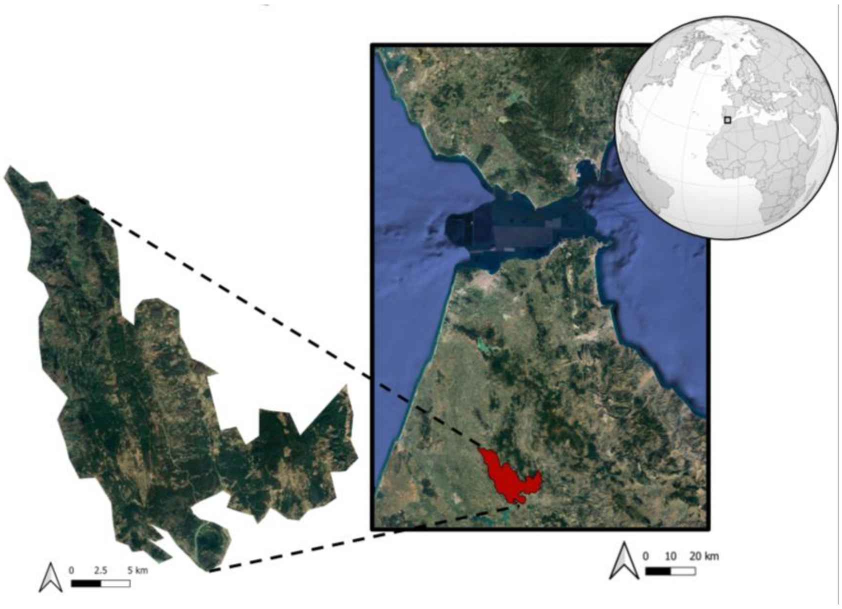

Figure 1. Study area.

2.2. Satellite Data

Landsat-8 is a satellite that observes the Earth's land surfaces with two advanced sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). It was launched in 2013 by NASA and the USGS to continue the Landsat program of collecting and archiving medium resolution multispectral image data. To compute NBR and LST, we employed a series of seven Landsat-8 images, covering a span of three years: three images taken in 2021, representing the pre-fire conditions, one image captured during the summer of 2022, corresponding to the fire period, and three additional images from 2023, signifying the post-fire phase (Table 1). We used specifically, four bands Red, NIR, SWIR2, and TIRS1, the characteristics of which are displayed in Table 2.

Table 1. Downloaded Landsat-8 images.

Year	Season	Image's Acquisition Date
2021	Winter	12 January 2021
	Spring	4 May 2021
	Summer	8 August 2021
2022	Summer	19 August 2022
2023	Winter	26 January 2023
	Spring	10 May 2023
	Summer	14 August 2023

Table 2. 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
Shortwave Infrared (SWIR 2)	Band 7	2.11–2.29	30
TIRS 1	Band 10	10.6–11.19	100

Landsat-8 images were initially acquired from USGS website (https://earthexplorer.usgs.gov/) at level-2 processing, (i.e., calibrated and atmospherically corrected). Our pre-processing procedures involved rescaling, resampling to unify the resolution, and clipping using mask layer [7].

2.3. Normalized Burn Ratio

In this study we employed NBR, a well-established biophysical index commonly utilized for assessing the severity of fire-induced changes in landscapes [8,9]. NBR relies on specific spectral bands, namely the NIR (i.e., band 5) and SWIR 2 (i.e., band 7), incorporated in the equation below.

$$\text{NBR} = (\text{Band 5} - \text{Band 7})/(\text{Band 5} + \text{Band 7}) \quad (1)$$

2.4. Land Surface Temperature

For LST, we followed a meticulous process [10,11]. This process entails a step-by-step calculation approach, commencing with the determination of the proportion of vegetation (Pv) (Equation (2)). Following this step, we incorporated measurements of emissivity (ε) as outlined in Equation (3). Finally, using band 10 we computed LST (Equation (4)).

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

$$\varepsilon = 0.004 \times \text{Pv} + 0.986 \quad (3)$$

$$\text{LST} = (\text{Band 10}/(1 + (0.00115 \times \text{Band 10}/1.4388) \times \text{Ln}(\varepsilon))) \quad (4)$$

3. Results and Discussion

After computing seven images of LST and NBR (i.e., three pre-fire, one during fire period, and three post-fire) (Figure 2), we extracted their mean and then generated time series (Figure 3).

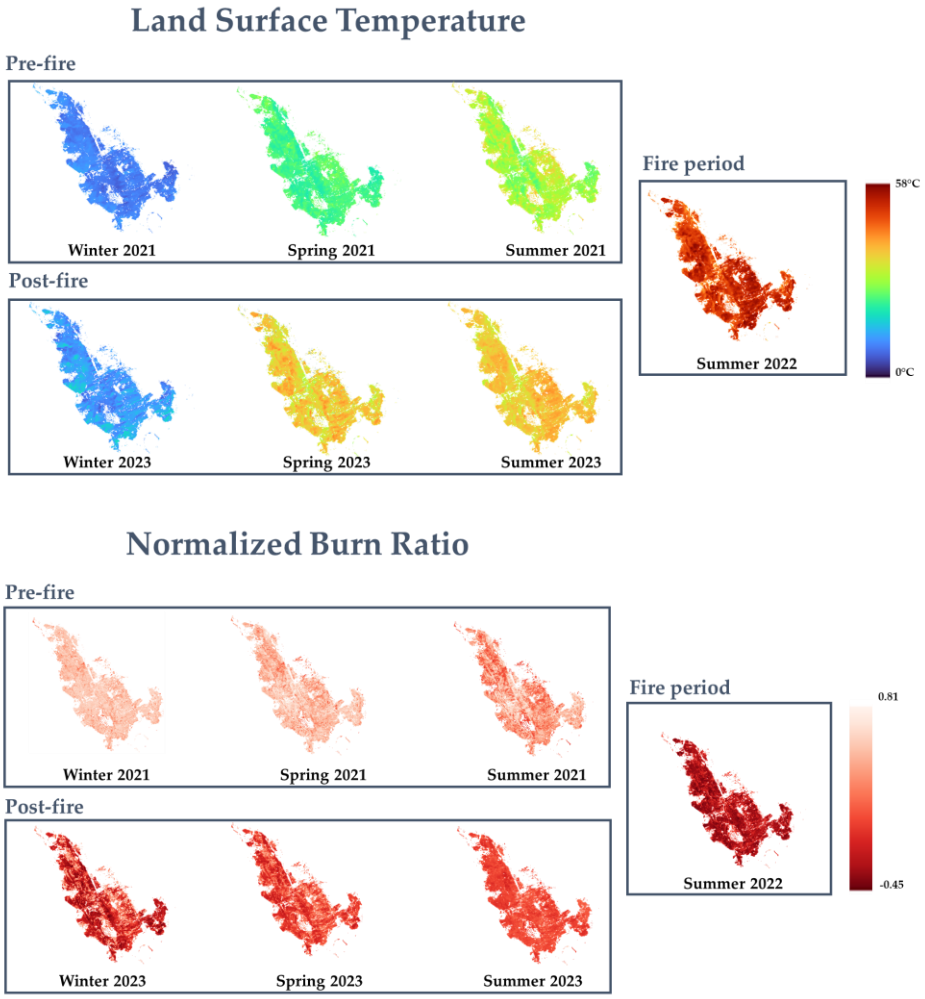

Figure 2. Bou Jedyane forest LST and NBR images.

From this study, we observed a consistent negative correlation between Land Surface Temperature (LST) and the Normalized Burn Ratio (NBR) in both the pre-fire (i.e., winter, spring, and summer of 2021). Same as the fire period (i.e., summer of 2022), LST increased reaching its highest temperature (i.e., 50 °C), and NBR decreased, signifying a substantial deterioration in vegetation health.

During the recovery period in 2023, LST exhibited normal seasonal fluctuations. Dropping to 12 °C in winter of 2023 after peaking in the fire period (i.e., 50 °C), only to rise in the subsequent spring and summer, reaching 36 °C and 37 °C, respectively. This pattern reflects the expected temperature variations in the study area, which is characteristic of seasonal changes in Mediterranean climates. In contrast to LST, NBR demonstrated a different behavior during the recovery phase. It gradually increased over time, moving from −0.2 in the immediate aftermath of the fire to −0.04 in winter and eventually rising to 0.03 in the summer of 2023. This upward trend indicates the gradual restoration of vegetation in the study area during the post-fire recovery period.

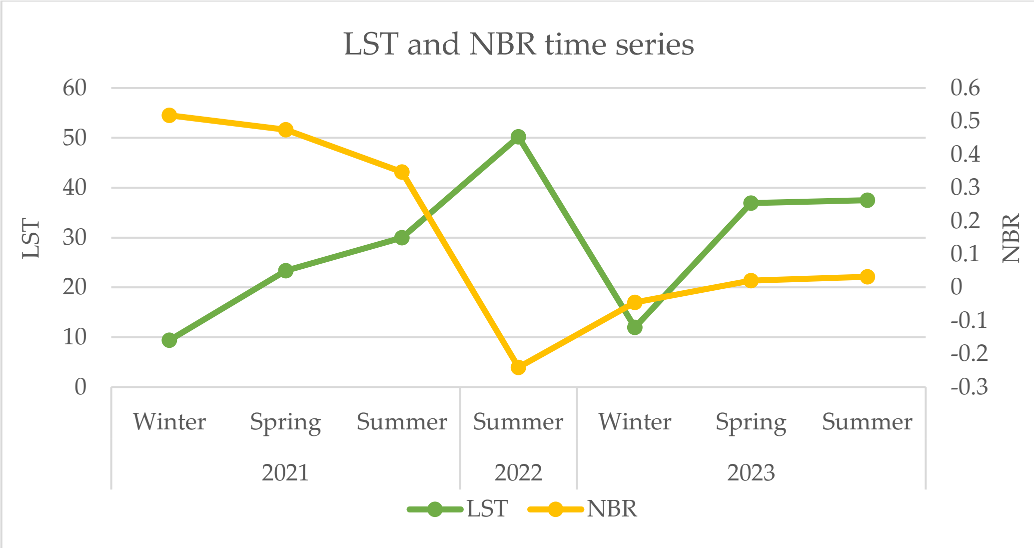

Figure 3. Bou Jedyane forest LST and NBR time series.

4. Conclusions

Our study provides important insights into how Normalized Burn Ratio (NBR) and Land Surface Temperature (LST) respond to wildfires in Mediterranean forest ecosystems. We analyzed the case of Bou Jedyane forest, and we found a negative correlation between these indices before and during the fire period. However, in the post-fire recovery phase, they showed different patterns: NBR increased steadily, indicating the gradual restoration of vegetation, while LST varied according to seasons. Therefore, our research highlights the robustness of NBR as an indicator of vegetation recovery after wildfires, and the need to integrate both NBR and LST assessments for a comprehensive understanding of fire impacts. This approach enhances our ability to monitor and manage Mediterranean forest ecosystems effectively, especially in the face of increasing wildfire challenges.

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