Evaluation of Several Spectral Indices to Produce Post Fire Maps (Case Study: Cedar-Fir Protected Area, Syria)

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Abstract

In this study, the application of four spectral indices (BAIS2, GEMI, NDVI, NBR) derived from sentinel 2 to map the burned areas for the Cedar-Fir Protected area was evaluated. Although the study area is considered as natural reserve, which is located in the top of coastal mountains (Slinfeh) in Syria, it was exposed to a large fire in the Fall of 2020. We used two Sentinel 2A images acquired before and after the fire on September 4 and October 22 2020. The studied Post-fire indices showed a similar spatial distribution for the burned area, with a preference for BIAS2 index. BIAS2 and dBAIS2 gave the best coefficient of variation value, which reached 40%. On the other hand, BIAS2 and dBAIS2 also recorded the highest values of Separation Index (more than 1). All indices which calculated from the difference between the before and after fire images gave higher values of the SI, as calculating the difference reduces errors in the classification of burned areas. The BIAS2 index takes advantage of the spectral bands in the Red Edge range provided by Sentinel 2A data and provides an important tool for accurately mapping fire in the Cedar-Fir protected area.

Keywords: Burned Area Indices**.;** Cedar- Fir Protected Area; Forest Fires; Sentinel 2A; Separation Index.

Introduction

Fire is one of the main causes of environmental change in Mediterranean forest ecosystems, so accurate knowledge of burned areas and fire intensity is essential for fire management, planning and monitoring of forest cover recovery (Brewer *et al.,* 2005; Fernández-Manso & Quintano, 2015), especially that the increase in the number, area, and frequency of fires in the Mediterranean region means that their effect on the natural regeneration after fires will become related to the environmental management of the burned areas (Pausas *et al*., 2008).

Protected areas are usually implemented for biodiversity conservation, and despite the management planning process is strictly going to protect biodiversity, the fire which had shaped what we aim to protect, is often forgotten to be managed. This harsh protection is producing important changes in the protected habitats and is increasing their vulnerability to destructive wildfires (Pereira et al., 2012).

Remote sensing and satellite imagery play an important role in assessing and monitoring forest disturbances due to various causes (Kalacska *et al*., 2005), as satellite images allow detecting the patterns of change (Merhej *et al*., 2021), and predicting what the situation will look like in

the future (Hamad *et al*., 2018). Rapid mapping of the extent and intensity of forest fires is a key support for forest fire management and the development of forest recovery plans (Chuvieco, 2009).
The determination of the burnet area, the intensity of the fire, and the recovery of the forest after a fire is related to the changes in the spectral values and their temporal dynamics, as many spectral indices that are able to accurately determine these spectral changes can be calculated and followed up on the temporal level through the use of series satellite images of the same area. By observing the temporal changes of these indices. we can describe the recoveries, succession and environmental distributions of vegetation cover (Bartels *et al*., 2016).
Spectral indices, obtained by a combination of data acquired at different spectral regions, are widely used for vegetation monitoring and assessment in fire-related studies (e.g., Chuvieco *et al.*, 2004; López *et al.*, 2002; Mbow *et al.*, 2004). However, when dealing with vegetation monitoring or characterization, there still remains certain confusion when choosing the most suitable index to be used depending on the study objectives. The Cedar-fir protected area is the main natural region for *Cedrus lebani* L. and *Abies Cilicica* L. in Syria, it was exposed to a major fire in the fall of 2020, which affected a large part of the eastern aspect, where the only natural spot of Lebanese cedar in Syria is found. This research aims to evaluate the application of some spectral indices to produce a map of the post fire took place September 5-8, 2020 in the Cedar-fir protected area.

Material and Methods

1. Study area

The Cedar-Fir protected area whose surface area is 88.5 km, located in the top of eastern mountains of the governorate of Lattakia, in northwestern of Syria, between latitudes 35.41 and 35.29 north, and longitudes 36.10 and 36.17 east, Figure (1).
The protected area has a typical Mediterranean climate, where the average annual rainfall ranges between 1390 and 2092 mm/year. Cedar and Fir forests of studied zone characterized by little summer rain that corresponds to the maximum temperatures resulting in a dry period lasting 3-4 months (June, July, August, September) are of environmental importance in their impact on species and ecosystems. The climate of the protected area is also characterized by the presence of snow and low temperatures during the winter, as the average minimum temperature for the coldest month (January and February) ranges between 0.8 and 2.4, depending on the height above sea level and exposure.
The protected area altitude ranges between 900 - 1560 meters, and its lowest point is the Jeb Al Shuh site. The eastern aspect slope reaches 35 degrees, while the slope of the western aspect ranges between 20 and 27 degrees (Ali, 2006).
The Cedar-Fir protected area was exposed to a major fire on 5-8 September/ 2020, the study samples were randomly taken during the months of September and October (30 samples in burned areas and 30 samples in non-burned areas), so that these samples included the entire area of the protected area on its eastern and western aspects (Fig 1).

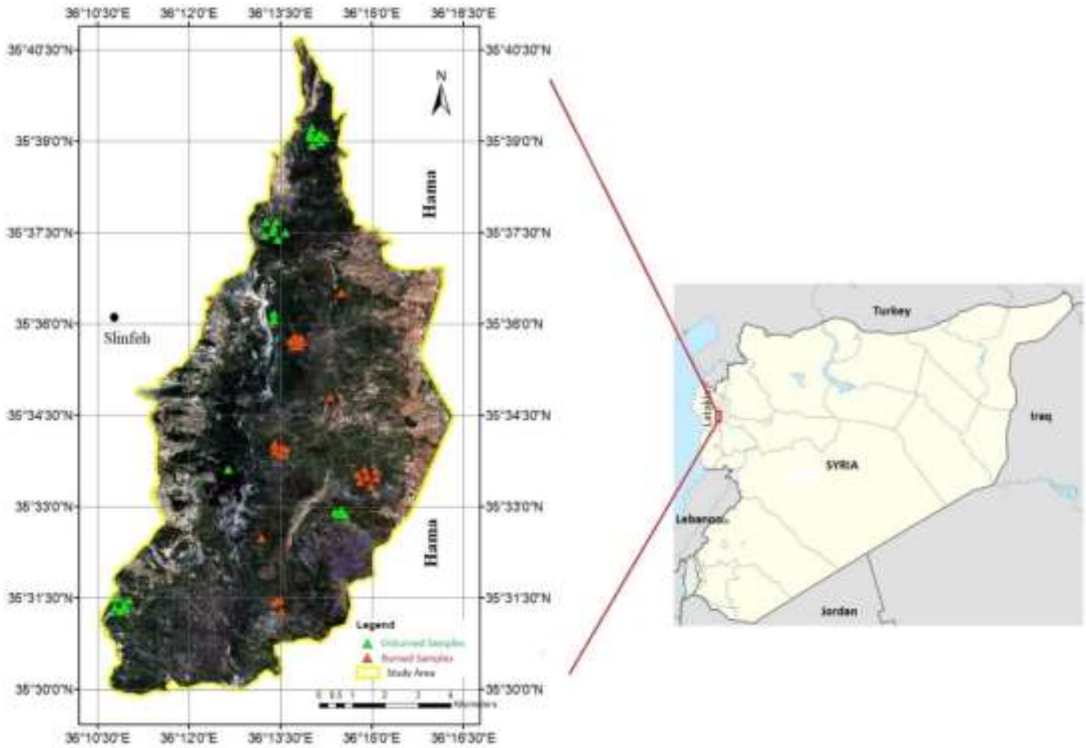

Figure (1): Location of the study area (Cedar-Fir protected area).

2. Spectral indices

From a wide range of spectral indices found in the fire studies, we selected four of them, calculated from Sentinel 2A images, which are freely available from Copernicus. Two images were used before and after the fire, acquired on September 4 and October 22, 2020, as they were downloaded corrected to the L2A level (Bottom Of the Atmosphere reflectance).

Table (1) shows the image bands and their spatial resolutions which range between 10 to 60 m. Using SNAP[1] software, we applied the resampling process to standardized all bands to 10 m resolution. The next step was cutting the study area out of each image by applying subset process, then we calculated the studied indices. Table (2) shows these indices and equations calculated.

Table (1): Sentinel 2 Bands.

Sentinel 2 Bands	Central Wavelength (μm)	Spatial Resolution (m)
Band 1- Coastal aerosol	0.443	60
Band 2- Blue	0.490	10
Band 3- Green	0.560	10
Band 4- Red	0.665	10
Band 5- Vegetation Red Edge	0.705	20
Band 6- Vegetation Red Edge	0.740	20
Band 7- Vegetation Red Edge	0.783	20
Band 8- NIR	0.842	10
Band 8A- Vegetation Red	0.865	20

[1] ESA SNAP from European Space Agency, Version 7.0

Edge		
Band 9- Water vapor	0.945	60
Band 10- SWIR- Cirrus	1.375	60
Band 11- SWIR	1.610	20
Band 12- SWIR	2.190	20

Table(2): List of spectral indices and their equations.

Reference	Equation	Abbreviation	Index Name
Rouse *et al*., 1973	$\frac{B4 - B8}{B4 + B8}$	NDVI	**Normalized Difference Vegetation Index**
Pinty *et al*., 1992	$\gamma(1 - 0.25 \times \gamma) - \frac{B4 - 0.125}{1 - B4}$	GEMI[2]	**Global Environmental Monitoring Index**
Key & Benson, 2006	$\frac{B8 - B12}{B8 + B12}$	NBR	**Normalized Burn Ratio**
Filipponi, 2018	$\left(1 - \sqrt{\frac{B6 * B7 * B8A}{B4}}\right) * \left(\frac{B12 - B8A}{\sqrt{B12 + B8A}} + 1\right.$	BAIS2	**Burned Area Index for Sentinel 2A**

Where:

B4 is the reflectance in the red band (Red);

B6, B7, B8A reflectance in Vegetation Red Edge bands where center wavelength is (0.740), (0.783) and (0.865) respectively;

B8 is the reflectance in the near infrared band (NIR);

B12 is the reflectance in the short-wave infrared band (SWIR);

One of the most popular and widely used spectral indices is NDVI because its simplicity and relatively good performance. The NDVI uses only the reflectance values in the red and near infrared bands, where plant damage due to fires causes a significant decrease in NDVI values. It has been widely used to produce maps of burned areas, assess burn severity and monitor restoration of vegetation (Escuin *et al*., 2008; Kennedy *et al*., 2010; Hudak *et al*., 2007; Vogelmann *et al*., 2012; Schmidt *et al*., 2015).

Similar to NDVI, GEMI uses red and near-infrared bands but has been designed with a nonlinear approach in an effort to minimize unwanted atmospheric effects. Although its application to detect the effects of fires was mainly done using MODIS and SPOT sensors (Cao *et al*., 2009; Stroppiana *et al*., 2002; Lasaponara, 2006), Given the Sentinel sensor is relatively recent, dating back to 2016, therefore a few studies have calculated the GEMI index using Sentinel images to map post forest fire.

Initially designed to extract and map the burned area, NBR is the most common spectral index used to assess the intensity of a fire using various sensors in many ecosystems, and the NBR

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[2] $\gamma = (2(NIR^2 - Red^2) + 1.5 \times NIR + 0.5 \times Red)/(NIR + Red + 0.5)$

has proven to be one of the most efficient spectral indices (Veraverbeke *et al*., 2010; Harris *et al*., 2011; Epting *et al*., 2005; Schepers *et al*., 2014). It also showed through time series analysis a significant correlation with fire intensity levels and the amount of recovery after years of fire, and thus it represents an effective tool for monitoring vegetation restoration (Hislop *et al*., 2018; Chen *et al*., 2011). Unlike previous indices, NBR uses the SWIR short-wave spectral channel instead of the visible red, which has been shown to be sensitive to changes in reflection caused by fire.

The BAIS2 index is a modified version of the Burned Area Index "BAI" designed for Sentinel 2A satellite imagery, which includes several spectral channels for data recording in the "Vegetation RED EDGE" spectral field, which is one of the best spectral domains describing the chlorophyll content. A spectral mixture of the aforementioned red, NIR, SWIR and vegetation red edge bands is suitable for detecting the burned area (Curran *et al*., 1990).

The difference indices for each of studied spectral index were derived from the difference in the index values calculated from images before and after the fire; as follows:

$dNDVI = NDVI_{pre\ fire} - NDVI_{post\ fire}$

$dGEMI = GEMI_{pre\ fire} - GEMI_{post\ fire}$

$dNBR = NBR_{pre\ fire} - NBR_{post\ fire}$

$dBAIS2 = BAIS2_{pre\ fire} - BAIS2_{post\ fire}$

3. Assessment indices

To measure the discrimination ability of each spectral index, Separability index was computed for images acquired after the fire and for the differences between pre- and post-fire images from the following equation:

$$SI = \frac{|\mu b - \mu u|}{\sigma_b - \sigma_u}$$

Where μb, μu: are the mean values of the studied indices calculated for samples from the burned and non-burned areas distributed within the images, σ_b and σ_u are the standard deviations values of the studied indices and the samples themselves (Lasaponara, 2006).

Using the SI index to measure the spectral sensitivity for the fire area and intensity of the calculated indices was evaluated in several studies (Mallinis *et al*., 2018; Kaufman & Remer, 1994; Veraverbeke *et al*., 2001; Filipponi, 2018). If the calculated SI value is higher than 1, the SI demonstrate that the index allows good separation between burnt and unburned areas.

Some other statistical indices were also used to evaluate the studied indices ability of separating the burned and unburned samples; which are:

Average standardized values = ((x-μ)/σ) n

Coefficient of Variation (cv%) = σ/μ

Where: x is the observation (index value in a pixel), n: number of pixels, μ and σ are the mean and the standard deviation values, respectively, of the studied spectral indices calculated for samples from the burned and non-burned areas. The x, n, μ and σ for each spectral index can be found in the metadata file.

Result and Discussion

Figure (2) shows BAIS2, GEMI, NBR, and NDVI indices derived from Sentinel 2A images before and after the September 5-8 fire in the Cedar-Fir protected area, where all indices show similar spatial patterns and distribution of burned areas in the reserve, but the contrast between burned and unburned areas in the maps of BAIS2 index appears more clearly than the rest of the indices. On the other hand, BAIS2 represents the most different values between the burned and unburned areas in the post-fire image and in the difference between before and after the fire images, as shown in Figure (3).

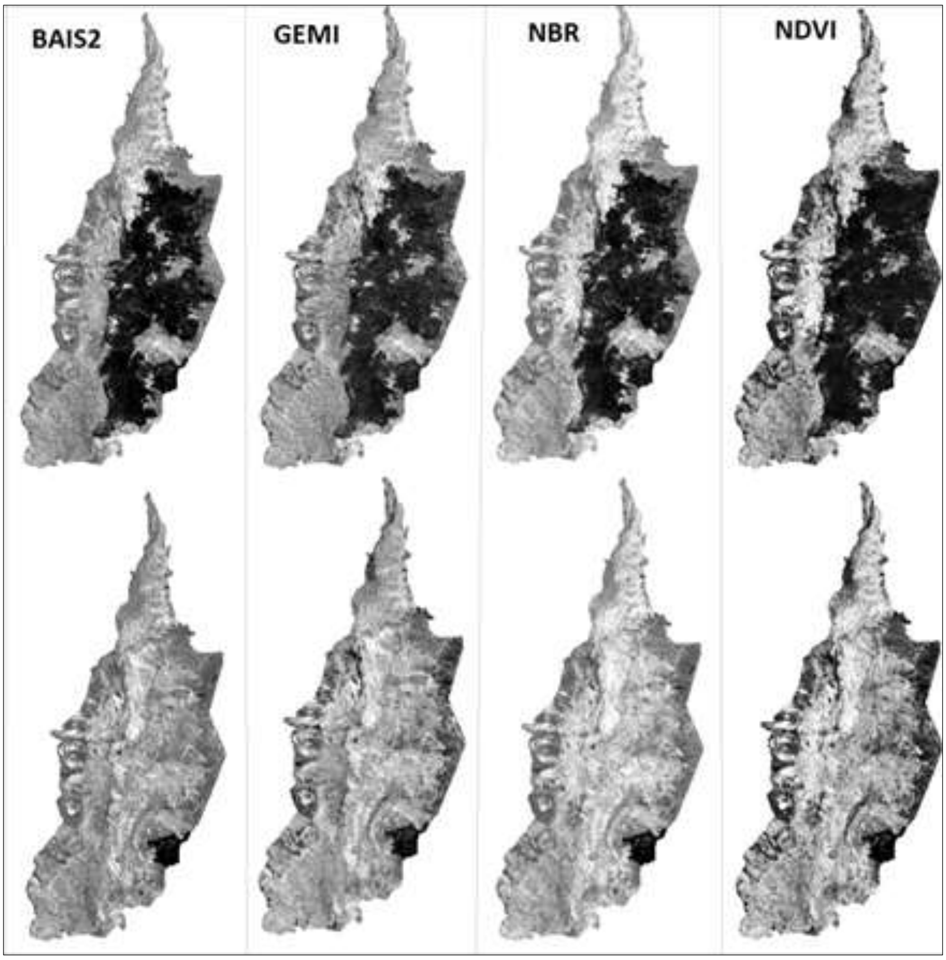

Figure (2): Spectral indices derived from Sentinel 2A images after (top) and before (bottom) the 5-6 September 2020 fire in the Cedar- Fir Protected area.

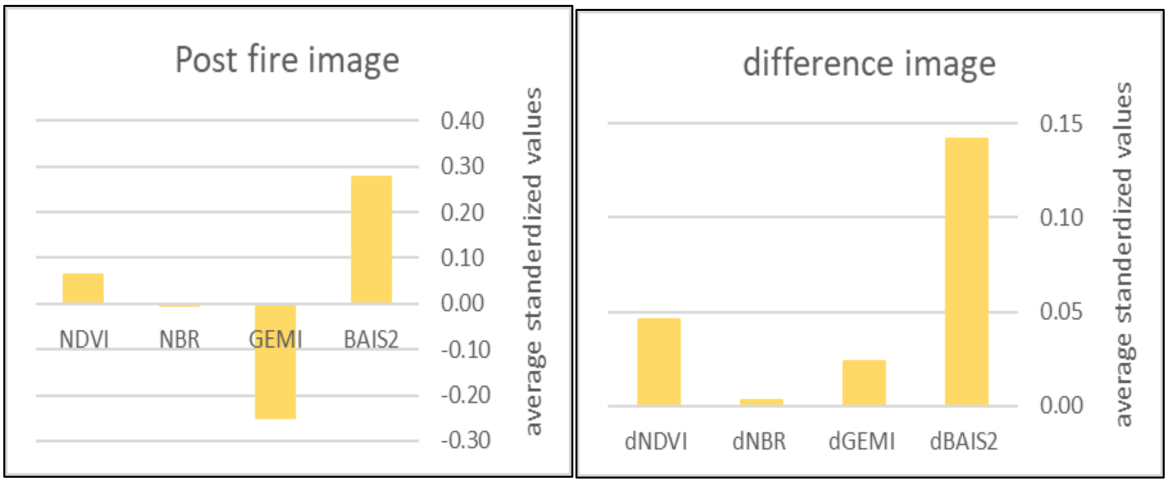

Figure (3): Average standardized values of the studied spectral indices in Cedar-Fir protected area (from Sentinel 2A data).

Figure 4. shows Coefficient of Variation (cv%) for the different spectral indices for Sentinel 2A post fire images in the protected area. BAIS2 and its dBAIS2 derived version obtained a score slightly higher than the correspondent NDVI index. BAIS2 also shows a significant coefficient of variation (cv%) over 40%, and NBR closes to 20% The high values of the coefficient of variation in the indices computed from the post-fire images indicate the spatial differences and the possibility of differentiating between burned and unburned areas due to the density of vegetation in the study area before the fire. In contrast, the NDVI index provides the lowest coefficient of variation between the indices calculated for the Cedar- Fir protected area with a value of 12%, which implies a lower discrimination for internal differences in the burned areas (Fig. 4).

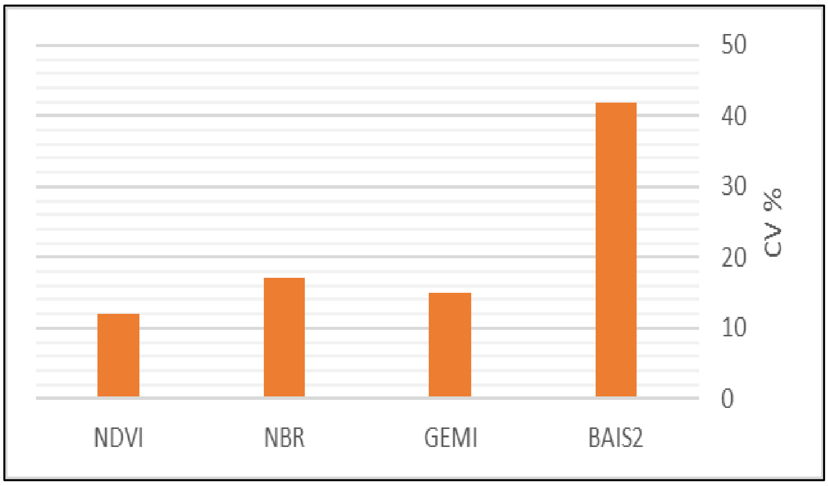

Figure (4): Coefficient of Variation (cv%) for the different spectral indices for Sentinel 2A post fire images in the protected area.

Statistics of the SI calculation are shown in Figure (5). As values greater than 1 should allow a good separation of the burnt areas, while a value smaller than 1 indicates a weak discriminant ability (Veraverbeke *et al*., 2001).

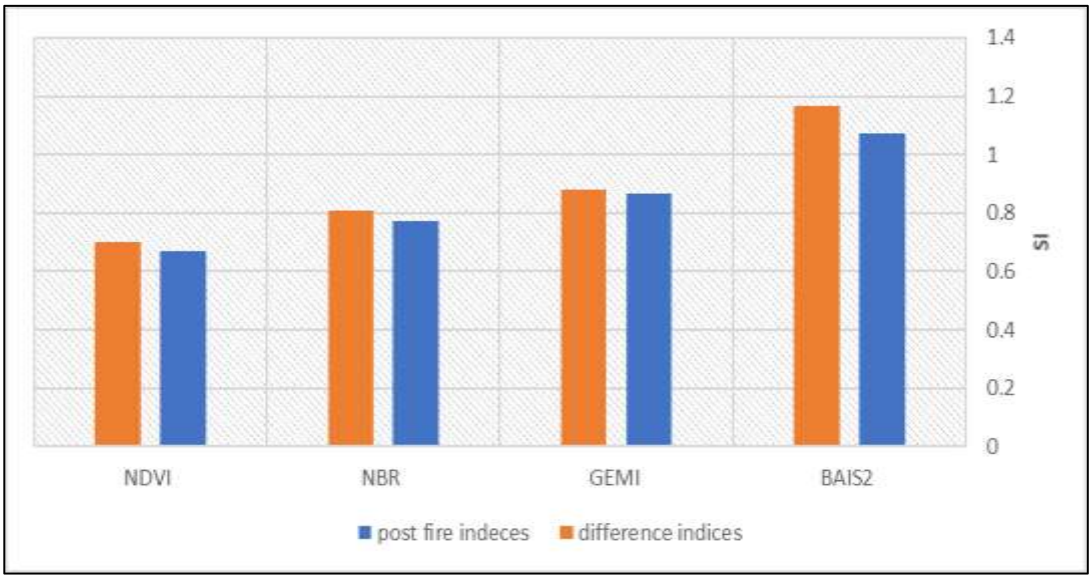

Figure (5): SI values for the studied indices.

For burned land mapping, thresholds for BAIS2 index should be very sensitive because it shows a high variability within burned areas. The index discriminates consistently burned areas

where charcoal signal prevails. It shows a high discrimination ability for burned areas in the Red Edge spectral domain, being more sensitive to burnt areas than NDVI, GEMI and NBR.
BAIS2 index discriminates consistently burned areas where charcoal signal prevails. It shows a high discrimination ability for burned areas in the Red Edge spectral domain, being more sensitive to burnt areas than NDVI, GEMI and NBR. As shown in Figure (5), post fire BAIS2 and dBAIS2 got the highest value with a preference for dBAIS2, which means that the two indices are able to separate the burned and unburned areas better than other indices. The results obtained from this study differ significantly from those obtained by Mallinis *et al*. (2018), indicating that these scores may depend strongly on the studied dataset, images used and classification problems, especially in points of low severity (Quintano *et al*., 2018; Cocke *et al*., 2005).
The indices of the difference between before and post fire images gave, for most of the studied indices, better results when compared to the indices derived from the post fire image only, because they depend on the estimation of the change in vegetation cover (Fig.5). Studies recommend the adoption of differential indices in order to reduce errors in the classification of burned areas, and the use of a time series of indices determines the exact time in which forest fires occurred and reduces errors resulting from ash removal (whether by rain or other factors) and recovery of vegetation (Fernández-Manso *et al*., 2016).

Conclusions

The accuracy of some spectral indices was compared in order to map the burned area in the Cedar-Fir protected area. The study results showed that BAIS2 performed well in distinguishing burnt from unburned areas compared to the other studied spectral indices (GEMI, NBR, and NDVI), whilst the NDVI index provides the lowest coefficient of variation, which implies lower discrimination for internal differences in the burned areas. Fire intensity data and maps can help to develop post-fire contingency plans for forest rehabilitation and recovery.

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تقييم عدة مؤشرات طيفية مستخدمة في إنتاج خرائط الحرائق (حالة دراسية: محمية الأرز والشوح، سورية)

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الملخص

تم في هذه الدراسة تقييم تطبيق أربعة مؤشرات طيفية (BAIS2, GEMI, NDVI, NBR) مشتقة من صور سينتينال 2أ في رسم خرائط المناطق المحترقة في محمية الأرز والشوح. على الرغم من أن منطقة الدراسة هي محمية تقع في الجبال الساحلية السورية، إلا أنها تعرضت لحريق كبير في خريف عام 2020. استخدمت صورتان من نوع Sentinel 2A ملتقطتين قبل وبعد الحريق في 4 أيلول و22 تشرين الأول 2020. أظهرت المؤشرات المدروسة توزعاً مكانياً متشابهاً للمنطقة المحترقة، مع أفضلية لمؤشر BIAS2. أعطت مؤشرات BIAS2 وdBAIS2 أفضل قيمة لمعامل التباين بلغت 40%. من ناحية أخرى، سجل مؤشرا BIAS2 وdBAIS2 أعلى قيم لمؤشر الفصل (أكثر من 1). أعطت جميع المؤشرات التي تم حسابها من الفرق بين الصور قبل وبعد الحريق قيماً أعلى لمؤشر الفصل، حيث أن حساب الفرق يقلل من الأخطاء في تصنيف المناطق المحترقة. يستفيد مؤشر BIAS2 من النطاقات الطيفية في مجال Red Edge التي توفرها بيانات Sentinel 2A، ويقدم أداة مهمة لرسم خرائط دقيقة للحريق في محمية الأرز والشوح.

الكلمات المفتاحية: مؤشرات المساحة المحترقة، محمية الأرز والشوح، حرائق الغابات، سينتينال 2 أ، مؤشر الفصل.