Forest fire area detection using Sentinel-2 data: Case of the Beni Salah national forest – Algeria

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Abstract: Forest cover plays an important role in terms of biodiversity and the environment. The Beni Salah national forest in its part which is located in the Guelma province in the extreme northeast of Algeria is an illustrative example where forest fires represent the chronic phenomenon which weighs heavily on this forest. The present study comes after a forest fire that occurred in 2021, when 3 000 ha of this forest were ravaged by forest fires according to the conservation of forests of Guelma. The main objective of this research is to map the severity of burns and estimate the severely burned area using Sentinel-2 satellite images based on remote sensing indices such as Normalized Difference Vegetation Index (NDVI), Differenced Normalized Difference Vegetation Index (dNDVI), Normalized Burn Ratio (NBR), Differenced Normalized Burn Ratio (dNBR), Green Normalized Difference Vegetation Index (GNDVI), Differenced Green Normalized Difference Vegetation Index (dGNDVI), Burn Area Index (BAI) and Relativized Burn Ratio (RBR). The result obtained revealed that 28.23% of the study area represents a seriously burned area. The established burn severity map is a real decision-making tool, but it still has certain limitations.

Keywords: burn severity; forest fires; remote sensing index; satellite image; state forest

In recent decades, forests have been strongly affected by climate change and human activities (Thapa 2021). Climate change and human land use are causing forest fires that damage infrastructure and cause loss of life (Verma et al. 2019). In Algeria, forest fires are among the three greatest threats to life, property and economic activity (Meddour-Sahar, Christine 2013). Between 2010 and 2019, Algeria recorded nearly 3 000 fires which devastated the equivalent of 32 000 ha each year (Bouhabila 2019). Annual asset losses reached the dizzying figure of EUR 10 millions in 2020; the compensation paid to victims amounted to EUR 4 millions (Kutter et al. 2021). The national forest of Beni Sale in its part located in the northwest of the Guelma province in the extreme northeast of Algeria is part of the national forest heritage. It is one of the most important forest massifs in the eastern region of the country (Charfi 2016). Forest fires represent the natural threat and the chronic phenomenon that weighs heavily on this forest massif. According to the conservation of Guelma forests, an area of 5 000 ha of forests and natural areas was ravaged by fires in 2017. In 2021, this forest did not
escape the phenomenon of fires; the area destroyed being estimated at 3 000 ha. According to the district of Bouchegouf forests, this forest massif in its part of the Guelma province loses between 50 ha and 100 ha of its forest cover each year. However, the years 2017 and 2021 remain the most severe in terms of the area destroyed. This forest suffers from the effects of degradation because of its floristic composition in very combustible species, the Mediterranean climate (hot and dry in summer) which favours the outbreak of fires and the anthropic activity which exerts a rather strong pressure on this forest massif. For sustainable forest management at the scale of this national forest, the establishment of an early warning system has now become necessary to fight against forest fires. The traditional method of prevention is no longer suited to current needs (Missoumi, Tadjerouni 2003). Whereas today remote sensing can contribute to the prediction and prevention of fires to protect forests, by offering up-to-date information on the surface of the earth in order to detect forest fires (Alkhatib 2014). The purpose of this research is to delimit the area ravaged by forest fires in 2021 and to map the severity of burns at the scale of the Beni Salah national forest in its part located in the Guelma province using data from the Sentinel-2 program, using the following indices: Normalized Difference Vegetation Index (NDVI), Normalized Burn Ratio (NBR), Green Normalized Difference Vegetation Index (GNDVI), Differenced Normalized Difference Vegetation Index (dNDVI), Differenced Normalized Burn Ratio (dNBR), Differenced Green Normalized Difference Vegetation Index (dGNDVI), Relativized Burn Ratio (RBR), and Burn Area Index (BAI) to identify burnt areas and analyse burn severity.

MATERIAL AND METHODS

Study area

The Beni Salah national forest is located in the extreme northeast of Algeria, with an area of 35 000 ha; it spreads over the territories of three provinces which are: El-Tarf, Souk Ahra and Guelma. This forest massif is home to the Barbary deer, an endangered species, mammals and an exceptional fauna and flora heritage. The part devoted to this study, which is located in the northeast of the Guelma province, occupies an area of 12 555 ha spread over two municipalities (Bouchegouf 7 130 ha and Medjez Sfa 5 425 ha). It is limited to the north and east by the El Taref province, to the south by the Souk Ahras province and to the west it extends into the territory of the Bouchegouf and Medjez Sfa municipalities (Figure 1). The climate in this forest is of the subhumid Mediterranean type, characterized by cold winters and hot summers with rainfall amounts varying between 600 mm-year$^{-1}$ and 800 mm-year$^{-1}$. The average annual temperature is around 18 °C. The hottest months are July and August when the average temperature is around 25 °C. The coldest months are December and January with average temperatures around 12 °C. The forest cover in this part of the study area is very diverse and takes different forms, globally distributed; in cork oak, zeen oak, maquis and some reforestation including eucalyptus.

Data used

In such a study as the case of the Beni Salah national forest it is necessary to be able to detect the zones of forest fires to resort to remote sensing. This study is based on the processing of images from the Sentinel-2 program acquired before and after the fires of 2021 using the software ArGSI (Version 10.3, 2015) and ENVI (Version 5.3, 2015). The base satellite images of this work are downloaded free of charge from the Earth Explorer website (Table 1). The near infrared spectral band (B8) is resembling at a resolution of 10 meters for a good combination with the other bands used in this way to avoid any affection of the raster data during the calculation operations. Thus, the working resolution is 10 m, and the projection system applied to all our data is Universal Transverse Mercator zone 32 N.

Methodology

To detect forest fire areas that occurred in the Beni Salah national forest on August 14, 2021, when the forest fire ravaged 3 000 ha of cork oak, zeen oak and maquis according to the declaration of the conservation of the Guelma forests, two satellite images from the Sentinel-2 program were used. The methodology is based on the processing of images selected before and after the fires using the spectral

<table>
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<tr>
<th>Sensor</th>
<th>Seasons</th>
<th>Acquisition date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel-2</td>
<td>summer (before the fires)</td>
<td>June 22, 2021</td>
</tr>
<tr>
<td></td>
<td>summer (after the fires)</td>
<td>August 16, 2021</td>
</tr>
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Table 1. Sentinel 2 images used
indices. Burn severity is mapped and quantified using object-based classification techniques.

**Spectral indices used**

**Normalized Difference Vegetation Index (NDVI).** The Normalized Difference Vegetation Index is used to generate an image displaying the vegetation cover. It is an index that uses the visible and near infrared bands of the electromagnetic spectrum (Rouse et al. 1973). NDVI values range from –1 to 1, with negative values corresponding to areas other than vegetation cover. Its Formula (1) is written as follows:

\[
NDVI = \frac{NIR - R}{NIR + R} \tag{1}
\]

where:
- \(NIR\) – near infrared (Band 8 for Sentinel-2);
- \(R\) – red (Band 4 for Sentinel-2).

**Differenced Normalized Difference Vegetation Index (dNDVI).** The Differenced Normalized Difference Vegetation Index (dNDVI) is calculated from the NDVI before the fire and the NDVI after the fire (Kurnaz et al. 2020), according to Formula (2).

\[
dNDVI = NDVI_{\text{pre-fire}} - NDVI_{\text{post-fire}} \tag{2}
\]

**Normalized Burn Ratio (NBR).** The Normalized Burn Ratio (NBR) allows the highlighting of burnt areas and also evaluating the burn severity using satellite images. The formula of NBR is very similar to that of NDVI [Formula (3)], except that it uses the near infrared band and the short-wave infrared band (Escuin et al. 2008).

\[
NBR = \frac{NIR - SWIR}{NIR + SWIR} \tag{3}
\]

where:
- \(SWIR\) – short-wave infrared (Band 12 for Sentinel-2).

**Differenced Normalized Burn Ratio (dNBR).** The dNBR difference between two NBRs of two successive dates is subtracted directly from the NBR before the fire and the NBR after the fire (Mallinis et al. 2018) [Formula (4)]. The fire occurred in areas with positive grey values in the dNBR index while areas with negative values are not affected by fire.

\[
dNBR = NBR_{\text{pre-fire}} - NBR_{\text{post-fire}} \tag{4}
\]

**Green Normalized Difference Vegetation Index (GNDVI).** This is the index that uses the green band instead of the red band to distinguish stressed vegetation (Li et al. 2014). Its Formula (5) is written as follows:

\[
GNDVI = \frac{NIR - SGN}{NIR + SGN} \tag{5}
\]

where:
- \(SGN\) – short-green band (Band 7 for Sentinel-2).
RESULTS

The raster calculation is carried out using the raster calculator algorithm of the ArcGis software in order to apply mathematical formulas to calculate the indices mentioned above. This application made it possible to classify each index into 5 classes.

Figure 2 shows that the normalized difference vegetation index (NDVI) of the study area decreased to a value higher than 0.66 and lower than –0.28 after the fire, while these values were between 0.75 and 0.10 before the fire. However, the normalized burn ratio (NBR) illustrates high values during the pre-fire period, indicating healthy vegetation; however, after the fire these values are reduced which shows burnt areas with bare soil.

Figure 3 illustrates high values of GNDVI and BAI before the fire. These values are regressed after the fire, indicating vegetation stress with burnt areas. Areas that have a red colour clearly increase in the GNDVI and BAI after the fire, indicating burnt areas and stressed vegetation.

The classification of the dNBR index made it possible to estimate the area affected by forest fires. Table 3 shows that the unburned area represents 45.01% of the study area. Areas of low severity occupy 21.42%, while those with moderate low severity...
Figure 2. NDVI (Normalized Difference Vegetation Index) and NBR (Normalized Burn Ratio) of the study area before and after the fire: (A) NDVI pre-fire; (B) NDVI post-fire; (C) NBR pre-fire and (D) NBR post-fire

Figure 3. Green Normalized Difference Vegetation Index (GNDVI) and Burn Area Index (BAI) of the study area before and after the fire: (A) GNDVI pre-fire; (B) GNDVI post-fire; (C) BAI pre-fire and (D) BAI post-fire
Figure 4. (A) Differenced Normalized Difference Vegetation Index (dNDVI), (B) Differenced Green Normalized Difference Vegetation Index (dGNDVI), (C) Differenced Normalized Burn Ratio (dNBR) and (D) Relativized Burn Ratio (RBR) of the study area.

Figure 5. Classification of the dNBR index in five classes.

unburned
low severity
moderate-low severity
moderate-high severity
high severity
The detection of burned forest areas using satellite images from the Sentinel-2 program, based on remote sensing indices, is one of the techniques currently most commonly used to estimate the area of forest fires. The established forest fire map still has some limitations, as this is the first time that this approach has been used to detect burned areas at the scale of the Beni Salah national forest. For the present study, high resolution satellite images may still give much better precision than Sentinel-2 images. This is explained by the phenomenon of climate change, drought, type of flammable vegetation (cork oak, zeen oak and Mediterranean-type maquis), human frequentation inside the forest, dense road infrastructure (national roads, provincial roads, municipal paths, forest tracks) and uneven terrain. At the scale of the Beni Salah forest in its part which lies in the Guelma province 28.23% of the total study area is at high risk, which is common in the rates of forest fires in the other regions of eastern Algeria with a very steep to steep slope. The remote sensing technique used in this research to map forest fires replaces that carried out in the field by traditional means that are costly and time-consuming. The result obtained using this technique is very fast, risk-free and economical. It contributes to the development of new techniques and methods used for the protection and management of the Beni Salah national forest using satellite images. In the absence of studies that address this issue of forest fires using remote sensing, the result obtained is closer to the reality on the ground according to the survey carried out two months later. The comparison of the result obtained with other studies carried out recently in other forest regions of the northeast of Algeria shows the relative reliability of the dNBR applied. Indeed, Boulgorba (2021) showed in a study on forest fires in the Khenchela region from Sentinel-2 images that the use of dNBR to detect burned areas gives a reliable and acceptable result of the ground. This comparison comes to add the result obtained in this study to the investigation of the ground. The result obtained, which confirms the reality on the ground, shows the potential of Sentinel-2 images for the detection of burned areas. It follows from the analyses that the Sentinel-2 images are of satisfactory quality to allow a good visualization of the unburned area and the burned areas. According to Labib and Harris (2018), the MSI sensors of the Sentinel-2 satellite show good performance in scene restitution with improved image readability and spatial resolution.

**DISCUSSION**

The detection of burned forest areas using satellite images from the Sentinel-2 program, based on remote sensing indices, is one of the techniques currently most commonly used to estimate the area of forest fires. The established forest fire map still has some limitations, as this is the first time that this approach has been used to detect burned areas at the scale of the Beni Salah national forest. For the present study, high resolution satellite images may still give much better precision than Sentinel-2 images. This is explained by the phenomenon of climate change, drought, type of flammable vegetation (cork oak, zeen oak and Mediterranean-type maquis), human frequentation inside the forest, dense road infrastructure (national roads, provincial roads, municipal paths, forest tracks) and uneven terrain. At the scale of the Beni Salah forest in its part which lies in the Guelma province 28.23% of the total study area is at high risk, which is common in the rates of forest fires in the other regions of eastern Algeria with a very steep to steep slope. The remote sensing technique used in this research to map forest fires replaces that carried out in the field by traditional means that are costly and time-consuming. The result obtained using this technique is very fast, risk-free and economical. It contributes to the development of new techniques and methods used for the protection and management of the Beni Salah national forest using satellite images. In the absence of studies that address this issue of forest fires using remote sensing, the result obtained is closer to the reality on the ground according to the survey carried out two months later. The comparison of the result obtained with other studies carried out recently in other forest regions of the northeast of Algeria shows the relative reliability of the dNBR applied. Indeed, Boulgorba (2021) showed in a study on forest fires in the Khenchela region from Sentinel-2 images that the use of dNBR to detect burned areas gives a reliable and acceptable result of the ground. This comparison comes to add the result obtained in this study to the investigation of the ground. The result obtained, which confirms the reality on the ground, shows the potential of Sentinel-2 images for the detection of burned areas. It follows from the analyses that the Sentinel-2 images are of satisfactory quality to allow a good visualization of the unburned area and the burned areas. According to Labib and Harris (2018), the MSI sensors of the Sentinel-2 satellite show good performance in scene restitution with improved image readability and spatial resolution.

**CONCLUSION**

The detection of the area of forest fires at the scale of the Beni Salah national forest in its part which is located in the Guelma province using Sentinel-2 images is essentially based on the application of these remote sensing indices: NDVI, dNDVI, GNDVI, dGNDVI, NBR, dNBR, BAI and RBR. The wildfire severity map is generated from the classification of the dNBR index into five classes according to the methodology proposed by the USGS. The result obtained shows that 28.23% of the study area represents a high to moderately high burn severity. Mapping burn severity and estimating the area of forest fires can be a useful planning database for decision-making. They are important for the conservation of the forests of Guelma province for the establishment of a program of reforestation of the seriously damaged area and to strengthen and expand the strategy of protection and the fight against fires. For the present zone, it is recommended to set up an effective surveillance system during the fire campaign. The creation of mobile brigades, the modernization of lookout posts, and the construction of trenches by fire, forest tracks and water points for rapid intervention on the site are mandatory pending the creation of a system of effective prevention which is essentially based on a new technology.
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