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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

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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 1. Sentinel 2 images used

Sensor	Seasons	Acquisition date
Sentinel-2	summer (before the fires)	June 22, 2021
	summer (after the fires)	August 16, 2021

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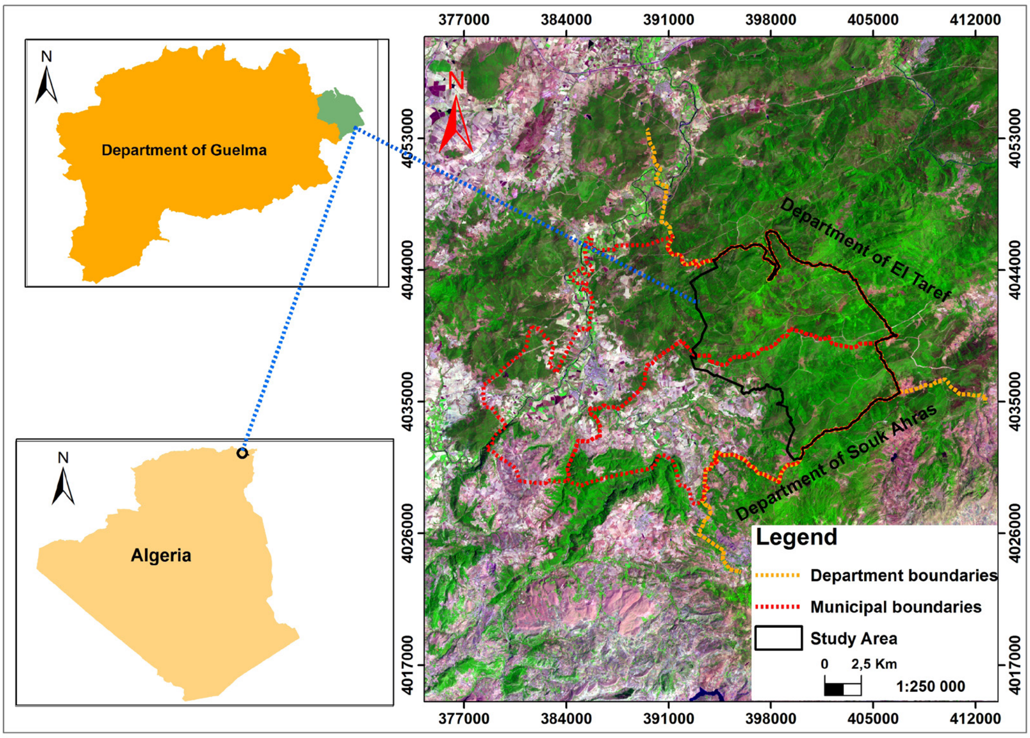

Figure 1. Location of the study area

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:

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

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).

$$dNDVI = NDVI_{\text{pre-fire}} - NDVI_{\text{post-fire}} \quad (2)$$

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).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \quad (3)$$

where:

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

Differenced Normalized Burn Ratio (*dNBR*). The *dNBR* difference between two *NBR*s 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.

$$dNBR = NBR_{\text{pre-fire}} - NBR_{\text{post-fire}} \quad (4)$$

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:

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$$GNDVI = \frac{NIR - G}{NIR + G} \quad (5)$$

where:

G – green (Band 3 for Sentinel-2).

Differenced Green Normalized Difference Vegetation Index (*dGNDVI*). It is an index to detect burned areas using a difference in *GNDVI* calculated from images before and after the fire (Kurnaz et al. 2020) [Formula (6)].

$$dGNDVI = GNDVI_{\text{pre-fire}} - GNDVI_{\text{post-fire}} \quad (6)$$

Relativized Burn Ratio (*RBR*). It is an index that uses the ratio of *dNBR* to *NBR* calculated from the image before the fires (Parks et al. 2014). It is expressed by the following Formula (7):

$$RBR = \frac{dNBR}{NBR_{\text{pre-fire}} + 1.001} \quad (7)$$

Burn Area Index (*BAI*). It uses reflectance values in the red part and the *NIR* part of the spectrum to identify areas of the ground affected by fire (Filipponi 2018) [Formula (8)].

$$BAI = \frac{1}{(0.1 - R)^2 + (0.6 - NIR)^2} \quad (8)$$

Burn severity mapping. Burn severity mapping is generated from *dNBR* classification (Franco et al. 2020). The meaning of *dNBR* values may vary by scene, and interpretation in specific cases should always be based on the field assessment (USGS 2022). However, the United States Geological Survey (USGS) has proposed a classification table to interpret the severity of the burn according to Table 2. For both classifications to be deemed acceptable, the overall accuracy and the kappa coefficient were calculated.

Table 2. Burn severity levels obtained from *dNBR* (USGS)

Severity Level	*dNBR* range (not scaled)
Enhanced regrowth, high (post-fire)	–0.500 to –0.251
Enhanced regrowth, low (post-fire)	–0.250 to –0.101
Unburned	–0.100 to +0.099
Low severity	+0.100 to +0.269
Moderate-low severity	+0.270 to +0.439
Moderate-high severity	+0.440 to +0.659
High severity	+0.660 to +1.30

dNBR – Differenced Normalized Burn Ratio; USGS – United States Geological Survey

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 *dNDVI*, *dGNDVI* and *dNBR* were obtained by subtracting the *NDVI*, *GNDVI* and *NBR* indices after the fire from the *NDVI*, *GNDVI* and *NBR* indices before the fire, whereas the *RBR* is calculated according to Formula 7. For all the indices the lowest values are the areas that are not affected by fires and generally represent vegetation. However, the highest values represent the burnt areas. The burn severity map to estimate the burned area is generated from the *dNBR* classification of the study area into five classes (Figure 5). The values of –0.500 to –0.251 represent the enhanced regrowth, the high (post-fire) class according to Table 2 does not exist because the *dNBR* values of the study area are between –0.16 and 0.99. For the values varying from –0.250 to –0.101 which represent the enhanced regrowth, low (post-fire) classes are very low and are not visible compared to the *dNBR* index of the study area.

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 sever-

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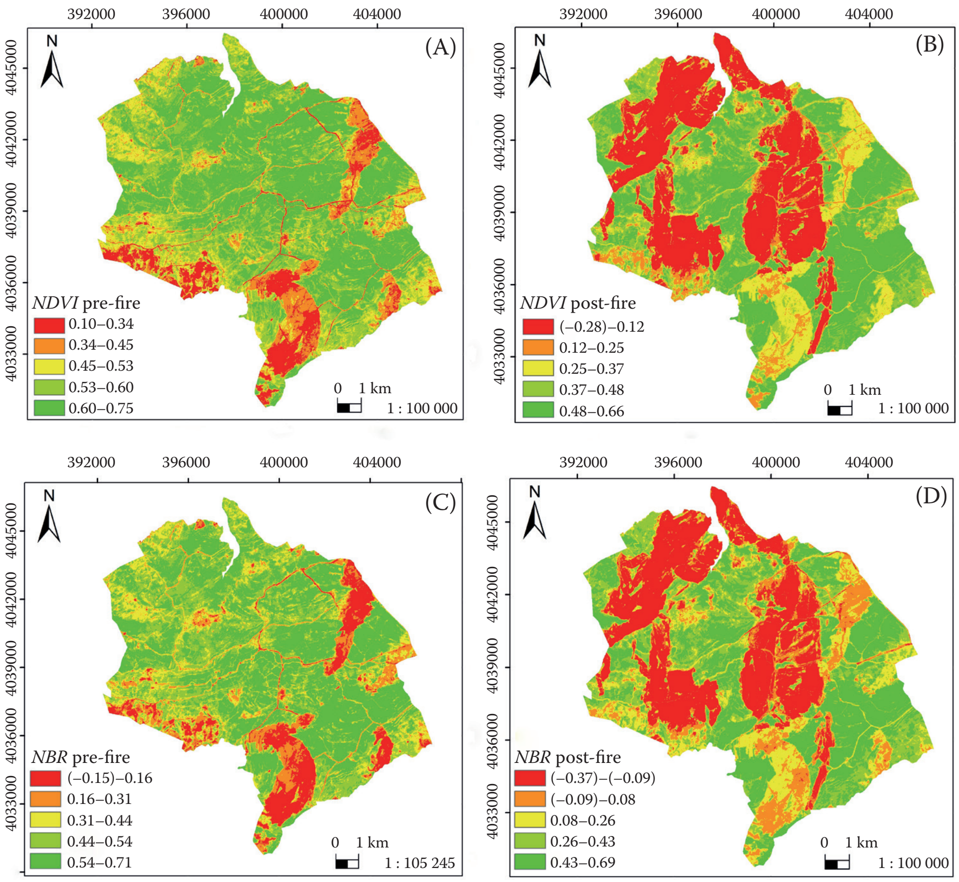

Figure 2. *NDVI* (Normalized Difference Vegetation Index) and *NBR* (Normalized Burn Ratio) of the study area before and after the fire: (A) *NDVI* pre-fire; (B) *NDVI* post-fire; (C) *NBR* pre-fire and (D) *NBR* post-fire

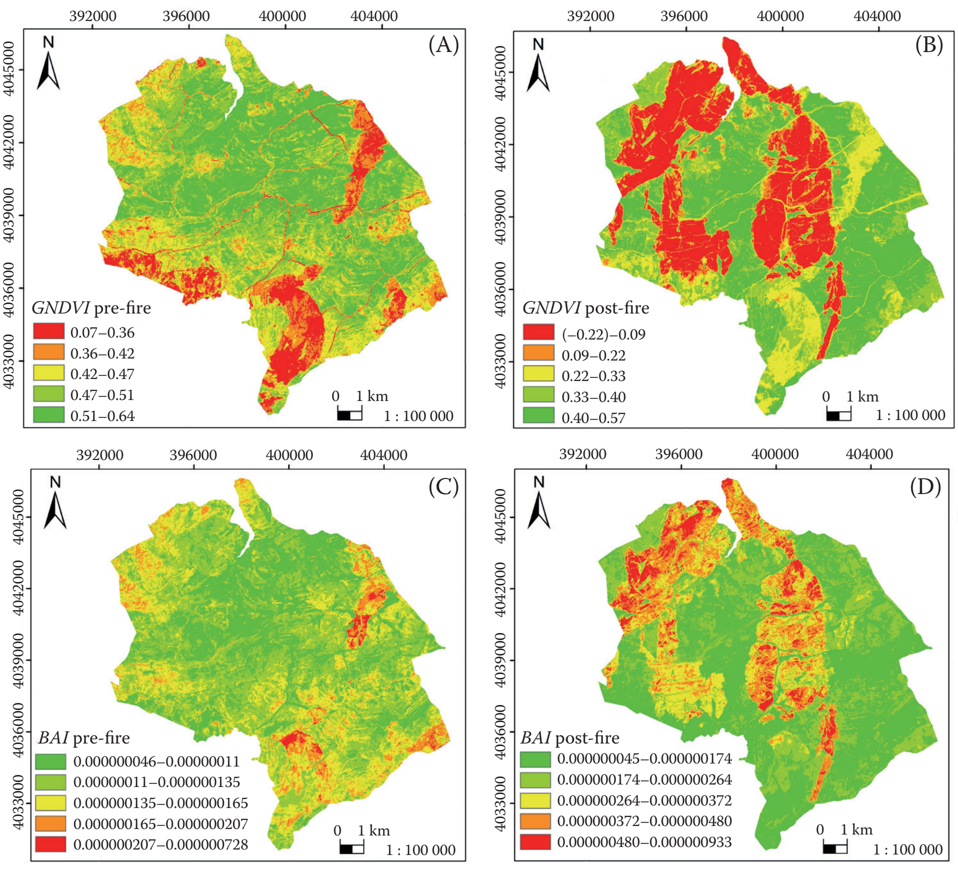

Figure 3. Green Normalized Difference Vegetation Index (*GNDVI*) and Burn Area Index (*BAI*) of the study area before and after the fire: (A) *GNDVI* pre-fire; (B) *GNDVI* post-fire; (C) *BAI* pre-fire and (D) *BAI* post-fire

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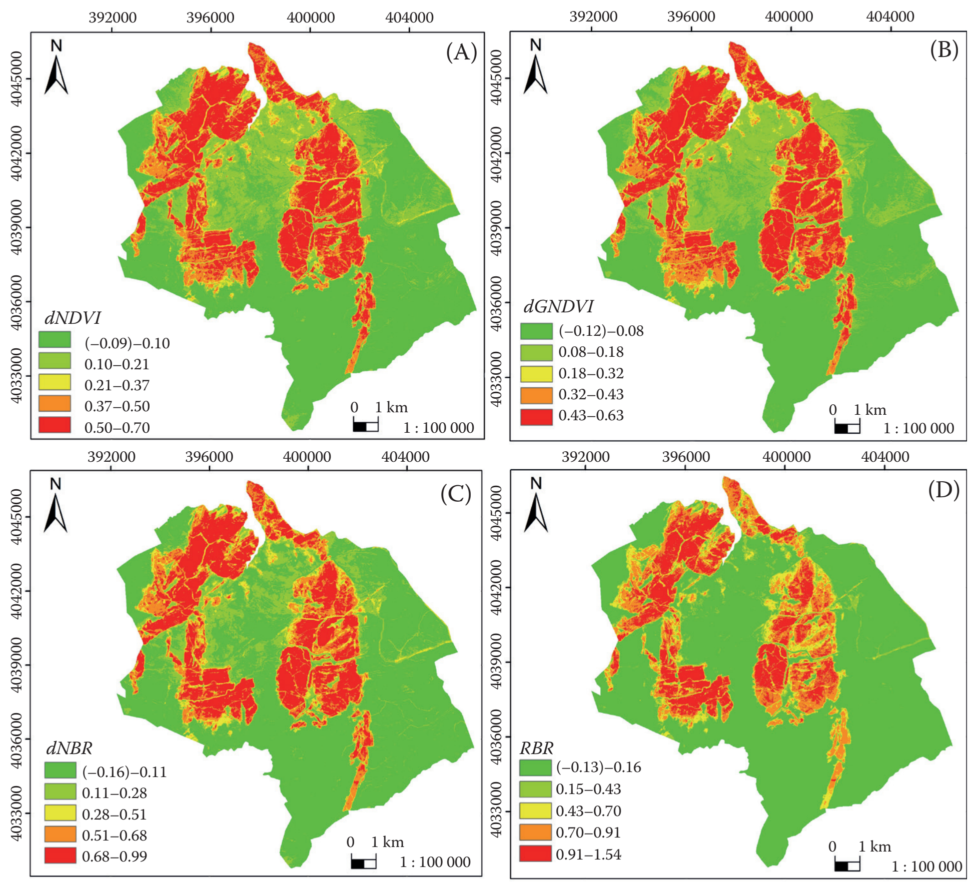

Figure 4. (A) Differenced Normalized Difference Vegetation Index (*dNDVI*), (B) Differenced Green Normalized Difference Vegetation Index (*dGNDVI*), (C) Differenced Normalized Burn Ratio (*dNBR*) and (D) Relativized Burn Ratio (*RBR*) of the study area

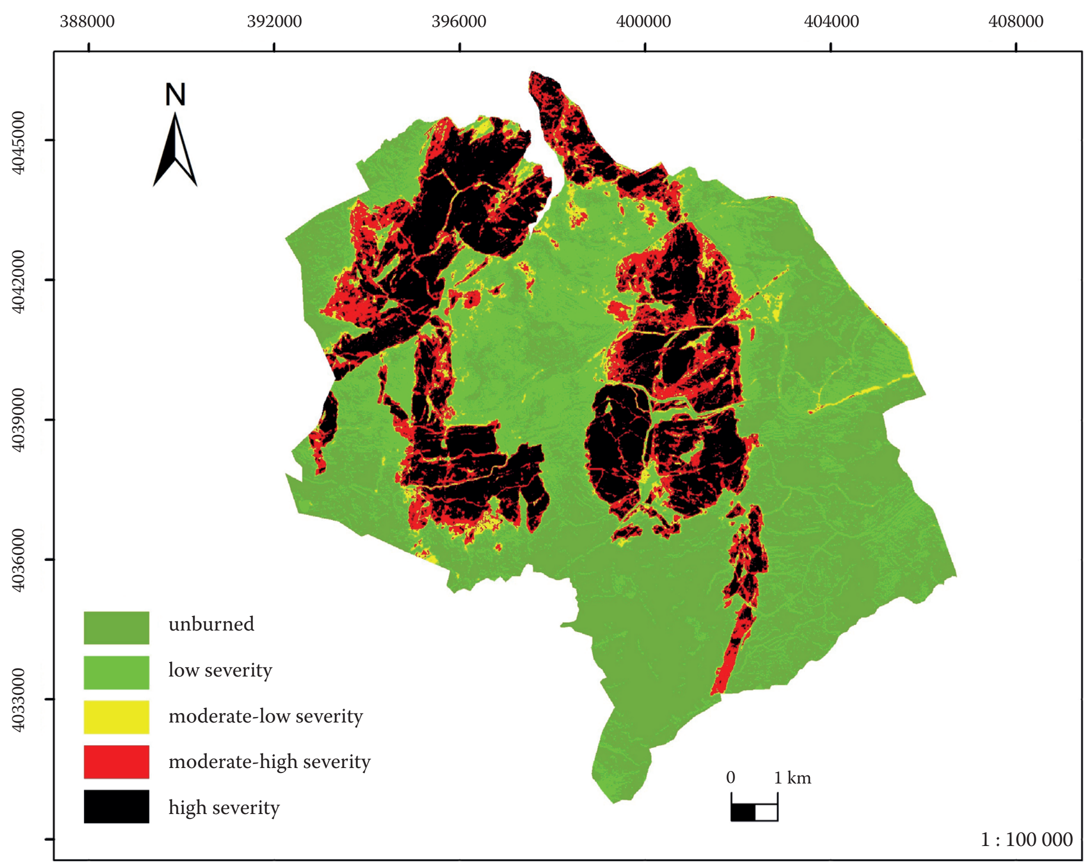

Figure 5. Classification of the *dNBR* index in five classes

dNBR – Differenced Normalized Burn Ratio

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Table 3. Estimating the forest fires area from the *dNBR* index

Classes	Area (ha)	(%)
Unburned	5 651	45.01
Low severity	2 689	21.42
Moderate-low severity	671	5.34
Moderate-high severity	1 381	11.00
High severity	2 163	17.23
Total	12 555	100.00

dNBR – Differenced Normalized Burn Ratio

ity and moderate high severity spread over an area representing 16.34% of the total area of the study perimeter. The severely damaged area which represents the last class (high severity) occupies 17.23%. The *dNBR* classification provided an overall accuracy of 98.65% with a kappa coefficient of 0.97.

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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REFERENCES

Alkhatib A.A. (2014): A review on forest fire detection techniques. International Journal of Distributed Sensor Networks, 10: 597368.

Bouhabila A. (2019): La forêt algérienne face au changement global quelle place pour l'agroforesterie? Available at: https://matheo.uliege.be/bitstream/2268.2/7787/1/TFE%20MS%20SGE%20PED%202018-2019%20BOUHABILA%20AMIR%20.pdf (in French).

Boulghobra N. (2021): Sentinel 2 imagery and burn ratios for assessing the July 5, 2021 wildfires severity in the region of Khenchela (Northeast Algeria). Geographia Technica, 16: 95–104.

Charfi G. (2016): Contribution à l'analyse des résultats de suivi des zones humides méditerranéennes par l'élaboration de profils de pays. Available at: https://tourduvalat.centre-doc.fr/doc_num.php?explnum_id=959 (in French).

Escuin S., Navarro R., Fernandez P. (2008): Fire severity assessment by using NBR (Normalized Burn Ratio) and NDVI (Normalized Difference Vegetation Index) derived from LANDSAT TM/ETM images. International Journal of Remote Sensing, 29: 1053–1073.

Filipponi F. (2018): BAIS2: Burned Area Index for Sentinel 2. Proceedings, 2: 364.

Franco M.G., Mundo I.A., Veblen T.T. (2020): Field-validated burn-severity mapping in North Patagonian forests. Remote Sensing, 12: 214.

Kurnaz B., Bayik C., Abdikan S. (2020): Forest fire area detection by using Landsat-8 and Sentinel-2 satellite images: A case study in Mugla, Turkey. Available at: https://www.researchsquare.com/article/rs-26787/v1

Kutter A., Ben Bih K., Jauffre S. (2021): Sustainable forest management will help Algeria tackle the risk of wildfires. Available at: https://blogs.worldbank.org/arabvoices/sustainable-forest-management-will-help-algeria-tackle-risk-wildfires

Labib S.M., Harris A. (2018): The potentials of Sentinel-2 and LandSat-8 data in green infrastructure extraction, using object based image analysis (OBIA) method. European Journal of Remote Sensing, 51: 231–240.

Li F., Miao Y., Feng G., Yuan F., Yue S., Gao X., Liu Y., Liu B., Ustin S.L., Chen X. (2014): Improving estimation of summer maize nitrogen status with red edge-based spectral vegetation indices. Field Crops Research, 157: 111–123.

Mallinis G., Mitropoulos I., Chrysafi I. (2018): Evaluating and comparing Sentinel 2A and Landsat-8 Operational Land Imager (OLI) spectral indices for estimating fire severity in a Mediterranean pine ecosystem of Greece. GIScience and Remote Sensing, 55: 1–18.

Meddour-Sahar O., Bouisset C. (2013): Large wildfires in Algeria: Human issues and public policies towards risk management. Revue géographique des pays méditerranéenne, 121: 33–40. (in French)

Missoumi A.K., Tadjerouni K. (2003): Algérie SIG et imagerie Alsat1 pour la cartographie du risque d'incendie de forêt. In: 2nd FIG Regional Conference. Marrakesh, Morocco, Dec 2–5, 2003: 14. Available at: https://fig.net/resources/proceedings/fig_proceedings/morocco/proceedings/TS13/TS13_2_missoumi_tadjerouni.pdf (in French).

Parks S.A., Dillon G.K., Miller C. (2014): A new metric for quantifying burn severity: The relativized burn ratio. Remote Sensing, 6: 1827–1844.

Rouse J.W., Haas R.H., Schell J.A., Deering D.W. (1973): Monitoring vegetation systems in the Great Plains with ERTS. In: Freden S.C., Mercanti E.P., Becker M.A. (eds): Proceedings of 3rd Earth Resources Technology Satellite Symposium. Washington D.C., Dec 10–14, 1973: 309–317.

Thapa P. (2021): Forest fire area detection using satellite remote sensing technologies. Available at: https://www.researchgate.net/publication/351413050

USGS (2022): Normalized Burn Ratio (NBR). Available at: https://www.un-spider.org/advisory-support/recommended-practices/recommended-practice-burn-severity/in-detail/normalized-burn-ratio

Verma S., Singh D., Singh A.K., Jayakumar S. (2019): Post-fire soil nutrient dynamics in a tropical dry deciduous forest of Western Ghats, India. Forest Ecosystems, 6: 6.

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