

SENTINEL 2 IMAGERY AND BURN RATIOS FOR ASSESSING THE JULY 5, 2021 WILDFIRES SEVERITY IN THE REGION OF KHENCHELA (NORTHEAST ALGERIA)

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ABSTRACT:

Wildfire events are majeure natural risks occurring in multiple ecosystems worldwide, and lead to significant damages on their human, ecological and socioeconomic components. This research interested on evaluating and mapping the recent and exceptional wildfires occurred in the Aures Mounts System near Ain Mimoun in July 5, 2021. Multidates Sentinel 2 images, the differenced Normalized Burn Ratio dNBR and its Relativized dNBR (RdNBR) have been used for extract and evaluate the recently burned areas. Results reveal that he July 5 wildfires lead to the loss of 6,607 ha (9 %) of Aleppo pine forest cover and municipalities of Tamza and Chelia were more damaged, with respectively 4,143 and 2,166 ha of burned superficies. In addition to the high-vulnerability to fire risk occurrence, essentially due to topographic and morphological features, the study area exhibited also favoring climatic features before and during the fire event occurrence, high daily temperatures and high variable wind directions were prominent factors in accelerating the fire spreading and increasing the fire extent. This study concludes that Sentinel 2, dNBR and especially RdNBR are effective geoinformatic data and indices for assessing, classifying and mapping burn severity extent due to wildfire events. To attenuate damages, it is necessary to adopt risk mitigation plans based on efficient measures to be applied before, during and after the fire events occurrence.

Key-words: Wildfire, July 5, Khenchela, Sentinel 2, Relativized Burn Ratio

1. INTRODUCTION

Forest fires occur in multiple regions worldwide and have been subject of many researches, interested essentially on assessment, mapping, and risk evaluation using often geomatic-based approaches (Rogan & Franklin, 2001; Roy et al., 2006; Furtună & Holobacă, 2013; Parks et al., 2014; Arellano et al., 2017; Parajuli et al., 2020), and often by adopting field measurement-based methodologies (Cocke et al., 2005; Cai & Wang, 2020).

In addition to the man-made activities, northern Mediterranean ecosystems are characterized by highly favoring climatic and physical circumstances for the forest fire occurrence, leading to multiple and repetitive wildfires events in France, Italy, Spain and Greece, especially during the last two decades, leading to significant damages (San-Miguel-Ayanz et al., 2017). In the southern Mediterranean, Algeria is facing important and recurrent forest fire risk events. According to Madoui (2002), 118,624 ha of forest areas were loosed due to fires from 1979 to 1995. Causes of forest fires in Algeria are multiples; according to Benkheira (2018), 75 % are of unknown causes, 23 % are due to premeditated human activity and 2 % are related to agricultural activities.

Northeast Algeria, the Aures Mountains belong to the Saharan Atlas System; this region is characterized by high altitudes (up to 2,328m), that this is the main reason for receiving more than 1,000mm of annual precipitation (Meharzi, 1994), leading to the growth of important forest cover. The Aures region is suffering a critical occurrence of forest fires events; according to the forest conservatory of Khenchela, more than 40 wildfires took place in the Aures from 2016 to 2018. Nevertheless, few researches interested in studying, assessing and mapping this major hazard: Rahmani and Benmassoud (2019) used remotely sensed data and GIS for modeling and mapping the

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Forest fire hazard in the region of Khenchela, by applying the Analytical Hierarchy Process AHP method considering related factors, namely vegetation types, topography and the anthropogenic activities. They reported that the Aures Mountain forests are considered as highly vulnerable to the wildfire hazard. The United Nations Satellite Centre and United Nations Institute for Training and Research (UNOSAT/UNITAR, 2012) used fine resolution RapidEye satellite imagery satellite for assessing and mapping the August 18, 2012 wildfires in the Aures Mountains (Regions of Biskra, Batna and Khenchela), they reported that wildfire damaged about 295 Km² (29,500 ha) of pine and oak forests. The year 2021 presented extreme meteorological conditions across entire Algeria, exceptional temperatures and heat waves exceeding 45 °C (113 °F) during late June, led to a multiplicity of wildfires in multiples regions such as Tebessa (Mountains of El-Atef) and Tikjda (Tell Atlas in Bouira governorate). In the region of Aures System west of the city of Khenchela, a wide wildfire took place in July 5 near the Ain Mimoun. During 5 days (July 5 to 10), the fires spreads in different directions and damaged significant forest superficies through Tamza, Chelia, Bouhmama and Ain Ouanjal municipalities, official preliminary reports declare the wildfires as man-made caused and estimate the forest loss to be 8,245 ha.

This research aims to assess and mapping the July 5, 2021 wildfires extents in the region of Khenchela, using time-series of Sentinel 2 images, and the relativized burn radio index RdNBR for extracting burnt superficies through the damaged municipalities. The study also interested on analyzing and understanding the climatic and topo-morphological circumstances of this wildfire genesis and propagation.

2. STUDY AREA

The study area is located west of the city of Khenchela (400,000 habitants), it extends over a superficies of 921 Km² (921,000 ha) and encloses 10 municipalities. Topographic pattern highlights the predominance of highly elevated landscape (**Fig. 1**) composed of prominent mountains (Djebel in Ar.) and hells (Kef, Rass in Ar.): Dj. Djahfa in the south (1,571m), the west-east chain alignment of Dj. Chelia (2,328m), Dj. Faraoun (2,071m), Kef Tifekrissa (1,900m) and Rass Serdoune (1,671m), in addition to the northern parallel chain mainly composed of Dj. Aures (1,571m), Dj. Tizi Ala (1,271m).

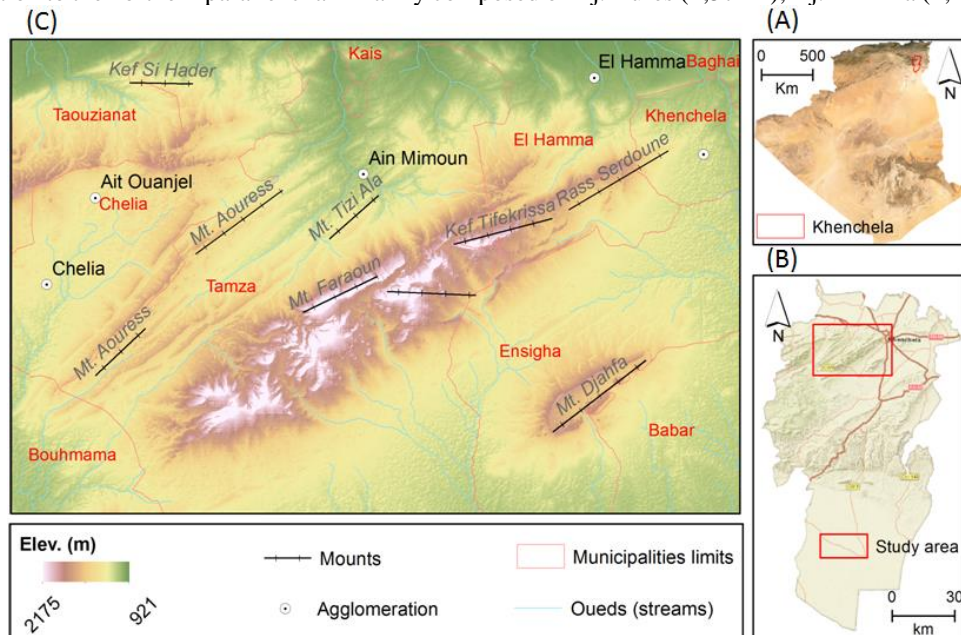


Fig. 1. (A) Localization of Khenchela governorate in northeast Algeria. (B) Localization of the study area in north of Khenchela. (C) Digital Elevation Model DEM by the Shuttle Radar Topography Mission SRTM of 40X40m resolution (www.usgs.gov), showing the major hypsometric patterns of the study area

Regarding the geological map by Kazi Tani and Oussedik (1977), the high-lands lithology is mainly composed of lower cretaceous (Aptian limestone), Albian marls, sandstones and dolomite in the middle areas; northern parts are composed of Tortonian Miocene sandstones, whereas low-lands parts correspond to quaternary plains. The region of Khenchela is characterized by Mediterranean climate, mean temperatures range from 1.8 °C in January to 27 °C in July; maximum temperatures could reach 40 °C. Mean annual precipitation is about 400mm in the meteorological station of El Hamma (987m ASL). However, rainfalls can reach 1,200mm depending on altitudes and exposure (Meharzi, 1994); these conditions contrast leads to the growth of important forest cover essentially composed of Aleppo pine (*Pinus halepensi*), Altas cedar (*Cedrus atlantica*), Holm oak (*Quercus ilex*) and Juniper (*Juniperus*), often protected as biosphere reserves and national parks.

3. DATA AND METHODS

3.1. Satellite imagery

For geospatially assessing and mapping of the July 5, 2021 wildfires extent in the region of Khenchela, it had been necessary to use multi dates satellite images corresponding to the pre, during and post fire phases. In addition to the required analysis scale and the study purpose, availability was a determinant criterion for choosing the data type. Time-series of high-resolution optical imagery were used, namely the Sentinel 2 (Copernicus Program) images dated May 21, July 5 and July 10, corresponding respectively to the pre, during and post fires phases. In total, 6 images were used since it was necessary to constitute image mosaic for each date, by assembling tiles couple having the scene centers (path/row) 193/035 and 193/036. Images are open source available, they present minimum cloud cover (less than 1 %); they are of Level-2A quality, i.e. are atmospherically corrected and are orthorectified and projected according to the Universal Transverse Mercator system zone 32.

Each satellite image provides multi spectral bands in both visible and infrared domains, wavelengths are ranging from the blue (0.458–0.522 µm) to the short wave infra red SWIR 2 (2.100–2.280 µm). After converting the bands on Geotiff format, and being of 20m of spatial resolution, the Short Wave Infra-Red 1 (SWIR 1) and Short Wave Infra-Red 2 (SWIR 2) bands were resampled to 10m to be spatially homogenized with the visible domain bands resolution. Besides, images were calibrated from radiance to surface reflectance to allow calculating the required spectral indices.

3.2. Differenced Normalized and Relativized Burn Ratios for extracting burned areas

Extraction of the damaged superficies due to wildfires in the study area was performed using the Normalized Burn Ratio NBR (ranging from -1 to 1); this derived index is based on the Near Infrared (NIR) and the Shortwave Infrared 2 (SWIR2) bands of the Sentinel 2 images, it is based on peak reflectance of both vegetation and mineral soil to provide an index of the amount of vegetation present on the landscape before and after the fire event, and this according to the formulae:

$$NBR = \frac{NIR - SWIR2}{NIR + SWIR2} \quad (1)$$

where:

NBR - Normalized Burn Ratio
NIR - Near Infrared
SWIR2 - Shortwave Infrared 2

Spectrally, the NBR is the opposite of the Normalized Difference Vegetation Index NDVI developed by Rouse et al. (1974), which refers to the NIR and Red spectral bands, and often used to discriminate vegetative cover abundance. Burned areas correspond to low reflectance pixels in the Near Infrared and high reflectance in the Short Wave Infra-Red 2 band; consequently, high NBR values indicate abundant vegetation, whereas very low values (close to -1) indicate recently burnt areas. For both pre fire (May 21) and post fire (July 10) images, NBR was calculated under Geographic Information System software; thereafter, recently burned areas due to the July 5 wildfire could be than calculated using the bi-dates difference according to the formulae:

$$dNBR = NBR_{pre-fire} - NBR_{post-fire} \quad (2)$$

where:

$dNBR$ – bi-dates difference

$NBR_{pre-fire}$ – NBR of pre fire images

$NBR_{post-fire}$ – NBR of post fire images

However, $dNBR$ values could be influenced by the atmospheric conditions during image acquisition, this contributes on confusing recently burned areas and originally unvegetated superficies during the pre fire phase (Roy et al., 2006; Rose et al., 2016). Parks et al. (2014) suggest using the Relativized Burn Ratio $RdNBR$, for being more accurate and reliable in measuring and classifying burn severity. $RdNBR$ severity maps could provide an adequate assessment of the degree of damages (Mallinis et al., 2018; Konkathi & Shetty, 2021); it can be calculated according to the following equation:

$$RdNBR = \frac{dNBR}{NBR_{pre-fire} + 1.001} \quad (3)$$

where:

$RdNBR$ - Relativized Burn Ratio

Both $dNBR$ and $RdNBR$ produced maps were classified into different fire severity levels, based on the scale developed by the *U.S. Geological Survey Earth Resources Observation and Science Center* (**Table 1**). Spatial distribution of different burn severity percentages was carried out, mapped and discussed.

Table 1.

Fire severity levels assigned to $dNBR$ classes.

Severity No.	Severity Level	$dNBR$ range
1	Enhanced Regrowth, High	≤ -0.251
2	Enhanced Regrowth, Low	-0.250 to -0.101
3	Unburnt	-0.100 to 0.099
4	Low Severity	0.100 to 0.269
5	Moderate-Low Severity	0.270 to 0.439
6	Moderate-High Severity	0.440 to 0.659
7	High Severity	≥ 0.660

4. RESULTS AND DISCUSSION

4.1. Wildfire vulnerability and pre fire circumstances

The ignition and combustion initiation require the presence of external heat source, combustible materials (as vegetation) and oxygen; afterward, the wildfire intensity and propagation depend on multiple factors such as climatic conditions (wind velocity/direction, temperature, humidity...), physical context of the ecosystem (slopes, aspect, morphology ...) and the vegetation types and composition (Merdas, 2007). The combination of these factors increases forest ecosystem vulnerability to fire occurrence. According to Rahmani and Benmassoud (2019), the Aures Mounts forests are high-risk regions, presenting highly favorable conditions to fire propagation, and this is due to multiple factors: 1) Predominance of high relief associated with steep slopes exceeding 45 %; 2) Predominance of medium to high piedmonts and mountains landscapes and; 3) the land cover is mainly constituted of high-combustibility species as Holm oak and Aleppo pine. Besides, the year 2021 is characterized with exceptional heat waves occurrences through entire Algeria reaching 49 °C in Saharan regions; the region of Khenchela as well was marked by extremes daily records, the July 5 wildfire was preceded by long period of ascending temperatures. From June 24 to July 5, daily maximum temperatures exhibit a continuous increasing from 39 to 44 °C; in associated with high

evapotranspiration and pluviometric drought, this could contribute on considerably favoring the fire occurrence aptitude, which was initiated July 5 near Ain Mimoun agglomeration.

4.2. Wildfire initiation and propagation

First fire events initiated July 5, 2021 near the village of Ain Mimoun. Investigation of the during-fire Sentinel 2 image which was taken at 10:21 AM, allows to visualize a series of 20km length and oriented southwest-northeast, composed of multiples and scattered ongoing fires exceeding 20 sites (Fig. 2B), signifying that fires were simultaneously initiated (at least timely close), and that they rapidly spread during short time.

Regarding the elevation map, it can be noticed that all of the fires occurred in the Mounts: Dj. Aouress (northwest), Dj. Tizi Ala (north) and Dj. Faraoun (south) on high altitudes, and along steep slopes, this can a favoring factor in fires spreading. Besides, wind direction was also a determinant agent since it was highly variable. In July 5, wind direction was 125° azimuth and oriented south east (Fig. 2A); July 6, air temperature increased to be 45°, daily-wind as well changed direction to be 70° and oriented north-east east, July 7 it changed to 258° according to the west-south west trend, this could be recognized and confirmed by visualizing the wildfire smoke trend (Fig. 2C). Later, wind directions were as well changed to 200° and 245° during July 8 and July 9 respectively (Fig. 2D). Therefore, highly-changing wind directional variability could be a major factor in rapid propagation of the fires, especially in presence of highly-combustible forest specie as Aleppo pine (Mitsopoulos & Dimitrakopoulos, 2007).

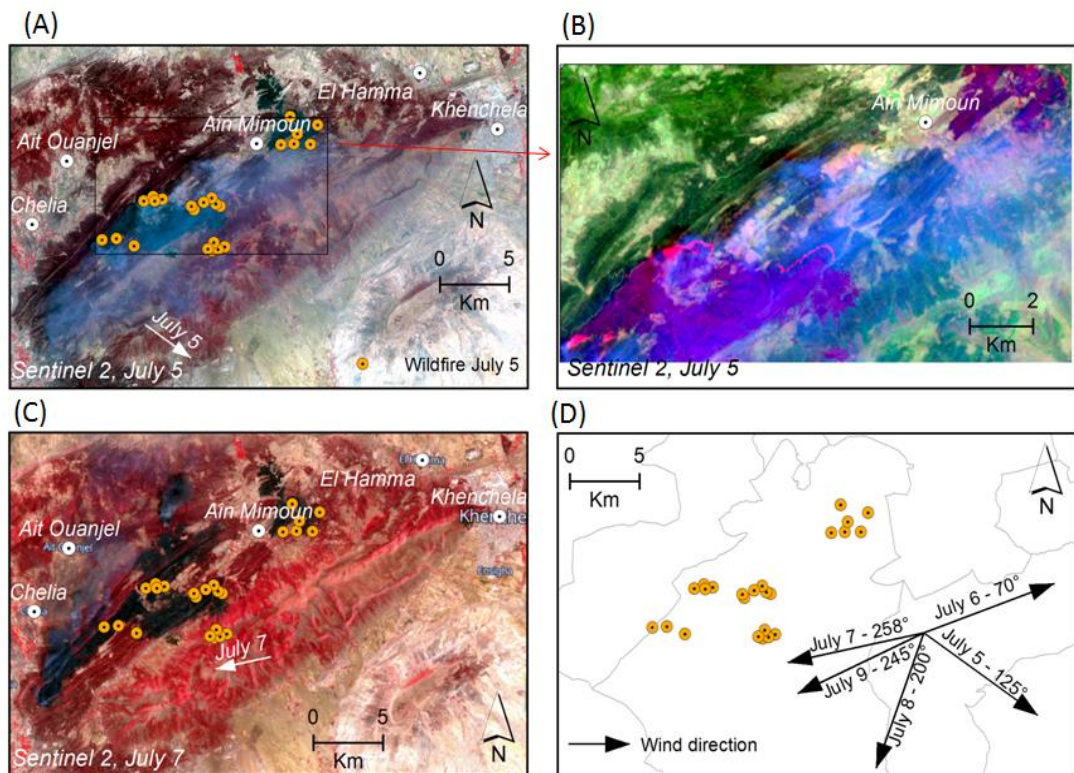


Fig. 2. (A) False color composite B8-B4-B3 of the Sentinel 2 image dated July 5 (during fire), with superimposed ongoing wildfire sites, note that the smoke direction is corresponding to the wind direction. (B) Excerpt of the July 5 image showing ongoing-fires in orange color. (C) False color composite B8-B4-B3 of the Sentinel 2 image dated July 7 (during fire); note that the smoke direction changed trending as response to the daily-wind direction. (D) Wind-rose showing directional variability from July 5 (fire starting) to July 9; note that the fire spreading was accelerated due to the high wind variability

4.3. Post fires and burned areas distribution

After 5 days of activity, the fire events were completely ended July 10; consequently, daily temperatures decrease gradually from 43°C in July 10 to 33°C in July 17.

The pre fire NBR map was ranged from -0.88 (no vegetation/bare soil) to 0.93 corresponding to healthy vegetation cover (variable-density Aleppo pine), the post fire NBR map presents a significant changing in pixel values that ranged from -0.97 to 0.98, where very low values correspond spatially to moderate and dense forest during the pre fire period.

Table 2 and **table 3** summarize rates and distribution of burn severity levels, respectively based on the reclassification of dNBR (**Fig. 3A**) and RdNBR maps (**Fig. 3B**); burnt areas are also evaluated and delimited (**Fig. 3C**, **Fig. 3D**).

Table 2.

Distribution of burnt areas based on differenced normalized burn ratio dNBR.

Fire Severity classes	Municipalities				Total (ha)	Total (%)
	Bouhmama	Tamza	Chelia	Kais		
Enhanced Regrowth, High	0	0	2	0	3	0
Enhanced Regrowth, Low	0	44	9	0	53	0
Unburnt	2,971	31,454	19,219	1,731	55,375	73
Low Severity	348	5,078	3,038	464	8,929	12
Moderate-Low Severity	88	2,099	1,206	14	3,407	4
Moderate-High Severity	185	1,653	861	16	2,715	4
High Severity	150	3,461	1,838	11	5,459	7
Total	3,742	43,789	26,173	2,237	75,941	100
Subtotal High Severity (burnt)	335	5,114	2,698	27	8,175	11

Table 3.

Distribution of burnt areas based on relativized burn ratio RdNBR.

Fire Severity classes	Municipalities				Total (ha)	Total (%)
	Bouhmama	Tamza	Chelia	Kais		
Enhanced Regrowth, High	0	1	4	0	5	0
Enhanced Regrowth, Low	0	14	7	0	21	0
Unburnt	3,061	32,341	19,617	1,770	56,789	75
Low Severity	267	5,365	3,377	433	9,442	12
Moderate-Low Severity	135	1,925	1,002	15	3,077	4
Moderate-High Severity	224	2,343	1,367	19	3,953	5
High Severity	55	1,800	799	1	2,654	3
Total	3,742	43,789	26,173	2,237	75,941	100
Subtotal High Severity (burnt)	279	4,143	2,166	19	6,607	9

Based on both dNBR and RdNBR maps, no significant high and low enhanced regrowth occurs, unburnt area classes predominates with respectively 73 and 75 %, only 12 % of the forest cover is of low severity and 4 % is of moderate-low severity. In addition to the localization of ongoing fire sites on the during-fire image dated July 5 (**Fig. 2A**), the visualization and interpretation of the post fire image confirm that these classes correspond to unburnt areas. In the opposite, high and moderate-high severity classes (dNBR or RdNBR ≥ 0.440) correspond to the effective total of burnt areas. By considering dNBR, total burnt area is about 8,175 ha (11 %) with more damages in Tamza (5,114 ha) and Chelia (2,698 ha). Differently, the total of effective burnt areas based on RdNBR is about 6,607 ha (9 %), distributed on 4 main municipalities: Tamza (4,143 ha), Chelia (2,166 ha), Bouhmama (279 ha) and kais (19 ha).

The accuracy of both dNBR and RdNBR in assessing burn severity is carried out; dNBR index is often overestimating damaged areas by presenting bias due to considering unburnt areas (**Fig. 3E**), RdNBR is more accurate since it delimitates high severity class in well accordance with effective burnt areas (**Fig. 3F**), this conclusion is in coherence with many similar studies (Arellano et al., 2017;

Quintano et al., 2018; Konkathi & Shetty, 2021) confirming that relativized dNBR is more appropriate and accurate in assessing high severity due to wildfires using Sentinel 2 and Landsat images.

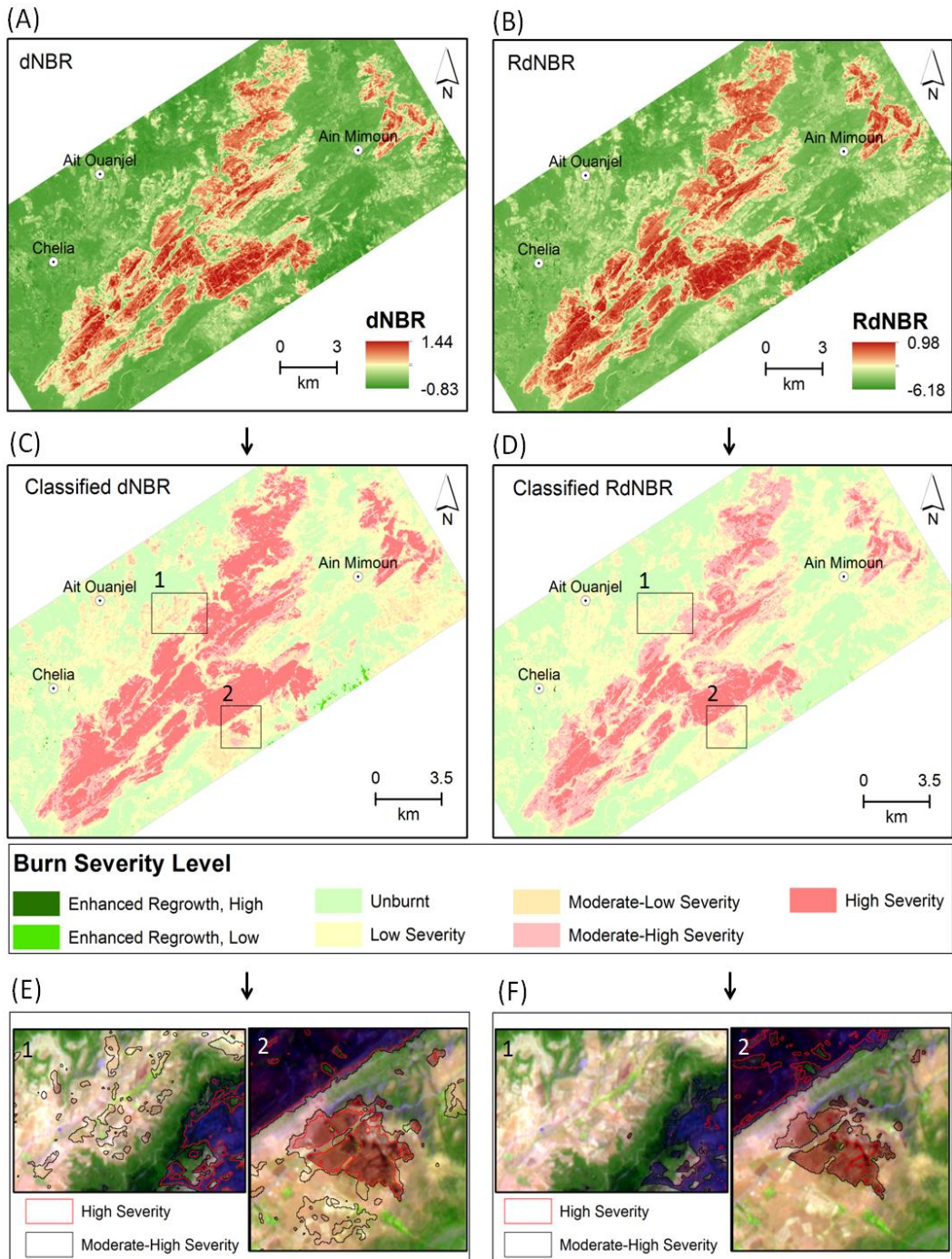


Fig. 3. (A) dNBR map showing delta NBR of pre and post fire. (B) RdNBR map. (C) Classified dNBR map showing severity level classes. (D) Classified RdNBR map showing severity level classes. (E) Zoom-in excerpts showing high fire severity precision based on dNBR classification. (F) Zoom-in excerpts showing high fire severity precision based on RdNBR classification

Most of the fires occurred in the northern mounts series, Tamza situated in the south-facing versant and Chelia located in the north-facing versant, they were the most damaged municipalities with 100 % of the total burned superficies. South, the higher mounts of Dj. Faraoun is separated from the northern mounts series by a relatively flat piedmont of low slopes (less than 15 %); this natural character could be the limiting factor of fires spreading toward more southern areas. In addition to the topo-morphological consideration, the 0.5mm precipitation occurred in July 7 could be a contributing factor in decreasing the combustibility aptitudes, and consequently limiting fire-propagation speed. 6,607 ha as total burned areas represent about 0.9 % from the east-Algerian forest superficies (800,239 ha), and 5 % from the total forest cover of Khenchela governorate estimated at 131,069 ha; the July 5, 2021 fire event is the second most degrading wildfires occurring in Khenchela after the August 18, 2012 which led to the loss of 15,000 ha and the emission of 1,000 Gg of CO₂ equivalent (Benkheira, 2018).



Fig. 4. (A) Ongoing wildfire dated July 5, 2021. (B) Juxtaposed moderate and high burn severity areas, note that high severity areas manifest damages in all stratum, whereas moderate severity areas is marked by unburnt tree stratum. (C) Juxtaposed low, moderate and high burn severity areas, note that highly burnt areas correspond to the cliff steep slopes that is a favoring factor is fire propagation. Photos courtesy by the forest directorate of Khenchela, cell of communication (2021)

5. CONCLUSION

This research is a case study conducted in the Aures Mounts System east of Khenchela, Algeria. It was interested on assessing the fire severity levels, and delimitating recent burnt areas due to the wildfires occurred near Ain Mimoun in July 5, 2021, using multitudes Sentinel 2 satellite imagery and burn ratios.

Results revealed that the July 5 fire event was due to favoring climatic, natural and topomorphological factors to the forest fire initiation and propagation, and this during pre and post fire phases. The domination of highly-elevated landscape characterized by steep slopes piedmonts, the dominance of highly-combustible trees species as Aleppo pine, are main factors in classifying the entire Aures Mounts among the high fire risk regions. The wildfire day was preceded by a long period of high and continuous daily temperature, this was a prominent factor on increasing the fire occurrence, the post fire period also was marked by highly-variable wind direction and, this pattern may be a determinant factor in the wildfire propagation during 5 days.

Based on differenced normalized burn ratio dNBR, highly-burnt area was assessed to be 8,175 ha. Differently, relativized dNBR allowed to accurately evaluating highly-damaged areas to be 6,607 ha of forest cover fully composed of Aleppo pine, with exceptional damage rates in municipalities of Tamza and Chelia, and this is due to their geo-situation in the south-facing and north-facing versants of the Dj. Aouress mounts, where the topography was an important factor in accelerating the fire spreading over the mounts system.

This study shows that Sentinel 2, dNBR and especially RdNBR are effective data and indices for assessing, classifying and mapping burn severity extent due to wildfire events. Nevertheless, it is important that future researches should be complemented with field assessment, soil analysis and floristic surveys for a better evaluation and more reliable interpretation, related to other ecological factors such as forest stratum (using Composite Burn Index CBI), density, trees species, biomass consumption etc.

Visualizing satellite images shows that the Aures Mounts forests are well equipped with firebreaks system; this could be an effective measure in attenuating the wildfire severity and propagation in such highly-vulnerable areas. Nevertheless, it is also important to adopt appropriate strategies and integrated risk mitigation plans, before, during and after the fire events occurrence.

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