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RESEARCH ARTICLE/ARAŞTIRMA MAKALESİ

Burned Area and Fire Severity Prediction of a Forest Fire Using a Sentinel 2-Derived Spectral Index in Çanakkale, Turkey

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Abstract

Objective: The objective of this study was to determine the extent and degree of severity of a burned area resulting from a forest fire using Sentinel 2 remote sensing data in Çanakkale, Turkey within the Mediterranean Basin, an area of the world where forest fire occurrence and severity are increasing.

Materials and Methods: Pre and postfire Sentinel images were obtained. The Normalized Burn Ratio (NBR) index was calculated for each scene. Then the difference NBR (dNBR) was calculated by subtracting the postfire NBR from the prefire NBR. dNBR ranges were classified into fire severity categories. A map with 20 m spatial resolution displaying the burned area and fire severity was generated from the classified dNBR image. Finally, a forest stand map of the burn area was laid over the fire severity map to examine the relationship between fire severity and stand and cover types.

Results: Approximately 1400 ha of area was predicted to have been burned. Twenty nine, 21, 42, and 8% of the burned area was identified as low, moderate low, moderate high, and severely burned using the dNBR index, respectively.

Conclusions: The overlay of the stand map on the burn severity map revealed that the forested areas were more severely burned compared to the agricultural sections. dNBR is an effective index to delineate fire area extent and identify fire severity. Sentinel 2 data provide a fast and accurate means to monitor forest fire extent and severity due to its improved spatial and temporal resolution.

Keywords: Wildfire, Forest, Çanakkale, Sentinel 2, Normalized Burn Ratio

Introduction

Wildfires are natural disasters that lead to functional and structural changes in ecosystems. The quantity and frequency of forest fires have been increasing in recent years in different parts of the globe (Hirschberger, 2016). Global climate change is an important contributor to this increasing trend in forest fire occurrence (Mack, et al., 2021). The Mediterranean Basin is one of the most sensitive regions to be affected by the warming effects of climate change. Studies show that wildfire activity is expected to increase across the Mediterranean Basin due to climate change (Turco, et al., 2018; Ruffault, et al., 2020), land use change, and short-sighted fire management policies (Moreira, et al., 2020). Human-induced land use changes include: agricultural land abandonment, expansion of mismanaged tree plantations, expansion of the wildland-urban interface, and introduction and invasion by fire-promoting exotic species. Short-sighted fire management policies aim to minimize burned areas in the short term without long term considerations to reduce fire hazard and risk. The combination of these land use and fire management policies along with the effects of climate change is likely to result in large and intense fires, larger burned areas and catastrophic socio-economic and ecological impacts (Moreira, et al., 2020; Pausas & Keeley, 2021). The western and southern parts of Turkey lie within the Mediterranean Basin, where long and dry summers are typical, with sclerophyllous vegetation making conditions favorable for fire occurrence. Not surprisingly, numerous forest fires have occurred in

Turkey in recent years, resulting in both property and life losses. Consequently, it is necessary to monitor the extent and severity of forest fires in this region.

Fire and burn severity often are used interchangeably, especially by fire ecologists. Even though both terms refer to the effects of fire on above and belowground components, there are some differences between the two terms, as discussed by Lentile et al. (2006) and Veraverbeke et al. (2010). To put it simply, fire severity specifically refers to first-order effects of fire (i.e. effects caused by the fire only) (Key & Benson, 2006), short-term severity (the pre-recovery phase after a fire) (Key & Benson, 2006) and initial assessment, which is executed immediately after the fire occurrence without much lag time (Key, 2006). Based on this information, the term "fire severity" has been adopted in this article since it is more aligned with the objectives and methodology of the study. Fire severity involves the loss or decomposition of organic matter above and belowground. As such, it includes the effects of fire on soil and plants (Keeley, 2009). Having sound information on fire severity helps ecologists and resource managers to plan postfire rehabilitation and remediation, since they gain a better understanding of the impact of fire on biotic and abiotic components of an ecosystem (Key & Benson, 2006).

However, ground surveys to detect the extent of burned areas and determine fire severity are difficult and costly because of complex terrain, large and inaccessible areas, and bad weather conditions, including smoke and high temperatures. On the other hand, remote sensing provides an easy, rapid, and accurate means to detect forest fire extent and fire severity. Even though there are numerous methods used for burned area detection, such as change detection (Liu, et al., 2020), image classification (Mitri & Gitas, 2004), spectral mixture analysis (Smith et al., 2007), and surface temperature inversion (Mukherjee, et al., 2018), spectral-index based methods are the most common due to their simplicity, intuitiveness, and accuracy. The rationale in using spectral indices for fire detection lies in the differential reflectance response of burned surfaces over near infrared (NIR) versus shortwave infrared (SWIR) regions of the electromagnetic spectrum (EM). Following a fire, reflectance in the NIR decreases, while the reflectance in SWIR increases. Among these indices, the Normalized Burn Ratio (NBR) index is one of the most widely used and tested to determine burnt area and fire severity in different geographic locations (Atun, et al., 2020; Adagbasa, et al., 2018; Saputra, et al., 2017; Schepers, et al,. 2014; Veraverbeke, et al., 2010; Escuin, et al., 2008; Roy, et al., 2006; Epting, et al., 2005; Garcia & Caselles, 1991). Difference NBR (dNBR) allows for the delineation of a burned area and categorization of the burned area into different fire severity classes using the pre- and postfire images (Key & Benson, 2006).

Medium resolution satellite data, such as Landsat (with 30 m spatial resolution), have been used to detect the extent of burned areas using NBR (Adagbasa, et al., 2018; Liu, et al., 2020). Sentinel 2 Earth Observation (EO) satellites launched in 2015 (Sentinel 2A) and in 2017 (Sentinel 2B) provide higher quality remote sensing data with improved spatial resolution (20 m) and a combined temporal resolution of 5 days compared to Landsat, which is important for disaster monitoring, including fires. Sentinel data are available free to users and have been tested for different applications. NBR derived from Sentinel data have been employed to detect fire extent and burn severity in different locations. For example Atun et al. (2020) used Sentinel 2 images to determine burnt forest area in Greece using NBR and NDVI. Teodoro & Amaral (2019) analyzed the affected areas from forest fires in Portugal using Sentinel 2 data. Sentinel 2 data were used to detect burned area and severity levels in Spain by Amos et al. (2019). Masshadi & Algancı (2021) examined the effectiveness of NBR and other indices to determine fire extent and severity in Turkey using Sentinel 2 data. Nasery & Kalkan (2020) tested dNBR derived from Sentinel 2 data to detect burn area and fire severity in Turkey. However, the use of recent Sentinel 2 EO satellite data for fire area and severity prediction is more limited compared to the older EO remote sensing data like Landsat.

In this study, the efficacy of using Sentinel 2 data to characterize the extent and fire severity of a fire in Çanakkale, Turkey was tested. The study site was situated in northwestern Turkey within the Mediterranean Basin. Using the recent Sentinel 2 EO data for this purpose, this study is expected to contribute to our knowledge in remote sensing of fire in an area of the world that will have a greater occurrence and more severe forest fires. Specific objectives of the study are to determine i) the extent of the burned area, and ii) the fire severity resulting from a forest fire in Çanakkale, Turkey using the dNBR index derived from Sentinel 2 data.

Material and Methods

Study site

A forest fire broke out near Ilgardere village in the Gelibolu district of Çanakkale Province on July 6, 2020 (Figure 1). The fire quickly spread in the W-SW direction with

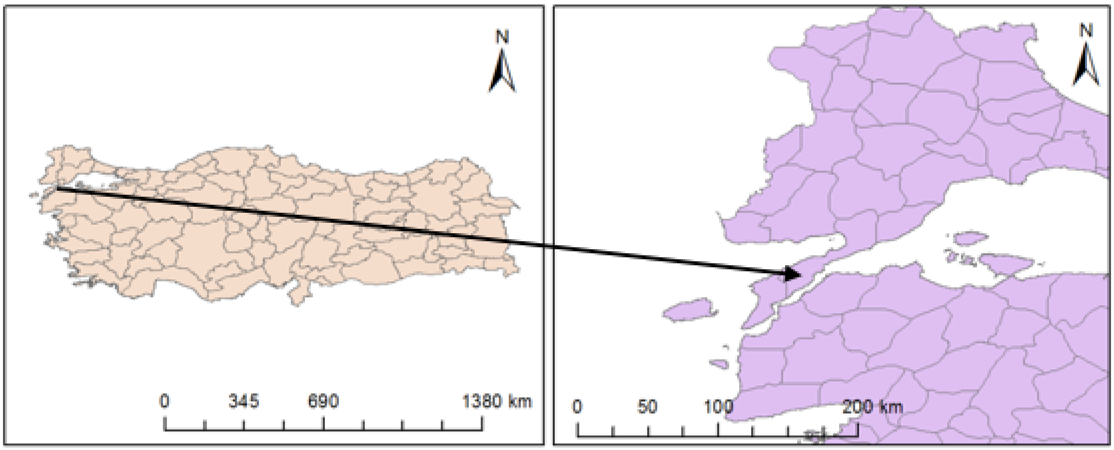

Figure 1. Location of fire site within Turkey.

the help of strong winds out of the NW at an average speed of 30 km/h on July 6. Wind gusts up to 60 km were observed on July 6 and the fire could not be contained until the next morning (Url 1). A considerable swath of area dominantly comprised of forest and some agricultural lands was burned.

Data and Methods

Sentinel 2 images with level 2A processing were acquired for pre- (July 4, 2020) and postfire (July 9, 2020) dates. Sentinel level 2A products are radiometrically and geometrically corrected (including orthorectification and spatial registration). Level 2A products provide Bottom of Atmosphere (BOA) reflectance images derived from the associated Level-1C products. Each Level-2A product is composed of 100x100 km^2 tiles in UTM/WGS84 projection (ESA, 2015). The Normalized Burn Ratio (NBR) spectral index was calculated according to the formula

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

where NIR and SWIR represent the near infrared and shortwave infrared bands, respectively (García & Caselles, 1991). Sentinel 2 bands 7 and 11, corresponding to 783 nm and 1613 nm central wavelengths, respectively, with 20 m spatial resolution, were used for the NIR and SWIR regions. The NBR index was calculated for both dates using the respective images. The NBR index is a more powerful tool to better understand fire extent and severity when the difference between pre and postfire conditions is used. Therefore, difference NBR (dNBR) was calculated according to the formula

$$dNBR = NBRprefire - NBRpostfire$$

The rationale in using dNBR stems from the fact that NBR values will be negative for areas without vegetation, such as after a fire, and positive for vegetated areas. Therefore, in the difference image, negative values will represent unburned and regenerated areas while positive values will represent burned areas of varying severities. Based on this, the following thresholds were used to determine both the extent and severity levels of the fire (Key & Benson, 2006) (Table 1).

Table 1. dNBR ranges used to classify fire severity levels.

Severity level	**dNBR range (not scaled)**
Enhanced regrowth	-0.500 - -0.101
Unburned	-0.100 – 0.101
Low severity	0.100 – 0.269
Moderate low severity	0.270 – 0.439
Moderate high severity	0.440 – 0.659
High severity	0.660 – 1.300

(dNBR value ranges are flexible; scene-pair dependent; shifts in thresholds +100 points are possible. dNBR less than about –550, or greater than about +1,350 may also occur, but are not considered burned. Rather, they likely are anomalies caused by misregistration, clouds, or other factors not related to real land cover differences).

A dNBR map displaying the extent and severity levels of the fire was generated.

A forest stand map of the burn area was laid over the fire severity map to examine the relationship between fire severity and stand and cover types. Average dNBR values corresponding to the stand types were calculated using zonal statistics.

Results

Pre- and postfire images of the burn site are shown in Figure 2. The borders of the burned area can be seen clearly in the postfire image.

The extent and the severity of the fire are shown in Figure 3. NBR is very effective in delineating the fire extent. The borders of the fire area are clearly evident. Additionally, the variation in the severity of the fire is also visible (Figure 3).

The predicted burn severity types according to dNBR are listed in Table 2. According to the map, approximately 1400 ha of the area was burned. Most of this burned area was of moderate high severity (42%) followed by low severity (29%), moderate low severity (21%) and high severity (8%). The majority of the burned area (63%) was classified as moderately burned, where moderate high severity burn areas constituted twice the size of moderate low severity burn areas (Table 2).

Table 2. Fire severity levels and associated burned areas.

Severity level	Area (ha)	Percent (%)
Low severity	417	29
Moderate low severity	295	21
Moderate high severity	591	42
High severity	107	8

There was a more uniform gradation of burn severity in the east (E) and southeast (SE) sections of the area where there was a large moderate high severely burned swath surrounded by thin stretches of moderate low severity and low severity burn areas. There was a more fragmented severity distribution in the other directions. Small fragments of severely burned areas were scattered among moderate high severity burn sections in the north (N) and southwest (SW) directions. Similarly, moderate high and moderate low severity burn areas were surrounded

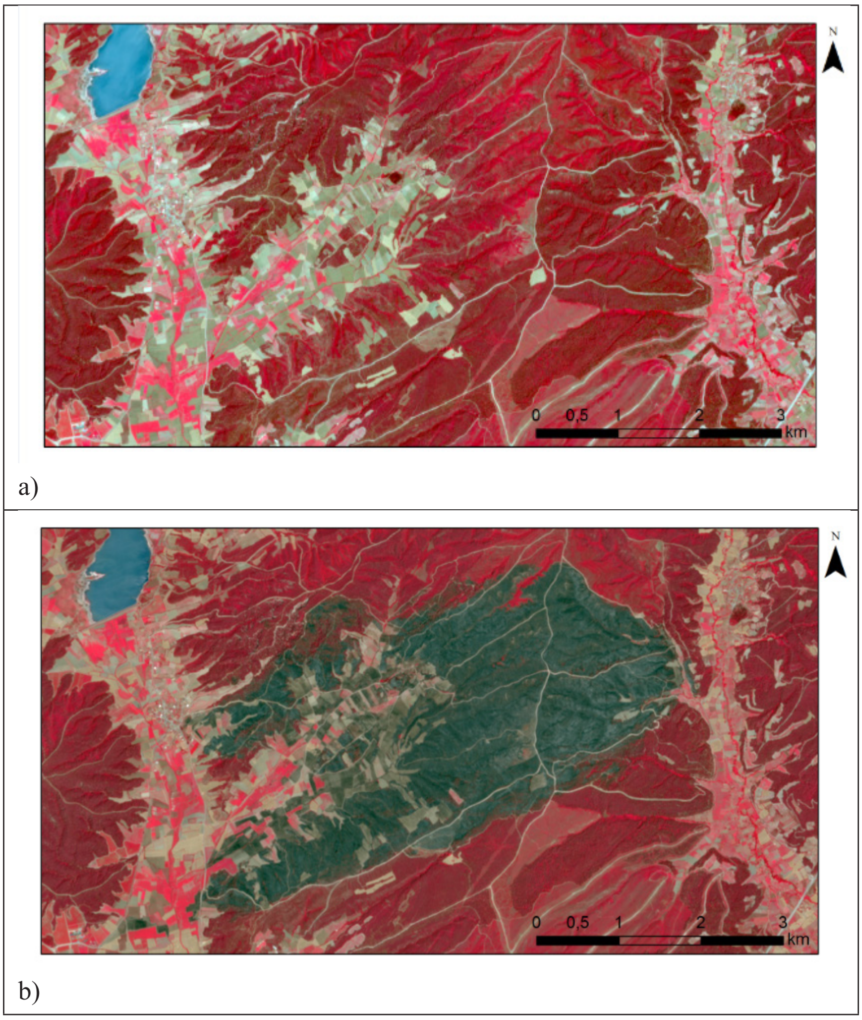

Figure 2. Sentinel 2 NIR color composite images of a) prefire on July 4, 2020, and b) postfire on July 9, 2020.

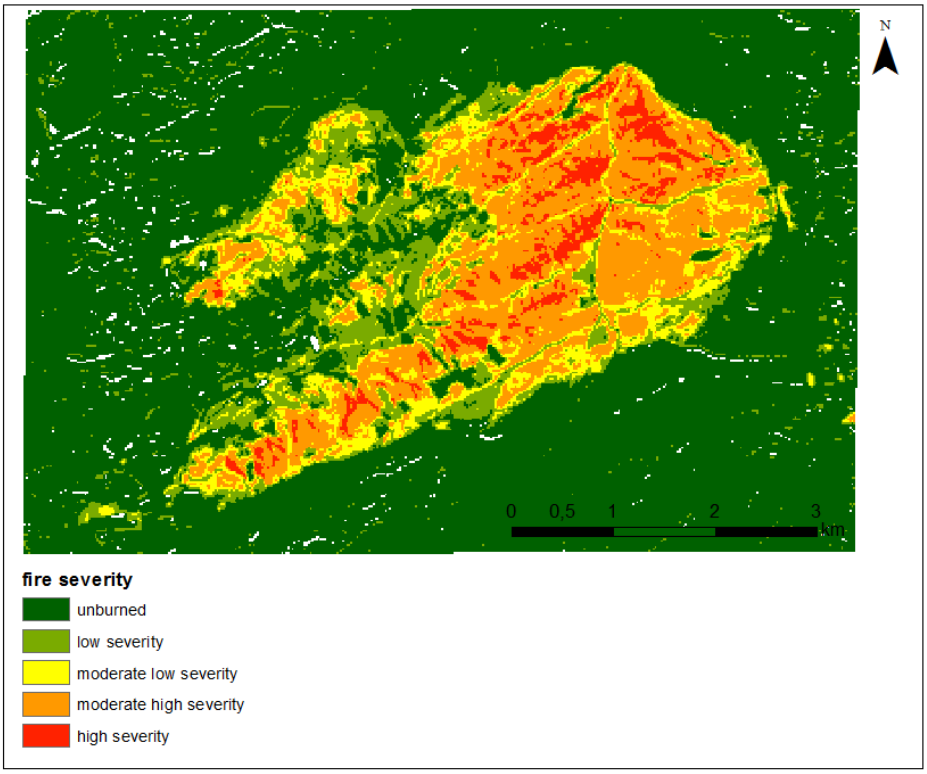

Figure 3. The extent and severity of the fire determined according to the dNBR index.

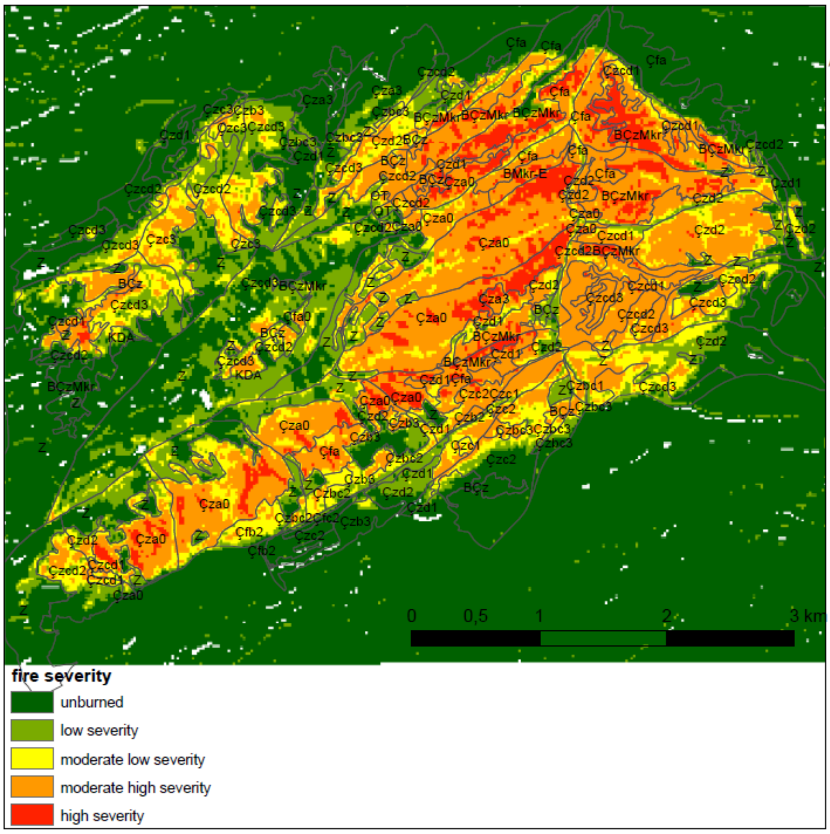

Figure 4. Forest stand map overlaid on the fire severity map. On the stand map Çz, Çf, and M stand for Turkish red pine, stone pine, and oak, respectively. OT: forest soil without trees; KDA: Non-cadastral area with trees; Z: agriculture; B: degraded stand. Lower case letters a-b-c-d represent stand development stages based on diameter at breast height values and numbers 1-2-3 indicate stand canopy closure ratios.

by low severity burn sections towards the western (W) flanks of the burn area.

The overlay of the stand map on the burn severity map revealed that the forested areas were more severely burned compared to the agricultural sections which are located to the W and SW of the burn area (Figure 4). The majority of the severely and moderate high severely burned areas were covered by pine stands composed of dominantly Turkish red pine (*Pinus brutia*) (Table 3). There also were small stands of stone pine (*Pinus pinea*) and oaks (*Quercus* spp.) on the severely and moderate high severely burned areas. The majority of the agricultural fields were unburned or burned with low severity (Table 3). The Turkish red pine stands within the periphery of the agricultural fields had low or moderate low severity burn (Figure 4). The majority of the agricultural areas burned consisted of wheat and olive crops.

Tablo 3. Stand types affected by the fire with associated average dNBR values and fire severity categories.

stand	mean dBNR	fire severity category
Çfc2	-0,01	unburned
Z	0,08	unburned
Çza3	0,09	unburned
Çzb3	0,17	low severity
Çzc2	0,25	low severity
BÇz	0,26	low severity
Çzbc3	0,26	low severity
Çzcd2	0,28	moderate low severity
OT	0,28	moderate low severity
KDA	0,29	moderate low severity
Çfa	0,31	moderate low severity
Çfb2	0,31	moderate low severity
Çzd1	0,31	moderate low severity
Çzc3	0,31	moderate low severity
Çzcd3	0,33	moderate low severity
Çzd2	0,33	moderate low severity
Çzbc2	0,33	moderate low severity
Çzc1	0,36	moderate low severity
Çfa0	0,37	moderate low severity
Çzbc1	0,41	moderate low severity
Çzcd1	0,51	moderate high severity
BÇzMkr	0,51	moderate high severity
Çzb2	0,54	moderate high severity
Çza0	0,54	moderate high severity
BMkr-E	0,59	moderate high severity

Discussion

Agricultural areas had lower degrees of fire severity compared to the forested areas. This difference is primarily related to the amount of fuel between the two ecosystems. Forested areas contained more flammable fuel in a continuous fashion compared to the agricultural areas. Also the presence of different agricultural crops and their different growth stages affect the spread and severity of the fire. For example, some of the agricultural lands were planted with sunflower, which was in its green vegetative phase at the time of the fire, and as a result these fields partially blocked the spread of the fire. The green vegetative phase of the agricultural crops are clearly visible in the NIR color composite image as seen in the red-colored regular geometric patterns (Figure 2). On the other hand, some of the agricultural fields were burned, which probably correspond to wheat fields that were in the maturity phase and completely dry, serving as flammable fuel. Others factors like topography, meteorological conditions including wind speed, direction, and humidity, and accessibility limitations could contribute to fire severity and how the fire spreads. Better management of firefighting as fire duration increases and as the fire approaches settled areas may also contribute to a fire's extent.

It is important to note that the aggregation of dNBR values in Table 3 reduces the variation that can be seen in Figure 4. Averaging is useful to show the general trends and get a quantitative estimate of fire severity values of different stand types affected by the fire, but the stand map overlay on the fire severity map displays more detail in terms of fire severity distribution. The two approaches combined provide a more accurate characterization of fire severity across the landscape.

The size of the burned area predicted in the study is greater than the area reported by the authorities and the media immediately after the fire was extinguished (url -1, 2 and 3). Authorities and media outlets reported 450 ha of burned area, which is about one third the size of the area (~1400 ha) that was identified in this study. A similar situation was reported by Nasery & Kalkan (2020) in İzmir, Turkey, who determined an approximately 14 times greater burned area than the one reported by the authorities and news agencies. Teodoro & Amaral (2019) also estimated greater burned areas using Sentinel 2 derived indices compared to the ones reported by the authorities in forest fires in Portugal.

The temporal resolution of Sentinel 2 increased from 10 to 5 days with the launch of the second satellite (2B). In the current study, this improvement made it possible to focus solely on the effects of fire right after the fire's occurrence while disregarding the effects of ecosystem processes such as recovery and regeneration. As Teodoro & Amaral (2019) noted, ecosystem processes can change the reflection over the NIR and SWIR portions of the EM and lead to different dNBR values, making it impossible to separate the effects of fire versus recovery and regeneration, as has been highlighted by Veraverbeke et al. (2010).

Results of the study agree with others. Amos et al. (2019) showed that Sentinel 2 data can be used successfully to discern the burn area and severity of a fire in NE Spain, which is located in a similar climate and vegetation to the current study. Likewise, Mallinis et al. (2018) found that dNBR index derived from Sentinel 2A was accurate in forest fire severity assessment and mapping in Mediterranean pine ecosystems in NE Greece. Delegido et al. (2018) reported improved prediction of fire severity using Sentinel 2 data in Argentina. Teodoro & Amaral (2019) found that Sentinel 2 data were more accurate in estimating burn area and fire severity levels in forest fires in Portugal.

Conclusions

This study examined the utility of recent Sentinel 2 satellite data to delineate fire area extent and identify fire severity of a forest fire that occurred in Çanakkale, Turkey, within the Mediterranean Basin, a particularly sensitive area of the world expected to have a greater occurrence and more severe forest fires. dNBR index was derived using the pre and postfire Sentinel images. A map with 20 m spatial resolution showing the fire area and fire severity levels was generated. The distribution and fire severity patterns reflect the characteristics of the different cover types in the area. Most of the burned area was pine forest composed of Turkish red pine. There were also patches of agricultural fields burned in the fire. Forested areas burned more severely compared to the agricultural fields primarily because they contained greater quantities of flammable fuel. Characteristics of agricultural crops, such as growth stages, played a role in the way the fire spread. Sentinel 2 data provide a fast and accurate means to monitor forest fire extent and fire severity as a result of its improved spatial and temporal resolution.

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