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The 2017 Large Wildfire of Braga - Evaluation of the Different Conditions of the Burned Vegetation

Le grand feu de forêt de Braga en 2017 - Évaluation des différentes conditions de la végétation brûlée

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Résumé: En 2017, 112 personnes sont mortes au Portugal prises au piège par de grands incendies de forêt, en seulement deux jours: le 17 juin et le 15 octobre. Le grand incendie de forêt de Braga, qui s'est produit lors du deuxième événement d'incendies de forêt, a brûlé 1007 hectares, dans une zone principalement occupée par des eucalyptus, mais avec d'importantes zones de forêts de chênes et de chênes-lièges, laissant l'interface habitat-forêt (IHF) de la ville de Braga sans protection. Ce feu de forêt a été aggravé par les conditions météorologiques résultant de l'ouragan Ophelia.

Bien que les conditions météorologiques soient un facteur déterminant de l'occurrence et de la progression des incendies de forêt, ce phénomène est également influencé par d'autres facteurs, tels que ceux liés à la végétation. Par conséquent, cette étude vise à évaluer les conditions de verdure, d'humidité et de sénescence de la végétation avant le grand incendie de Braga en 2017, ainsi que sa gravité, à l'aide d'indices spectraux. Les données du senseur Sentinel 2, du 2 et du 22 Octobre, ont été utilisées.

Par conséquent, sur les 30 points identifiés comme non brûlés, un seul a été classé comme brûlé, ce qui représentait un taux de réussite de 0,967; sur les 30 identifiés comme brûlés, tous étaient discriminés, ce qui représentait un taux de réussite de 1,0. Sur les 60 échantillons utilisés, la proportion de bonnes réponses était de 0,983. Pour la gravité des brûlures, nous avons trouvé 456,4 hectares de zones de brûlures de faible gravité; pour les zones de brûlures d'intensité modérée à faible, nous avons trouvé 338,76 hectares; 279,84 hectares de zones de brûlage modéré à élevé; et 270,52 hectares de zones de forte gravité.

Mots-clés: Grand feu de forêt de Braga, Indices spectraux, Sentinel 2, Analyse discriminante, Gravité des brûlures.

Abstract: In 2017, 112 people died in Portugal trapped by large wildfires, in just two days: June 17 and October 15. The large wildfire of Braga, which occurred in the second event of widespread wildfires, burned 1,007 hectares, in an area predominantly occupied by eucalyptus, but with significant oak and cork-oak forest areas, leaving the wildland-urban interface (wui) of the city of Braga unprotected. This wildfire was heightened by the weather conditions resulting from the hurricane Ophelia.

Although weather conditions are a determining factor for wildfire occurrence and progression, this phenomenon is also influenced by other factors, such as those related to vegetation. Consequently, the present study aimed to evaluate the greenness, humidity and senescence conditions of the vegetation prior to the 2017 large wildfire of Braga, as well as its severity, using spectral indices. Data from the Sentinel 2 sensor, from October 2 and 22 was used.

As a result, of the 30 points identified as unburned, only 1 was classified as burned, which represented a 0.967 hit ratio; of the 30 identified as burned, all were discriminated, which represented a 1.0 hit ratio. Of the 60 samples used, the proportion of correct answers was 0.983. For the burn severity, we found 456.4 hectares of low severity burn areas; for the moderate-low severity burn areas we found 338.76 hectares; 279.84 hectares of the moderate-high burn areas; and 270.52 hectares of high severity areas.

Keywords: Large wildfire of Braga, Spectral Indices, Sentinel 2, Discriminant Analysis, Burn Severity.

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INTRODUCTION

It is generally accepted that fire is one of the most ancient tools for cleaning areas in order for them to be cultivated and their pasture renewed, among other activities (SÁ *et al*., 2007).

Nevertheless, wildfires are becoming increasingly frequent as a result of climate change and poor forest planning, with deleterious impacts on vegetation and soils. Fire drastically reduces or eliminates the vegetation cover, thus exposing the surface to rainfalls that easily erode the top soil layer, which is the major nutrient pool in most soils, in particular the shallow soils affected by wildfires in Portugal. Higher sediment wash rate by runoff erosion typically occurs during the first autumn rainfall events, roughly meaning that the first 6 months after a wildfire are the most critical for nutrient mobilization in eroded soil particles and runoff water.

The destruction of vegetation by fires makes soils vulnerable to erosion, by promoting the removal of nutrients together with organic and mineral components. This significant and continuous degradation of soil, especially visible in Mediterranean areas, makes the implementation of slope protection measures urgent in order to mitigate the effects of wildfires and reduce the loss of soil and nutrients (SHAKESBY *et al.*, 1993; BENTO-GONÇALVES & COELHO, 1995; WALSH *et al*., 1998; BENTO-GONÇALVES & LOURENÇO, 2010; VEGA *et al.*, 2010; SHAKESBY, 2011; BENTO-GONÇALVES *et al*., 2012; VIEIRA *et al*., 2018).

Nevertheless, this process is closely dependent on fire recurrence, intensity, severity, and spatial variability of soil hydrophobicity (JUNGERIUS & DEJONG, 1989; RITSEMA & DEKKER, 1994; COELHO *et al*., 2004; BENTO-GONÇALVES *et al*., 2012; FERREIRA-LEITE *et al*., 2011), as well as the physical characteristics of the affected area (for instance slope gradient and aspect, climate, geological composition) as some pioneering studies conducted in Portugal have demonstrated (BENTO-GONÇALVES & LOURENÇO, 2010). Therefore, is important to take all these factors into consideration and adapt the different mitigation measures and techniques to each specific context.

Science can help solve these problems, by increasing and strengthening present knowledge on actual risks, so as to provide solutions for those posed by future fire regimes and their impact on land degradation.

In this context, the use of remote sensing data is a valuable and indispensable source of information for studies on wildfires and for assessing the conditions, characteristics and structure of the vegetation. Spectral, spacial and temporal resolution of images is also important, which condition the success of applying remote sensing in the analysis of these vegetation characteristics (WULDER *et al.*, 2009; CALLE & CASANOVA, 2008).

The use of different indices to assess the characteristics and conditions of the vegetation can be of great use in assessing the potential risk of ignition or spread of wildfire at each period of the year, and especially before and after the critical wildfire period.

Moreover, the effects of wildfires in the ecosystems, in all their different dimensions, have been the subject of extensive research (NEARY & LEONARD*,* 2015), especially related to soil erosion and degradation (BENTO-GONÇALVES *et al*., 2012), and, in this sense, due to the temporality of data acquisition remote sensing has proved to be an excellent tool (CHUVIECO *et al*., 2002; CHUVIECO *et al*., 2005; FRANÇA, 2000).

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Portugal has a "pyro-environment", as stated by STEPHEN PYNE, since it combines Mediterranean characteristics, such as warm, dry seasons, and Atlantic features, allowing for high plant productivity.

Indeed, this has been the reality in Portugal year after year, for, while up to 1986 we had never suffered a wildfire affecting more than 10,000 hectares, in 2003 one wildfire covered 20,000 hectares, and in 2017 such fires affected 38,000 hectares twice.

The circumstances in 2017, however, were quite peculiar, which may in part justify the catastrophe that ensued, such as the passage of the hurricane Ophelia, responsible for the exceptional weather conditions on October 15.

Hurricane Ophelia, formed in the middle of the North Atlantic, followed an unusual path heading towards Portugal, which increased both the cloud cover and the winds, which in a way facilitated the propagation of the fire. Cloud cover hinders the view of the surface when using remote data sensing (Figure 1).

The large wildfire of Braga broke out under these conditions, starting on October 12 in the municipality of Guimarães (Leitões), and spread to the municipality of Braga on October 15, burning about 1,007 hectares (967 hectares of forest and 40 hectares of shrub), in an area predominantly covered by eucalyptus (*Eucaliptus globulus*), but with a significant area of oak (*Quercus robur*) and cork-tree (*Quercus suber*) forest (Figure 2).

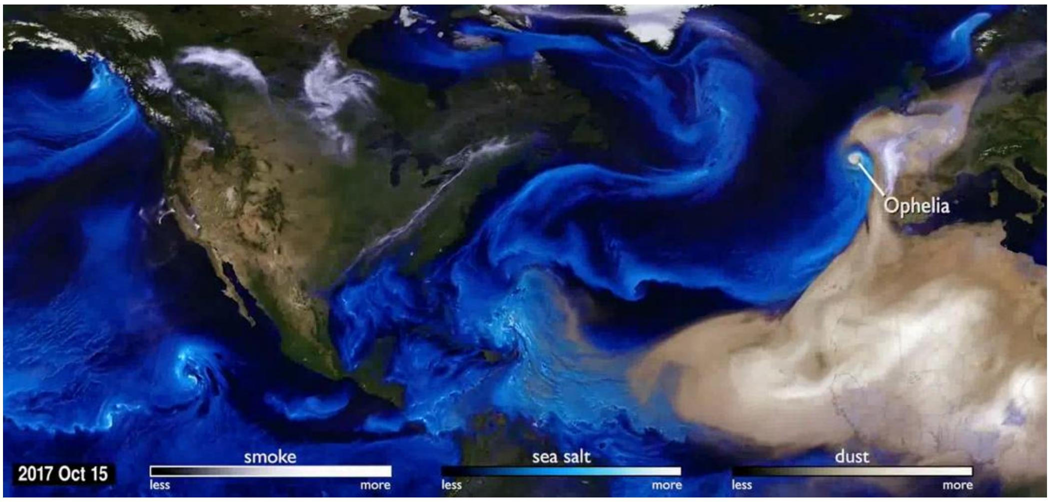

Figure 1 – Ophelia hurricane in Portugal on October 15, 2017, had shown smoke, sea salt and dust mixture. Source: GSFC/NASA

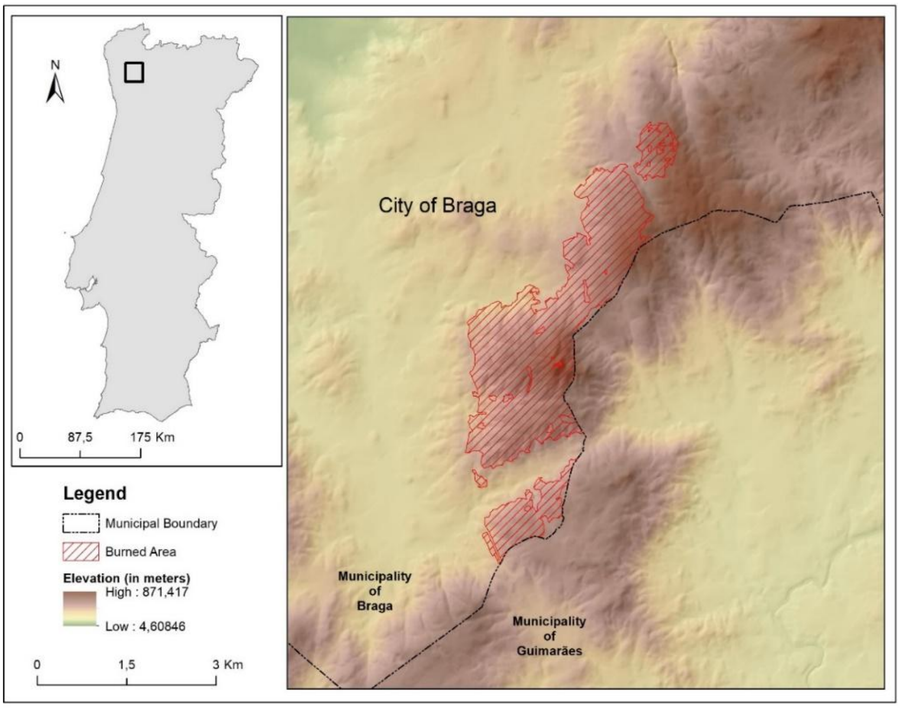

Figure 2 – Area affected by the Braga wildfire (only area within Braga municipality).

The wildfire spread across the steep and disorderly wildland-urban interface (BENTO-GONÇALVES & VIEIRA, 2019) of the city of Braga, leaving its slopes stripped of its undergrowth, which, together with the steep slopes and intense rainfall caused serious problems downstream, such as, for example, during the first rainfalls after the wildfire, on December 10, when the storm "Ana" passed.

Public authorities should, therefore, assess the severity of wildfires in order to enable the definition of priority areas of intervention and, thus, establish plans for the implementation of measures to mitigate the emergency.

At the start of the so-called "fire season", the vegetation conditions should also be assessed, which would allow them to be proactive in Defending the Forest against wildFires, and thereby increase surveillance and the fire-fighting mechanisms in the critical areas.

MATERIAL AND METHODS

To conduct this study, we have used data from the Multispectral Instrument (MSI) sensor of Sentinel 2, relating to October 2, considered as the pre-fire scenario (Figure 3), and to October 22, the post-fire scenario (Figure 4). The analysis carried out was based on surface reflectance data – L2A product –, with the correction of atmospheric effects and a 20-meter spatial resolution.

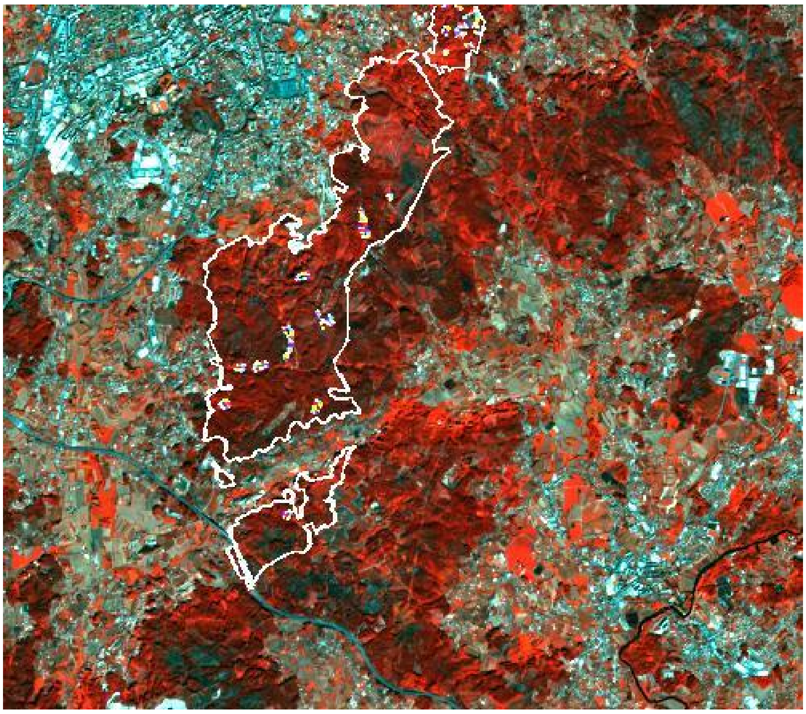

Figure 3 – Pre-fire scenario of the Sentinel 2 MSI, on October 2, 2017, R7G2B1false color composition.

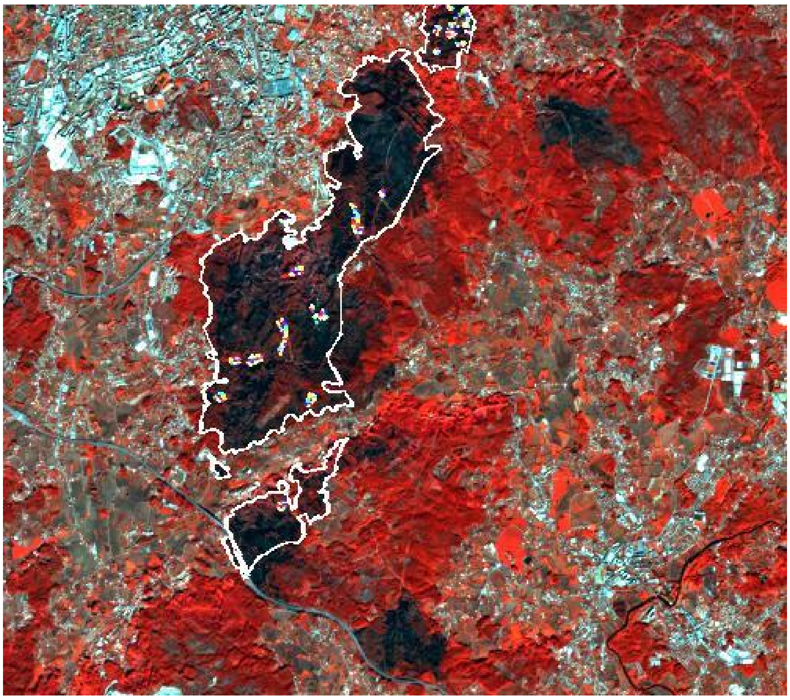

Figure 4 – Post-fire scenario of the Sentinel 2 MSI, on October 22, 2017, R7G2B1 false color composition, highlighting the burned areas.

The grounds for choosing these types of data were twofold. First, the fact this data source shows a 5-day temporal resolution, because the Sentinel system is a constellation formed by two identical satellites positioned at 180º between each other. We were thus able to identify scenarios with no cloud cover, in a rather difficult period in terms of weather, due to the passage of hurricane Ophelia. As regards the Landsat OLI data, for example, since the temporal resolution is of 16 days there was no scenario without cloud cover available to assess this wildfire.

Another reason for choosing the Sentinel 2 data is that the MSI sensor has about 3 bands that cover the red-edge band, required for the investigation of senescence by means of spectral indices.

The pre-fire data served to calculate the greenness – NDVI (Normalized Difference Vegetation Index) –, humidity – NDII (Normalized Difference Infrared Index) –, and senescence – PSRI (Plant Senescence Reflectance Index) spectral indices.

The NDVI (Normalized Difference Vegetation Index), proposed by ROUSE *et al.,* (1973) measures the greenness of vegetation by means of the intensity of the spectral red-edge feature (665 nm) in relation to the near infrared (NIR – Near InfraRed) (864.8 nm) (Equation 1).

$$NDVI = \frac{(\rho_{864.8} - \rho_{665})}{(\rho_{864.8} + \rho_{665})} \quad \text{(Eq. 1)}$$

where ρ_{865} corresponds to the reflectance in NIR, in 864.8 nm; and ρ_{665} corresponds to the reflectance in red, in 665 nm.

The NDII (Normalized Difference Infrared Index) (HARDISKY *et al*., 1983) (Equation 2) uses the same principle as for the NDVI, that is, the differences between the bands divided by their sum; however, it verifies the relation between the near infrared (864.8 nm) and the short waves (1610 nm) to measure the canopy humidity.

$$NDII = \frac{(\rho_{864.8} - \rho_{1610})}{(\rho_{864.8} + \rho_{1610})} \quad \text{(Eq. 2)}$$

where $\rho_{864.8}$ corresponds to the reflectance in NIR, em 864.8 nm; and ρ_{1610} corresponds to the reflectance in the ShortWave InfraRed (SWIR), in 1610 nm.

The PSRI (Plant Senescence Reflectance Index) (MERZLYAK *et al*., 1999) (Equation 3), measures plant senescence, by subtracting between the blue (496.6 nm) and the red (665 nm), divided by the red-edge (740.2 nm).

$$PSRI = \frac{(\rho_{496.6} - \rho_{665})}{\rho_{740.2}} \quad \text{(Eq. 3)}$$

where $\rho_{496.6}$ corresponds to the reflectance in blue, in 496.6 nm; ρ_{665} corresponds to the reflectance in red, em 665 nm; and $\rho_{740,2}$ corresponds to the in the red-edge, in 740.2 nm.

To select the pixel samples of burned and unburned areas, we adopted the October 22 post-fire scenario. To do so, 30 points were selected for each class, using the pure pixel criterion. Consequently, we reduced the dimension of data and noise, through the *Minimum Noise Fraction* (MNF) method (GREEN *et al*., 1988).

Then, by selecting the MNFs with a predominance in variance and signal, the *Pixel Purity Index* (PPI) (BOARDMAN *et al*., 1995) was adopted, which uses the iterative method to assess how often the pixel was at one end of the simplex formed by the clusters. Pure pixels are those that have been more often at the ends and are thus classified.

After selecting the pure pixels of burned and unburned areas, we surveyed the NDVI, NDII and PSRI values in the October 2 image, that is, before the wildfire, in order to understand the behavior of one area and of another to find the separability criterion between the areas.

Once we had the value of each index for each of the points, we used Fisher's discriminant multivariate analysis to separate the pixels of burned and unburned areas. To do so, the BioEstat 5.3. free statistical software was used.

To calculate the Braga wildfire severity degree, the same Sentinel 2 MSI scenarios were used, the October 2 fire scenario corresponding to the pre-fire and the October 22 to the post-fire scenario.

The NBR (Normalized Burn Ratio) (ROY *et al*., 2006) was calculated for each scenario, which is based on the normalized difference ratio between the NRI (864.8 nm) and the SWIR regions (2202.4) (Equation 4).

$$NBR = \frac{(\rho_{864.8} - \rho_{2202.4})}{(\rho_{864.8} + \rho_{2202.4})} \quad \text{(Eq. 4)}$$

Where $\rho_{864.8}$ corresponds to the reflectance in NIR, in 864.8 nm; and $\rho_{2202.4}$ corresponds to the reflectance in the ShortWave InfraRed (SWIR), in 2202.4 nm.

The wildfire severity is calculated as the difference in the NBR in the pre-fire and post-fire scenario, as per equation 5.

$$dNBR = NBR_{pré-fogo} - NBR_{pós-fogo} \quad \text{(Eq. 5)}$$

RESULTS AND DISCUSSION

With regard to greenness through the NDVI, for the pixels of the unburned area, it varied from 0.907 to 0.998, with a mean of 0.943 and a standard deviation of 0.025. The variance of the greenness sample was 0.00065. As for the pixels of the burned areas, they showed less greenness, varying between 0.703 and 0.889. The mean was of 0.852, with a standard deviation of 0.04 and variance much greater than that of the pixels of the unburned areas, at 0.0016. Figure 5 shows the NDVI variation for the pre-fire scenario, while Figure 6 applies to the post-fire scenario.

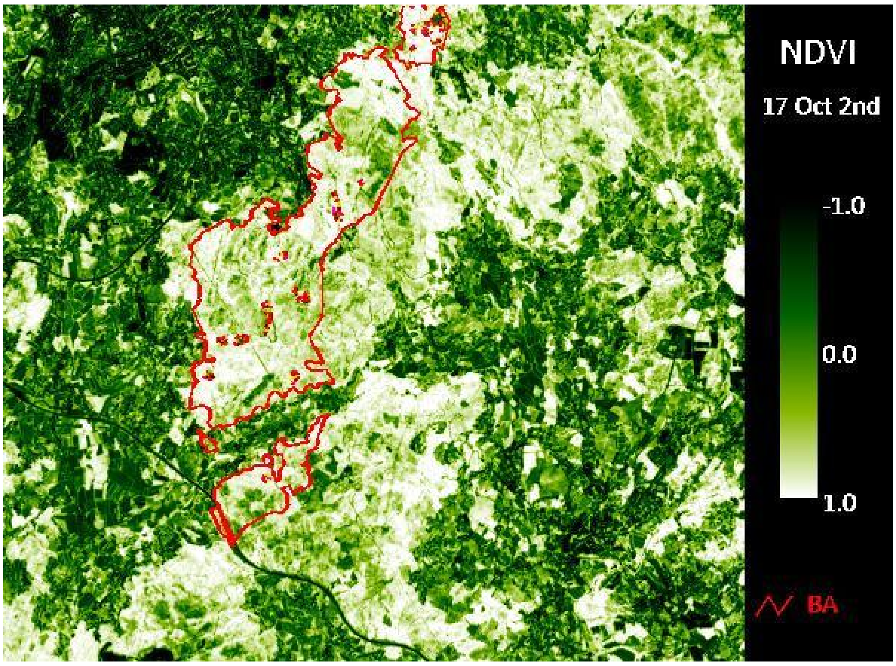

Figure 5 - NDVI variation for the pre-fire scenario.

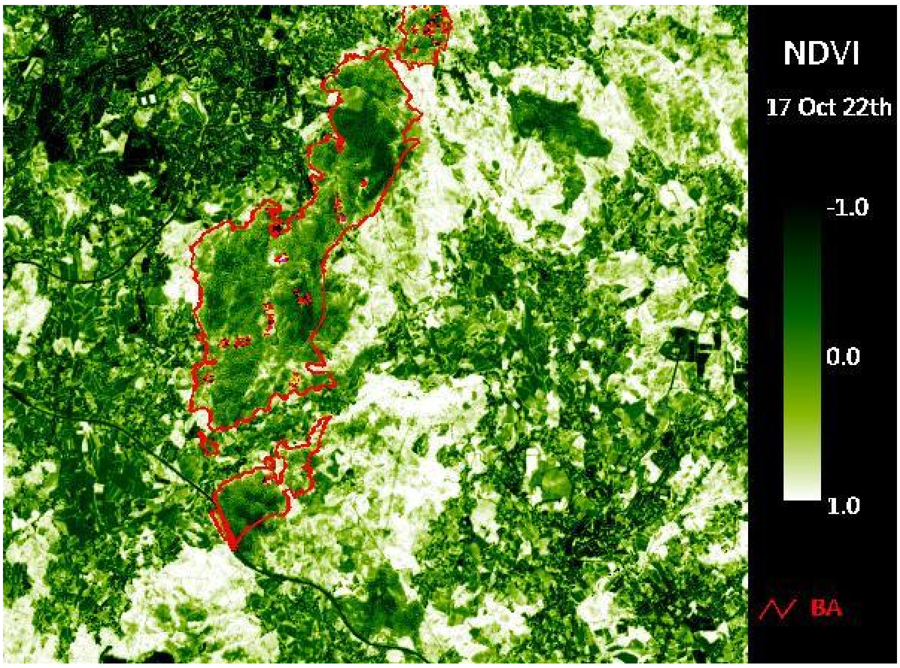

Figure 6 - NDVI variation for the post-fire scenario.

The comparison between figures 5 and 6 shows that the areas that are photosynthetically active, or that present positive NDVI values are transformed into non-photosynthetically areas in the post-fire image, in particular those found within the boundaries of the area affected by the wildfire. This explains the drop in greenness, as well as the drops in the values obtained in the samples assessed in the burned and unburned areas.
As regards humidity, obtained from the NDII index, the pixels of the unburned area show more humidity ($\mu = 0.42 \pm 0.11$) and minimum values of 0.132 and maximum values of 0.579, with a sample variance of 0.012. The pixels of the burned area, in turn, show less humidity ($\mu = 0.35 \pm 0.10$) and range from 0.062 to 0.518, with a 0.010 variance. Figure 7 presents the NDII variance for the pre-fire scenario, while figure 8 shows that of the post-fire scenario.

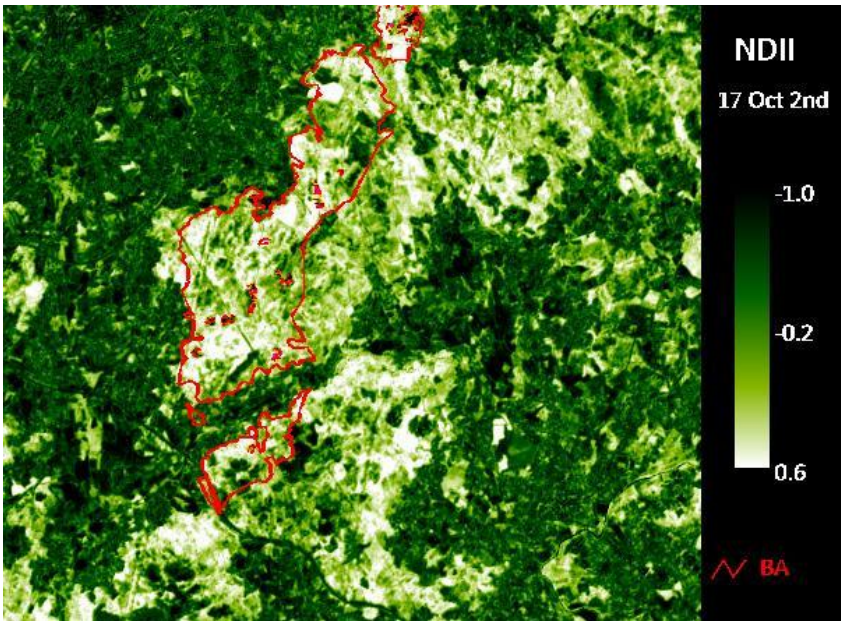

Figure 7 - NDII variation for the pre-fire scenario.

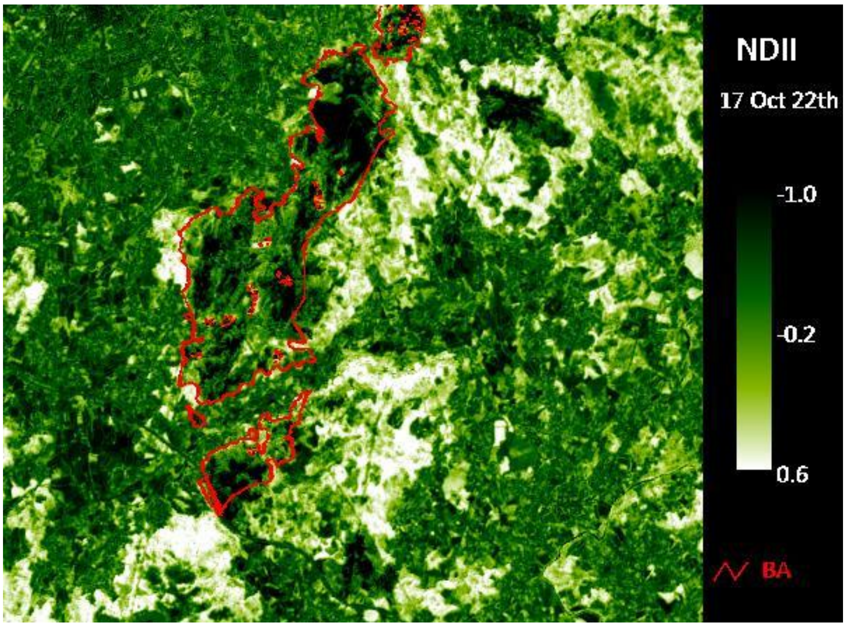

Figure 8 - NDII variation for the post-fire scenario.

As with the greenness, humidity falls to negative values in the burned areas.

With regard to senescence, the unburned area showed a mean value at the threshold of what is considered as senescent vegetation ($\mu = 0.20 \pm 0.049$), with minimum values of 0.12 and maximum values of 0.31, and a

0.002 variance. Green vegetation is commonly said to exist between the interval of -0.1 and 0.2, while above that senescent vegetation is considered to exist. The burned class pixels presented greater senescence, with a mean of 0.26 and a 0.02 deviation. The minimum and maximum values of 0.21 to 0.35 are all above what is considered as senescence vegetation, with a 0.0006 variance. Figures 9 and 10 present, respectively, the PSRI variation for the pre-fire and post-fire scenario.

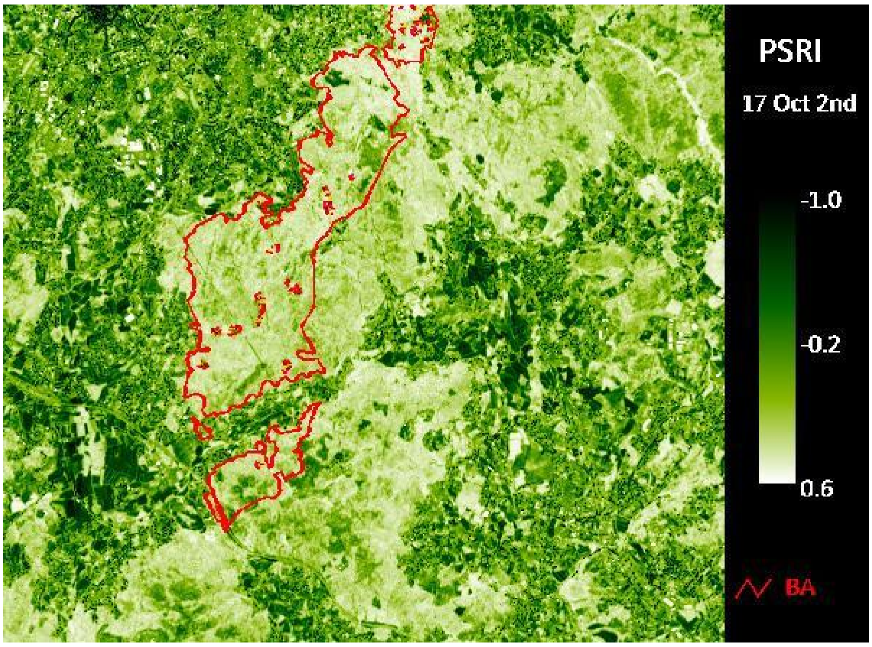

Figure 9 - PSRI variation for the pre-fire scenario.

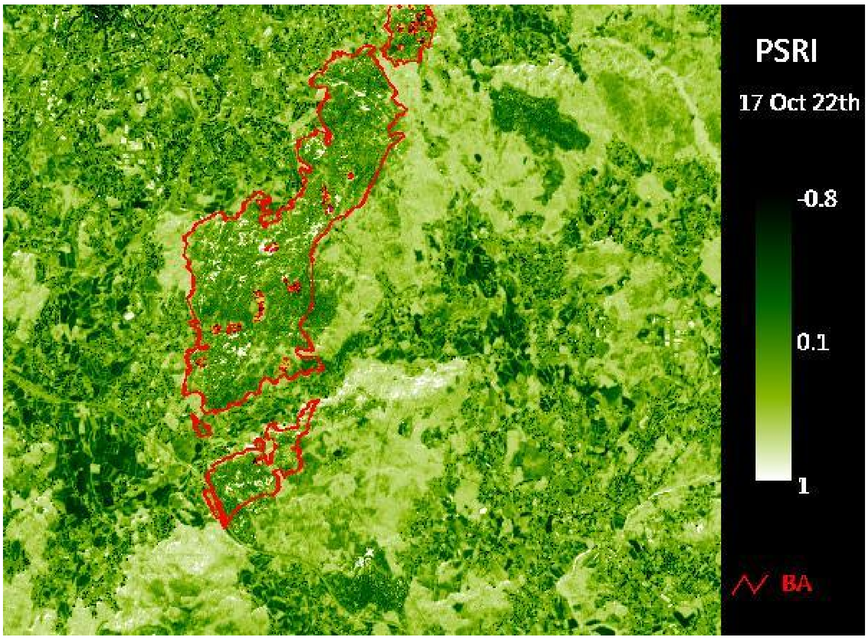

Figure 10 - PSRI variation for the post-fire scenario.

As BAPTISTA *et al*. (2017) pointed out, unlike other indices, the highest values obtained show areas with greater senescence, that is, with less humidity and less greenness. That is to say, the burned class showed less greenness ($\mu = 0.85 \pm 0.04$), less humidity ($\mu = 0.35 \pm 0.10$) and greater senescence ($\mu = 0.26 \pm 0.02$) compared to the class of pixels that did not burn.

To check the availability of fuels for the Braga wildfire, a colored composition was also performed, considering the negative values of NDVI and NDII, and the negatives of the inverted PSRI image, that is, multiplied by -1. The result shown in Figure 11 presents, in cyan, the areas with less greenness, less humidity, and greater senescence. In Figure 12, the class of available fuels was sub-divided into four classes, the green one showing the highest values, followed by the yellow one, the red one and the dark red one. The areas obtained totaled 835.8 hectares (green); 1,939.68 hectares (yellow); 1,313.4 hectares (red) and 888.24 hectares (dark red).

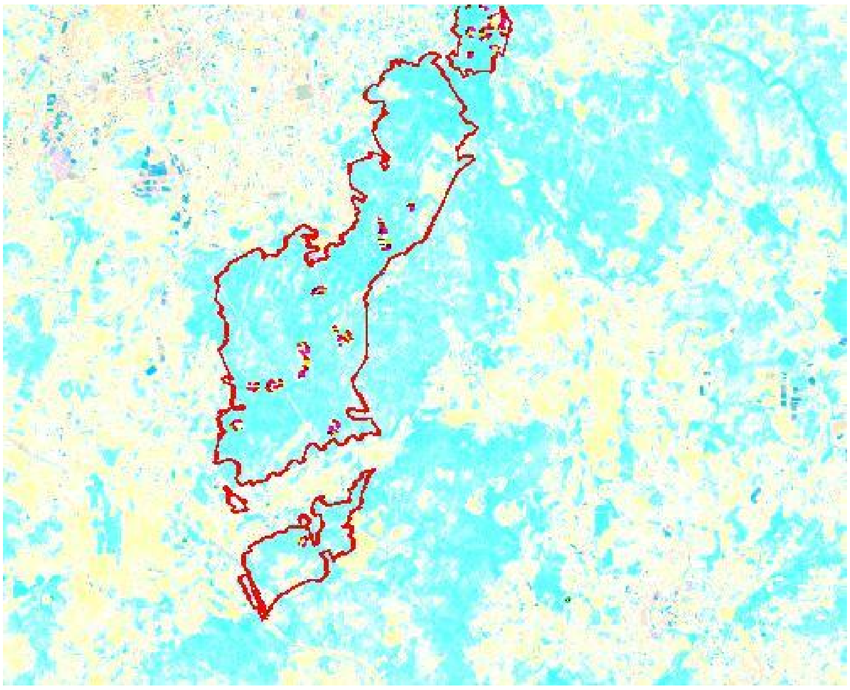

Figure 11 - R(-PSRI)G(NDVI)B(NDII) colored composition. The areas depicted in cyan point to the greater availability of fuel, as they show less greenness, less humidity and greater senescence.

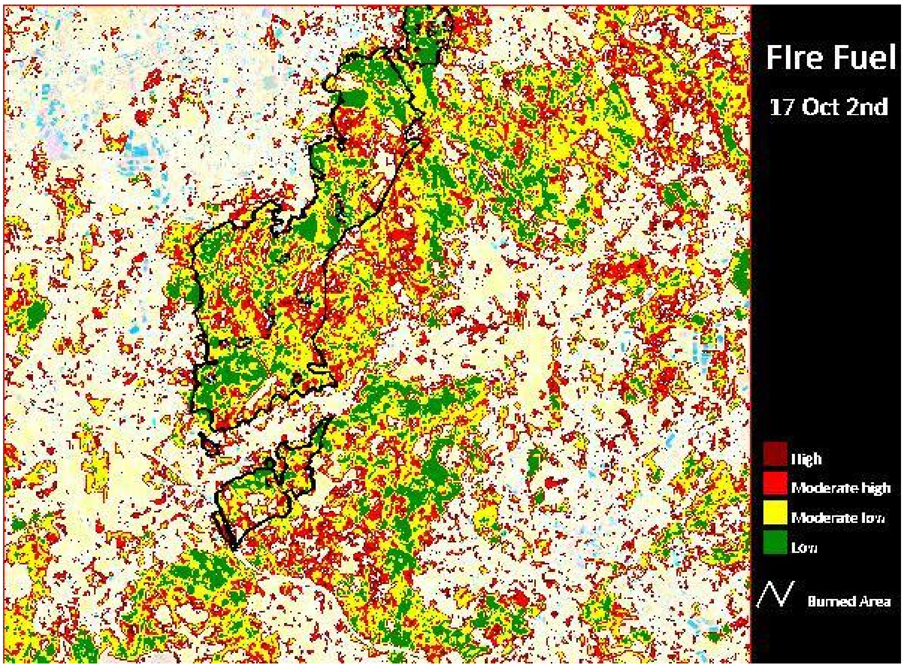

Figure 12 – Slicing of the R(-PSRI)G(NDVI)B(NDII) color composition, showing the availability of wildfire fuels in the pre-fire image. The highest values range from green, yellow, red, to dark red.

With a view to assessing the separability of the two classes, Fisher's discriminant analysis was applied. The discriminant equations found were Y1 = -0.0817 X1 + 0.9462 X2 -0.3129 X3 and Y2 = 0.2945 X1 + 0.3027 X2 + 0.9064 X3, where X1 corresponds to the NDII values; X2, to NDVI values, and X3 to PSRI values. The spatialization of the discriminant analysis is presented in Figure 13.

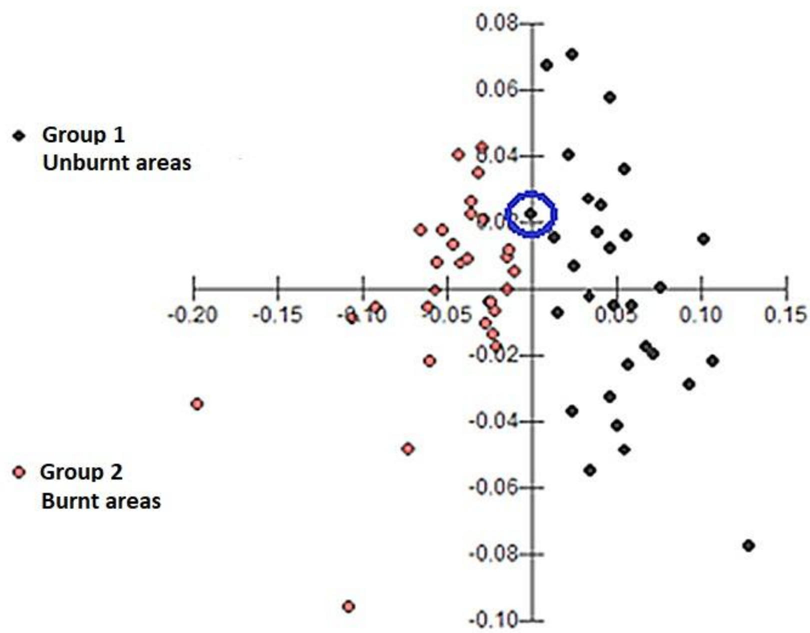

Figure 13 – Discriminant analysis with the pixels of the unburned areas (Group 1) and burned areas (Group 2). The blue highlights the pixel of the unburned area classified as burned area.

As a result, of the 30 points identified as unburned areas, only 1 was classified as burned, highlighted by the blue polygon in Figure 14, which represented 96.7% of hit ratio in class discrimination. As for the 30 pixels identified as burned, they have all been discriminated, representing 100% of the hit ratio. Overall, the hit ratio for the 60 samples used was of 98.3%. Table 1 shows the result of the discriminant analysis.

Table 1 – Result of the discriminant analysis.

Groups	**True Groups**	
	Unburned Area	Burned Area
Unburned Area	**29**	0
Burned Area	01	**30**
Total N	30	30
Correct N	29	30
Ratio	0.967	1.000
Total N		60
Correct N		59
Correct ratio		0.983

This discriminant analysis technique was also used by SANTOS *et al*. (2017) and was able to separate, in semi-arid conditions, preserved *caatinga* from degraded *caatinga* and from degraded pasture land, but with a lower percentage of hit ratio, at about 70%.

The verification of the severity degree of the wildfire was obtained by using the NBR and deducting the pre-fire and post-fire NBR, as shown in Figure 14. Low burn areas consist of 456.4 hectares; those of moderate-low burn cover 338.76 hectares; moderate-high burn areas, 279.84 hectares; and 270.52 hectares of high burn areas.

The validation of the wildfire severity using field methods, as per the BAER method (NAPPER, 2006; PARSON *et al*., 2010), largely confirmed the modeling performed through the dNBR calculation, thus allowing us to identity the areas where the vegetation was more severely affected.

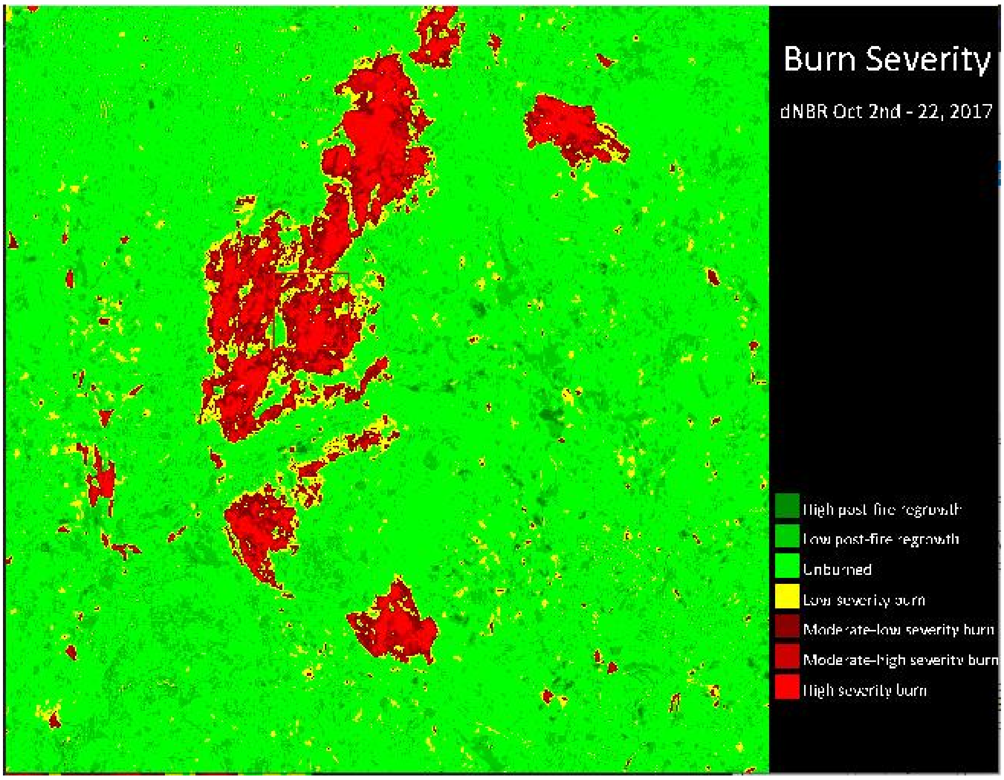

Figure 14 – Assessment of the severity of the Braga wildfire.

While this is not the central objective of our work, we cannot forget to briefly refer to the direct consequences observed in these areas affected by the wildfire, following the subsequent adverse rainfall conditions.

As it happened, on October 10 the area was strongly hit by the storm Ana (affecting the north of the Iberian Peninsula), with heavy rainfall. So, on the 10th, rainfall exceeded 100 mm in Braga (pluviograph set up in Sameiro, at approximately 600 meters altitude in the area affected by the wildfire), with precipitation felt most in the afternoon, right after 12 p.m., but more intensely at 5 p.m. and continued during the night, reaching the highest value at 8 p.m. (Figure 15). As a result, there were dozens of occurrences in Braga, especially in the area hit by the wildfire and in the urban areas downstream, with special emphasis on the parishes of Esporões and Fraião.

In addition to widespread erosion along the slopes, especially in the worst affected areas, there were many cases of runoff concentration, promoting the development of crevices (Figure 16) and the destruction of infrastructures (VIEIRA *et al*., 2019).

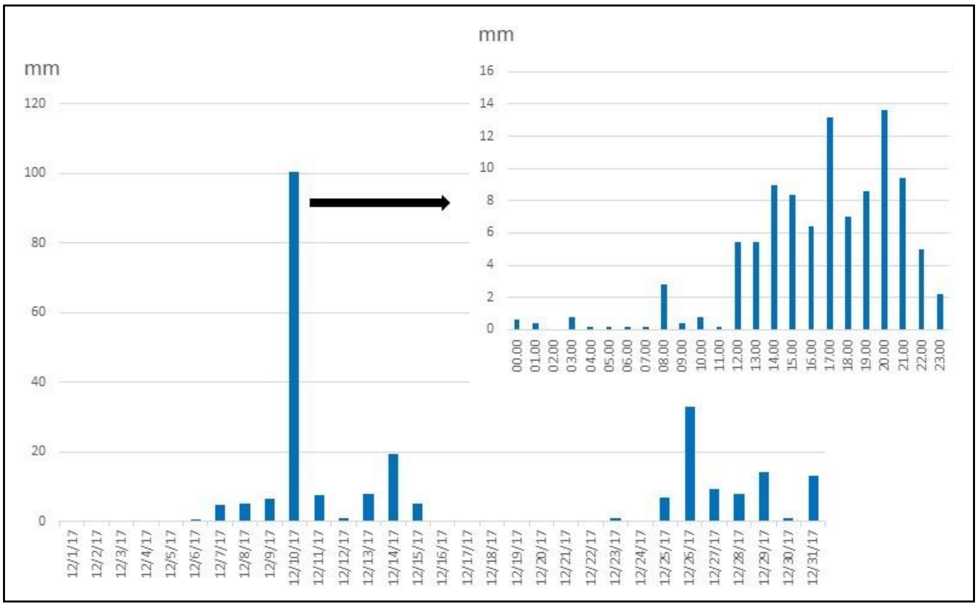

Figure 15 – Daily distribution of rainfall in December and hourly distribution on December 10, 2017.

Figure 16 – Examples of the erosion in the areas affected by the fire.

The use of mapping techniques and resources presented throughout our work can be extremely useful for preventing the occurrence of fires and for mitigating the effects arising from the expected erosion.

CONCLUSIONS

This study has discretized the areas that burned from those that did not, by adopting spectral indices that have indicated the state of vegetation greenness, humidity and senescence. Thus analysis has suggested that the pixels of the burned areas are really different from those that did not burn, and the indices prove that the more susceptible areas show less greenness, less humidity and greater senescence.

The validation of the wildfire severity (low, moderate-low, moderate-high and high) using the BAER method, largely confirmed the modeling performed through the dNBR calculation.

Another aspect that this work has brought to light is that these indicators may be truly important for monitoring potential burn areas and can prevent disasters like those seen in 2017 in Portugal from happening.

New studies should be encouraged to better understand past conditions in order to avoid catastrophic events such as those that took place in Portugal in that year.

ACKNOWLEDGMENTS

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