SEMI-AUTOMATIC APPROACH OF BURNT AREA EXTRACTION BASED ON DIFFERENT INDICES

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ABSTRACT:

The following study is focused on the analysis of burnt areas extracted by the use of an automatic tool. The burnt areas are obtained by applying different vegetation and burnt areas indices available in the literature (NDVI, NDB, SAVI, BAIM and BAIS2), calculated as combinations of two or more bands of the satellite images to synthesize the information carried by multispectral sensors and frequently used for the mapping fires. The research aims to find strong and alternative methods to combine with survey field activities. Traditional methods can often be subject to sampling errors or even to the non-perimeter of the event where the area is inaccessible. Satellite images allow to perform these activities simply and automatically, reducing costs and significantly increasing the accuracy and completeness of the data. Some areas analysed in the Copernicus Rapid Mapping and Risk and Recovery Mapping service were taken as case studies. A validation test has been made on all the selected indices, to evaluate the limits and potential of the different approaches and provide a burnt area closer to reality. Not having ground surveys data, the reference information for validation is given by the photointerpretation by experts in the sector.

1. INTRODUCTION

Wildfires are among the most destructive disasters, with an enormous impact in populated regions, where population is forced to move or killed, houses and infrastructures are damaged or destroyed, but also in isolated ones, where natural vegetation and animals are affected. In recent years wildfires are growing, partly due to the effect of global warming, with the increase of extremely high temperature and drought (Kerr, 2007), partly due to illegal wildfires, linked to land management policy that favours agriculture and pastures.

Remote sensing multispectral imagery has proved to be a valuable tool in fire's monitoring. In particular, the variation in content of chlorophyll in vegetation can be derived from the analysis of the spectral firm of a particular vegetated area, which highlights areas that have little content or have been deprived of it, as in the case of vegetated areas devastated by a fire. These indices, known as vegetation indices, are mainly used to evaluate the state of the vegetation, a topic widely explored in remote sensing research applications, but are also used to detect, delineate, and quantify burnt areas. In addition, the use of remote sensing products allows the monitoring of large and remote places, contributing to planning actions of Civil Protection, Forestry Corps and other actors involved in the emergency management.

The Copernicus Emergency Management Service (EMS) is an on-demand service of European community devoted to providing relevant and updated geospatial information to give a timeline response to various types of disaster using remote sensing imagery[1]. The EMS is divided into two components: Rapid Mapping, that provides geospatial information within hours or days in the immediate aftermath of a disaster, and Risk & Recovery Mapping, which supports prevention, preparedness, risk reduction and recovery phases activities. A focal point of these services is the timeliness in product delivery: the use of fast and reliable automatic and semi-automatic extraction tools of imagery, which are then manually refined thanks to the team's expertise, are one of the keys to reduce delivery time. In this study, a two-step QGIS plugin has been developed in order to calculate five different vegetation indices and then automatically extract burnt areas over imagery, depending on a threshold value decided by an expert operator by means of visual interpretation. Through the tool the authors aim to automate the comparison the five indices result and evaluate which one better extract a burnt area. Thanks to a validation activity, performed on ten EMS wildfire activations, the accuracy of the burnt areas extracted with the plugin is compared with the same areas manually digitized by photointerpretation. Results of validation are discussed to estimate the different performances of vegetation indices in the burnt area identification. In addition, the validation results are used to demonstrate the timesaving of plugin processing with respect to a manual photointerpretation extraction: the effectiveness of the plugin makes it a good candidate to be used for wildfire extraction in the Copernicus Rapid Mapping and Risk and Recovery Workflow. Finally, the strengths and the critical points of the used images and the implemented plugin are discussed, to identify the main problems encountered during the processing and the possible future developments.

2. METHODOLOGY

2.1 Vegetation indices and plugin processing

The first aim of the authors was to develop a tool to extract burnt areas from a satellite image in a more automated way, by relying on the calculation of a vegetation index.

Following previous burnt land studies, five spectral indices based on the Red, Near Infrared (NIR) and Short-Wavelength Infrared (SWIR) spectral domains, have been chosen: the Normalized Difference Vegetation Index (NDVI), the Soil Adjusted

[1] https://emergency.copernicus.eu/

Vegetation Index (SAVI), the Normalized Burn Ratio (NBR), The Burnt Area Index for MODIS (BAIM) and the Burnt Area Index for Sentinel-2 (BAIS2).
The NDVI is an indicator of the greenness of the biomes, which has been extensively used also in burnt land discrimination (Fernandez et al. 1997). Thanks to its simple formulation it is widely used for ecosystem monitoring. The SAVI was developed with the aim to correct the NDVI when the vegetative cover is low (< 40%): it applies a "soil brightness correction factor" to the NDVI, in order to minimize the soil reflectance effect, which can influence the NDVI value up to 20% (Richardson et al. 1992). The other three indices are specifically designed to delineate burnt areas. In particular, the NBR index is very similar to the NDVI, but combines the use of both NIR and SWIR wavelengths, because the difference between the spectral responses of healthy vegetation and burnt areas reach their peak in the NIR and the SWIR regions of the spectrum (Keeley, J. E. 2009). The BAIM (Martín et al., 2006) is designed to analyse large regions using the MODIS sensor, and focus on the maximisation of the spectral distance between coal and other land covers, which can be potentially confused with burnt areas. The BAIS2 is a newly developed index specifically designed to take advantage of the S2 MSI spectral characteristics which have been demonstrated to be suitable for post-fire burnt area detection at 20 m spatial resolution (Filipponi F, 2018).

Figure 1 shows the workflow of the procedure defined to extract burnt areas, implemented through the development of two QGIS plugins.

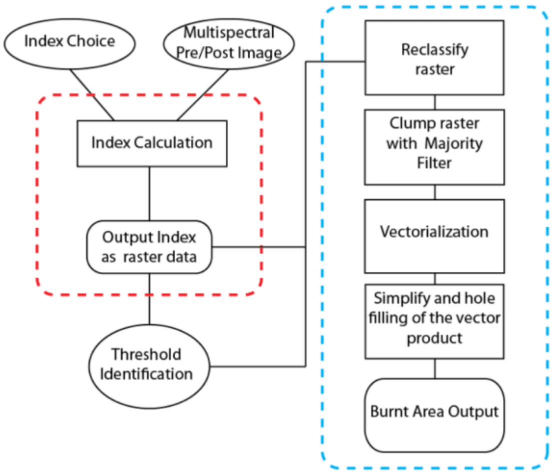

Figure 1. Workflow for burnt area extraction.

In the first plugin, "Burnt Index Tool", whose workflow is shown in the red box in Figure 1, the operator can choose between the five different vegetation indices previously described. In addition, in order to reduce the processing time, he can add a region of interest, drawn as a rough polygon around the burnt area (used to clip the image) and/or choose a cell resample value. Usually, for emergency mapping purposes, a 20 meters resolution is considered enough to obtain a homogeneous result, even if it may affect the precision of the burnt area delineation. In general, the resampling value choice is left to the expertise of the operator. However, if the post event image shows a well-defined and homogeneous burnt area limit, setting the resampling value equal to the input image resolution allows precise delineation results. The output of the first plugin is a raster representing the index selected. This raster must be manually analysed by the operator, which has to visually identify the burnt/unburnt threshold pixel value needed as input parameter for the second plugin. Sometimes it is a good practice to stretch the image properly, in order to raise the contrast of the burnt and the unburnt areas.
The processing steps of the second plugin "Extraction of Burnt Area" are shown in the blue box of Figure 1. Using the threshold value identified previously by the operator, the second plugin classifies the input index raster into a Boolean raster, which is divided into burnt or unburnt values (0 or 1). Next, after a clumping with a majority filter, the tool generates a rough burnt area polygon. A final edge smooth and hole filling are applied to the polygon, and the burnt area is saved as shapefile.
In order to avoid false positives led by clouds, smoke and shadows, the plugin allows to add a delineation of these elements through a shapefile, that will be used as erase features over the burnt area extracted. Using the SWIR post image band as additional input, it is also possible to extract the active flames using a threshold value identified on this band. For the purposes of this work this last product was not considered.

2.2 Validation

In order to properly test and validate the plugins, a validation procedure was applied to the ten forest fires in analysis, selected from the EMS Rapid Mapping and Risk and Recovery Activations list and shown in Figure 2.
The selected wildfires span from August 2019 to April 2021, have different sizes (the Areas of Interest range from 1,300 ha to 254,000 ha around), and are located in different countries of the world, in particular seven in Europe, two in Australia and one in South America.

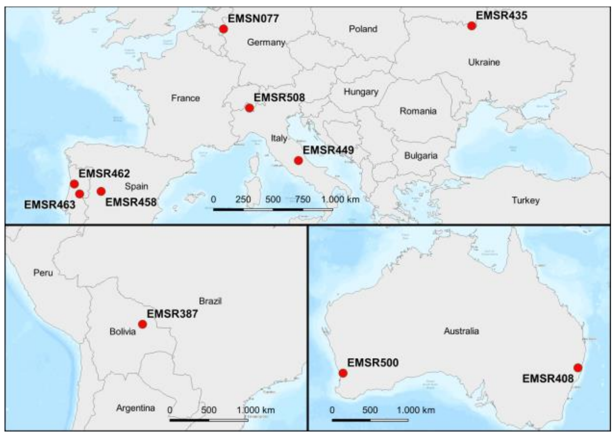

Figure 2. Pilot cases with the relative activation name.

To obtain more consistent results in the validation process, Sentinel-2 (S2) images have been used for all the analysed wildfires, thanks to their great spatial (10 meters) and temporal (potential five-day) resolution, and their open and easy access (Malenovský et al. 2012). In addition, they are particularly suitable for chlorophyll analysis (and burnt area detection), as the Multispectral Instrument (MSI) has 13 bands, with the visible RGB and the NIR bands available at a 10 meters spatial resolution, and four red-edge bands available at 20 m spatial resolution (De Simone et al. 2020).
Twenty S2 images were downloaded for analysis, two S2 for each area acquired a few days or weeks before and after the fire, to reduce the vegetation differences caused by the different seasons. All the images are downloaded as level 2A (atmospherically, radiometrically and geometrically corrected) and cloud free.
The validation applied in this study is a thematic validation with a binary classification i.e., burnt or unburnt area. The methodology is based on a publication of the JRC "International

workshop Validation of geo-information products for crisis management" (Corbane et al. 2009). In the specific case it was not possible to validate the plugin result with ground truth data, therefore representative and independent reference data were used, considered intrinsically more accurate than the product to be evaluated, i.e., the digitization of the burnt area carried out on S2 images by expert digitizers (Broglia et al. 2010).
As a first step of the validation, the burnt areas for each single index were extracted so that the accuracy of all 5 indices could be analysed. Subsequently, five indicators necessary to calculate the thematic accuracy for each individual index were calculated, as shown in Figure 3.

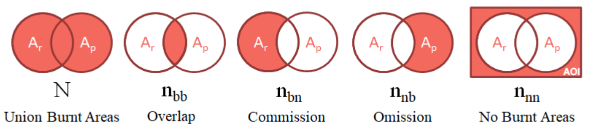

Figure 3. Description of the 5 indicators. A_r is the reference data's burnt area and A_p is the plugin's burnt area and AOI is the Area of Interest (Readapted from Broglia, 2010).

In order to accurately and completely validate the plugin results, the indicators described above were used to calculate three final factors of the thematic validation: the overall thematic accuracy, the omissions (i.e., the burnt areas that the plugin has not recognized as such) and commissions (i.e., the unburnt areas that the plugin has classified as burnt). The calculations performed are shown in Table 1.

THEMATIC VALIDATION			
Burnt Area		Plugin	
		Burnt (ha)	Not Burnt (ha)
Reference data	Burnt (ha)	n_{bb}	n_{bn}
	Not Burnt (ha)	n_{nb}	n_{nn}
OVERALL THEMATIC ACCURACY %		$\frac{n_{bb}}{n_{nb}+n_{bb}+n_{bn}}100$	
COMMISSION %		$\frac{n_{bn}}{n_{nb}+n_{bb}+n_{bn}}100$	
OMISSION %		$\frac{n_{nb}}{n_{nb}+n_{bb}+n_{bn}}100$	

Table 1. Scheme of the calculations performed in the validation (Readapted from Broglia, 2010).

3. RESULTS

This chapter presents the analysis and the validation results. The authors focused on two main aspects: the identification of the index that best suited this kind of automation and the analysis of the characteristics of each studied area, to highlight the natural elements that may affect the final result.
The chart in Figure 5 shows the overall thematic accuracy for each individual index and the respective errors of omission and commission.
NBR is the index with the highest precision (about 83%). It was an expected result, indeed NBR is the most widely used and studied index in literature and which, thanks to the use of the SWIR band, has characteristics that are well suited to the extraction of burnt areas. Despite this, the SAVI is in second place with an accuracy of about 77%; it is certainly an unexpected result. BAIM and NDVI indices have similar thematic accuracy values. Finally, the BAIS2 index, which should instead be specific to S2, and therefore higher accuracy values were expected, is the least performing.

For all the indices there is a higher percentage of omissions compared to commissions; this certainly depends on the threshold value established by the operator and on the presence of clouds or areas without vegetation that affect the resulting index calculation.

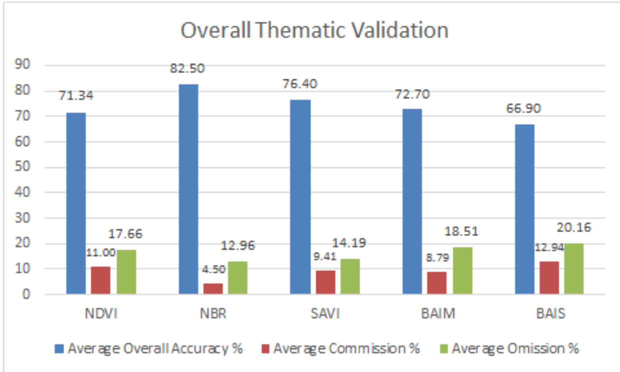

Figure 5. Average thematic accuracy, omissions, and commissions for each index.

Figure 6 shows a detail of the extraction of the burnt area for EMSR500 activation in which is shown how the various indices behave compared to the reference data.

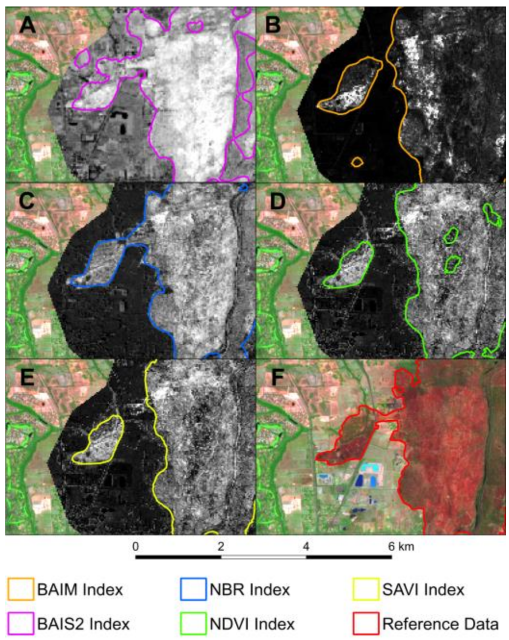

Figure 6. From Figure A to Figure E are shown the five raster indices on the EMSR500 and the respective five extracted burnt areas. Figure F shows the reference data used for validation.

Finally, in Figure 7, the overall thematic accuracy for each activation is reported. These results are important to investigate the reasons for low or high accuracy highlighting the tool's limits, which will then be described with greater precision and completeness in the last chapter.
The EMSR463 activation is the case study with high thematic accuracy for all indices. The reason is that the perimeter of the fire is very clear, most of the area was probably covered by a canopy fire, in fact the vegetation is visibly compromised, and the plugin does not create holes inside of the polygon of the burnt area. On the contrary, in the EMSR435 activation, the area was probably crossed by a crawling fire that causes patches in which the index does not perceive a change in the vegetative state of the

plants, as the canopy has remained intact. The EMSR387 activation has quite high accuracy values, despite the presence of many clouds, which usually, together with the relative shadows, create problems in the extracted area, since there the index shows values similar to the burnt area. This demonstrates the usefulness of the plugin's feature which allows to delete the clouds areas in the image, using a previously digitized cloud shapefile.
The activation in which lower accuracy values were found is the EMSR449. Following an accurate analysis, it was noted that the fire is difficult to identify even for an expert, because it was very jagged and arose in an area with already little if not non-existent vegetation. The lack of vegetation, before and after the fire, prevents the index from classifying that area as burnt.

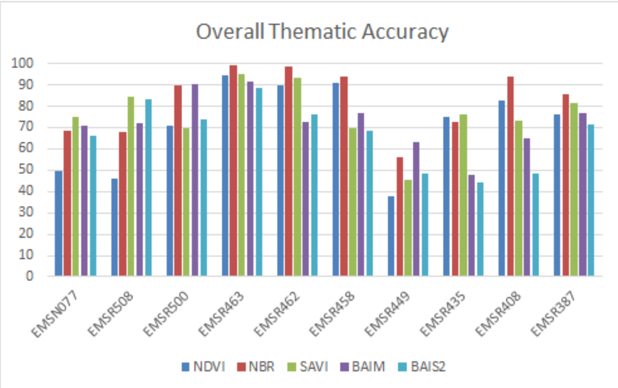

Figure 7. Overall thematic accuracy for each activation.

4. CONCLUSIONS

Wildfires manual delineation can be a time-consuming procedure that can require from several minutes to several hours of interpretation of pre and post event images and digitalization, especially in Rapid Mapping service where timeliness is a crucial part of the service. In this paper, the authors provided a procedure based on a bundle of two QGIS Plugins that can considerably reduce the operative time of wildfire delineation methods.
The validation process has demonstrated the appropriateness of the plugin to extract a burnt area with a good thematic accuracy and in a short time and the NBR index results the most appropriate to delineate burnt area in the context of the Rapid Mapping. The tool contributes to saving time respect to a manual delineation in case of large wildfires, whereas is not recommended for small burnt areas. The use of QGIS for the implementation guarantees a user-friendly interface and ease of sharing.
Between limits of the proposed approach, the automated extraction has generally an inaccurate result in case of crawling fires, where the canopy not burned may cover the burned area on the ground, and in case of not uniform land cover or large presence of non-vegetated area. In addition, the plugin still relies on the strong expertise of the operator. The initial choice of the resample value must be guided by evaluation of the scale of analysis and the type of wildfire, to not get a rough output polygon, and the identification of the appropriate threshold in the second step of the plugin, is conditioned by the operator and may results in a loose delineation.
As further development, in order to reduce the contribute of the operator in the approach, the authors propose to automate the choice of the threshold value on range list, depending on the type of image used as input, index chosen, type of wildfire and characteristic land cover of the area. This may be achieved through a machine learning approach on a larger amount of wildfire cases, based on a classification of wildfire types, land cover and scale of analysis.

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