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# Application of the BAI index for the classification of the burned area in ground measurements

**Abstract**

Quick determination of the area of the burned forest or field caused by the fire is important when estimating losses, monitoring the rebirth of vegetation on the site of fire and planning strategies for forest reconstruction. In order to provide quick information about the area burned by large fires, the BAI index (Burn Area index) is used. This index is obtained using optical methods of satellite remote sensing. In Poland, most fires are the fires of soil cover, the area of which does not exceed 1 ha. In such cases, the use of satellite technology is not applicable due to a number of limitations that are discussed in the text. The article presents the possibility of using the BAI index from a small height. Since the BAI index was originally used for satellite measurements, the article discusses the differences in ground measurements. Experimental research has been described and results from controlled firing have been presented.

**Keywords**: BAI, burned area classification, remote sensing, wildfire.

## 1. Introduction

The dynamic development of satellite technology has enabled the observation of physical phenomena from the Earth's orbit and the rapid transmission of recorded images of the earth's surface by radio. Over time, more and more accurate detectors have been constructed and the images obtained were recorded in an increasing number of spectral bands. This led to the development of remote sensing and of many specialised remote sensing indices that reflect to a greater or lesser extent the phenomena occurring on the surface of the earth. The development of research in spectrophotometry resulted in the creation of various indices determined on the basis of the amount of radiation from two or more different spectral ranges that can be obtained from transducers placed in remote sensing satellites [1]. The remote sensing properties of individual materials are determined on the basis of the ratio of total radiation falling on a given object to the amount of radiation reflected in spectral intervals characteristic for a given material. Fig. 1 shows properties of electromagnetic wave reflection for soil, burned area and vegetation [2].

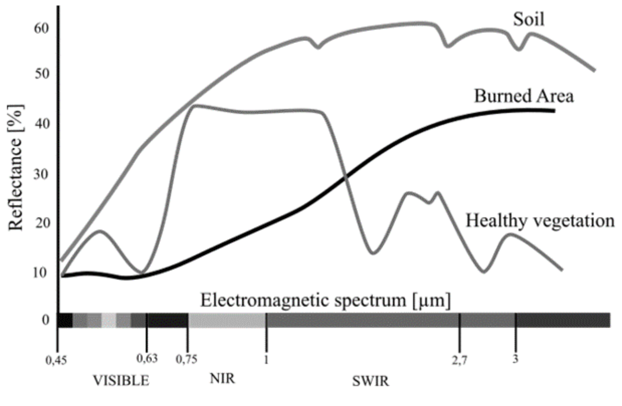

Fig.1. Graph of spectral reflection curves for soil, burned area and healthy vegetation with RED bands for Ikonos-2 and Landsat-8 based on [2, 3 ,4, 5]

When it comes to fire protection, particular attention should be paid to the indices related to fire risk and indices that classify the burned area. By studying the radiation for two different wavelengths, the properties of the material to be tested can be determined with high probability. One of the first indices was NDVI (Normalised Difference Vegetation Index), which was developed in 1973 by J.W. Rouse [6] formula 1.

$$\mathrm{NDVI}=\frac{\mathrm{NIR-RED}}{\mathrm{NIR+RED}} \tag{1}$$

where: NIR - the amount of light reflected for the near-infrared band (0,75..1) µm, RED - the amount of light reflected for the red colour band (627..750) nm.

The index was originally intended to assess the condition of vegetation, but it can also be successfully used to classify the burned area [1, 7, 8]. The next classification index is NBR (Normalized Burn Ratio) formula 2. The operation of this index is similar to NDVI with the difference that the RED band was replaced by the SWIR band.

$$\mathrm{NBR}=\frac{\mathrm{NIR-SWIR}}{\mathrm{NIR+SWIR}} \tag{2}$$

where: SWIR - (short wave infrared) - the amount of infrared light reflected from the surface in the wavelength range (1..2,7) µm.

This index can be used to estimate the degree of burnout and the degree of regrowth of the forest after a fire. A very useful index is ΔNBR, which is a differential NBR index from before and after a fire (formula 3).

$$\Delta\mathrm{NBR}=\text{Pre fire NBR-Post fire NBR} \tag{3}$$

Knowing the value of this index, it is possible to assess the degree of forest burnout, plan for its reconstruction, degradation of the area and the possibility of landslides in the river valleys. In the aspect of large-scale fires, the effectiveness of NBR and NDVI was compared, indicating ΔNBR as an optimal index for the classification of the burned area [9]. For NBR calculations, data from two different detectors are needed because at present it is not possible to obtain an image from one detector in the NIR and SWIR bands. In order to determine ΔNBR, the spectrograms from before the fire are also needed. There are no such restrictions in satellite remote sensing. Subsequent modifications of NDVI resulted in the SAVI [10] (Soil-adjusted vegetation index) formula 4.

$$\mathrm{SAVI}=\frac{\mathrm{NIR-RED}}{\mathrm{NIR+RED}}\cdot(1+L) \tag{4}$$

The impact of soil on the measurement result was reduced using the constant *L*. The constant L is selected empirically in the range 0..1. Value "0" is selected for lush vegetation, then the result is the same as NDVI. The value of "1" is for soil that is very sparsely vegetated. The value of $L$ = 0.5 is in most cases sufficient.

As a result, the MSAVI (Modified Soil-adjusted Vegetation Index) in which the selection of the constant *L* was automated and MSAVI2 in which the constant *L* was eliminated, were created, formula 5.

$$\mathrm{MSAVI2}=\frac{2\cdot\mathrm{NIR}+1-\sqrt{(2\cdot\mathrm{NIR}+1)^2-8\cdot(\mathrm{NIR-RED})}}{2} \tag{5}$$

In terms of applying these indices to the classification of the burned area, they are not more effective than NDVI as they only reduce the soil impact on the estimated amount of biomass. There is also a specialised index BIAS2 (Burned Area Index for Sentinel-2) for determining the burned area for the satellite Sentinel-2 [11] formula 6.

$$\mathrm{BIAS2} = \left(1 - \sqrt{\frac{\mathrm{B06 \cdot B07 \cdot B8A}}{\mathrm{B4}}}\right) \cdot \left(\frac{\mathrm{B12 - B8A}}{\sqrt{\mathrm{B12 + B8A}}} + 1\right) \quad (6)$$

where: B4 – (646..685) nm, B06 – (731..749) nm, B07 – (761..796) nm, B8A – (848..881) nm, B12 – (2.072..2.321) µm - spectral ranges characteristic for the Sentinel-2 satellite.

The BIAS2 index uses 5 spectral bands characteristic for the detector used in the Sentinel-2 satellite. There is also a BAI index, the measurement of which can be made with one detector in two spectral ranges of RED and NIR, which gives good results in the classification of the burned area at the same time (formula 7.)

$$\mathrm{BAI} = \frac{1}{(0{,}06 - \mathrm{NIR})^2 + (0{,}1 - \mathrm{RED})^2} \quad (7)$$

## 2. Limitations of satellite measurements

Despite the undoubted advantages of using artificial satellites to record spectral images, this method has some disadvantages, which under certain conditions make this technologically advanced tool useless. The limitations of using satellite remote sensing are detailed below.

- Limited time availability: time windows in which measurement is possible are determined by the periodicity of the remote sensing satellite flight over the areas under investigation.
- Unavailability due to cloudiness: the area may be unavailable due to cloudiness or fog.
- The spatial resolution of the image is too small for small areas.
- Ambiguity of measurements: caused by different spectral ranges used depending on the detector used in the satellite.

It should be noted that the spatial resolution of detectors in satellites is constantly increasing, but the problem related to the possibility of taking satellite images at any time over any area remains unsolved. Satellite images are available in specialised websites, which make it possible to download spectral images from the Landsat-8 and Sentinel-2 satellites from the area where the controlled firing of the soil cover was carried out. The spatial resolution of the spectograms in these satellites is 30 m for the Landsat-8 satellite and 20 m for the Sentinel-2 satellite. The experiment was carried out on 19 April 2018 in Dobieszowice (Bobrowniki district, Będzin poviat, Silesia voivodeship). The tested sector was located on a plot of land with agricultural wasteland (50 ˚24'14”N, 19 ˚00'11”E). The burned area was a square with a side of 25 m (Fig. 2).

Fig. 2. View of the experimental firing of the soil cover

Downloaded satellite images confirmed no change in spectrograms for such a small area because the burned area did not significantly exceed the size of one pixel of detectors in both satellites.

The problem of the ambiguity of measurements results from the technological differences of the detectors used. These differences cause the lack of unambiguous determination of the ranges of electromagnetic spectrum bands for selected indices. Even the remote sensing targets determined for the same area using two different satellites can be different. This is due to the fact of using different spectral ranges for selected bands. In literature, it is common that the authors of the newly developed index do not use the spectral range but the band number of a given satellite [11] The band numbers are conventional and refer to a specific satellite. Fig. 3 shows the measurement ranges for the RED band in three different satellites. Similarly, Fig. 4 presents the same combination for a near-infrared detector. The spectral ranges in the detectors of the three example satellites are different. The radiation reflectance curve for biomass in the range from 690 nm to 750 nm is steep (Figure 1) resulting in average quantitative reflection of waves on this spectrum section in the range from 10 to 45%. Fig. 1 shows the frequency ranges for the RED band of the detectors in the Landsat-8 and Ikonos-2 satellites. The method of determining the NDVI, BAI, SAVI, etc. indices is the same for both satellites. The results of the index determination are strictly dependent on the selection of the RED filter band. It is important which section of the RED band is taken into account when determining the index from narrow spectral ranges.

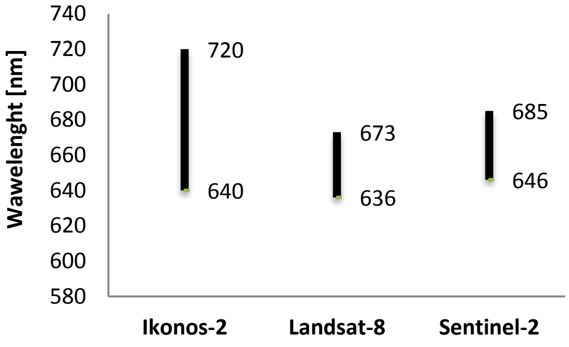

Fig. 3. Spectral ranges for the red colour in the example of Ikonos-2, Lanssat-8, Sentinel-2 satellites

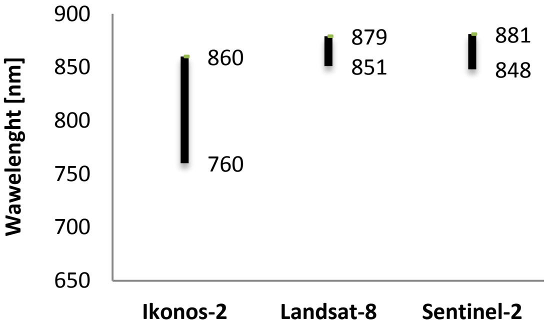

Fig. 4. Spectral ranges for the NIR band in the example of Ikonos-2, Lanssat-8, Sentinel-2 satellites

## 3. Description of the research

The work presents the possibility of using the BAI index to estimate the area burned from a low altitude. This index can be determined using a boom or by installing appropriate equipment in an unmanned aircraft. In this way, the problem of accessibility and spatial resolution can be solved.

Due to the simple hardware implementation, the focus was on this index. Two spectrograms are sufficient to determine the BAI index: in the spectrum of RED and NIR. There is also a similar BAIM index, however, it uses the SWIR spectral range which, like the NBR index, requires the use of two detectors. The BAI index can be obtained with one CMOS photosensitive sensor and an automatic band-pass filter changer. BAI was originally used in satellite remote sensing to classify the burned area. The measurement in the conducted test was carried out from a low altitude, thanks to which it could be performed at any time in daylight. The Basler ACA1300 NIR camera was used in the test, which covers the spectral range of RED and NIR with the sensitivity range of the detector. The band-pass filter for red colour was transmitting the radiation in the range of (630..730) nm and the NIR filter in the range of (815..915) nm. The measuring apparatus in the conducted test was placed in an aerial platform (Fig. 5) at a height of 18 m above the ground level.

Fig. 5. Camera installed in the platform together with an automatic filter changer

The burned area of the soil cover had an area of 620 m$^2$. The vegetation that was burned in the place of the experiment was mainly the Common Goldenrod (Latin: Solidago virauera). The average length of plant material before burning was about 110 centimetres. It was cloudless and the angle of the sun inclination was 46°. The view of the experimental polygon is shown in Figure 5. On the test area, reference points (markers) were used for the subsequent reduction of distortion and geometric distortions resulting from the deviation of the lens axis from the vertical position. The examined image was cropped in such a way that its one half showed the burned area and the other half the area not affected by the fire. The image of BAI index distribution was then made based on the spectrograms performed. Normalised brightness levels in the range of 0..1 for both bands were applied. According to the formula 6, the BAI index can range from 0.59 to 73.5 for such input data. Then the optimal threshold for classifying the burned area was determined. For this purpose, the iterative image thresholding from 1 to 73 for the BAI index was performed. The percentage share of pixels classified as burned area was counted at each step. A computer program was written to determine the index and the optimal selection of the threshold. For existing conditions, the threshold of “6” of the BAI index turned out to be optimal because at this value the algorithm classified 50% of the frame content as the burned area. It should be noted that regardless of the accepted classification threshold in each iteration, there was the phenomenon of false acceptance and false rejection. This means that part of the burned area was not detected and that part of the unburned area was falsely classified as burned area. The value of the threshold established in this way is strongly dependent on the condition of plant material, smoke and shadows cast by higher plant formations. Fig. 6 shows an image in the visible light of the observed test area. Fig. 7 shows the image of the BAI index distribution. Values lower than 6 have been coloured in white. Values greater than or equal to 6 are black.

Fig. 6. A view of the burned area and the unburned region in visible light

Despite the good imaging conditions, the homogeneity criterion of the isolated areas was not observed. Fig. 7 shows the phenomenon of false acceptance and the phenomenon of false rejection. Further improvement of homogeneity of classified areas is possible, for example, by dividing homogeneous areas by means of erosion and growth. However, the use of such methods may affect the integrity of the data.

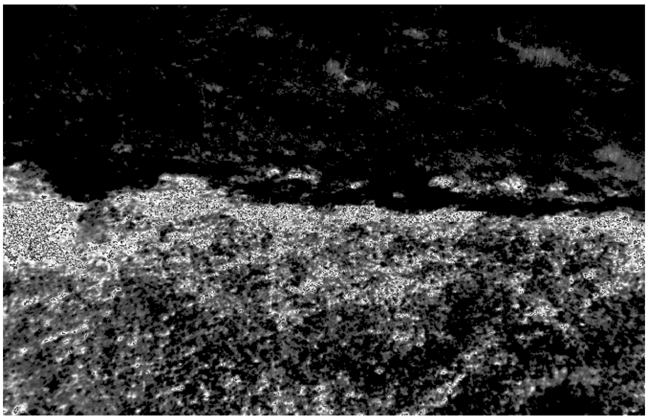

Fig. 7. Distribution of the BAI index on a burned field

## 4. Conclusions

The use of the BAI index for the classification of a burned area from a low height, as well as satellite measurements, is limited. The homogeneity of data cannot be obtained after the areas have been separated, but estimation of small areas of the fire is possible with a margin of error. The surface cannot be measured using this method without markers placed on the ground and without knowing the exact height from which pictures of flat terrain are taken. The nature of fire brigade operations during forest fires or other fires on the surface of the soil cover requires quick acquisition of imaging in real time or close to it, which in the case of satellite images can last several days. In this case, the unmanned aerial vehicles equipped with a camera, filters and a microwave altimeter can be used.

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