Application of gvSIG in a study related to forest fire monitoring

Summary

This research aims to compare the vegetation renewal of Karst woodland and pine forest in burnt areas with the natural evolution of the same vegetation typologies in areas not damaged by the fire which occurred in July 2003. This comparison has been made calculating the years needed for the NDVI and NDWI indices, obtained from Landsat satellite multispectral images, to reach the same values found in areas not exposed to fire. The NDVI (Normalized Difference Vegetation Index) quantifies the green biomass while the NDWI (Normalized Difference Water Index) is affected by leaf water content and soil humidity. Although the vegetation structure in the burnt areas is still in an evolutionary stage, after 5 years the two indices almost match the unaltered area values.

Key words: Karst, forest fire, Landsat, NDVI, NDWI

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1. Introduction

Vegetation is a fundamental element of ecosystems because it represents the base for the food web and for energy fluxes, it regulates the water cycle and the soil conditions and guarantees the ecosystem’s conservation.
Severe fire damage causes virtually total disappearance of vegetation cover and an hydrophobic soil condition (MacDonald and Huffman, 2004), with consequent erosion risk due to superficial runoff.
Ecosystem monitoring after a forest fire is based on the study of vegetation dynamics. Remote sensing analysis gives an important contribution in finding quantitative differences in green biomass and soil-plant water amount, allowing to examine the ecosystem's capacity to return to the former conditions (i.e. before the fire), namely its resilience.
NDVI (Normalized Difference Vegetation Index) (Rouse *et al.*, 1974; Tucker, 1979) is the most commonly used green biomass index in remote sensing analysis. It is calculated using the reflectance in the red band and in the NIR (Near Infrared) band (Figure 1). In the spectral vegetation signature the red band is located in the maximal absorbing interval due to chlorophyll, whereas the NIR band is located in the high reflectance plateau due to the structure of spongy mesophyll tissue. Therefore NDVI index is correlated with the green biomass density and with the vegetation health status.
Using the NIR (Near Infrared) and the SWIR (Short Wave Infrared) bands, a second index called NDWI (Normalised Difference Water Index) (Gao, 1996) can be calculated, which is sensitive to leaf water content and soil humidity. SWIR reflectance is negatively related to leaf water content (Tucker, 1980).

Multi-temporal and multi-spectral images, with a special resolution of 30m and 16 days rivisitation time, can be easily obtained by the Landsat7 ETM+ (Enhanced Thematic Mapper Plus) satellite and used for this kind of analysis even though these images are affected by striping noise (Liu and Morgan, 2006).

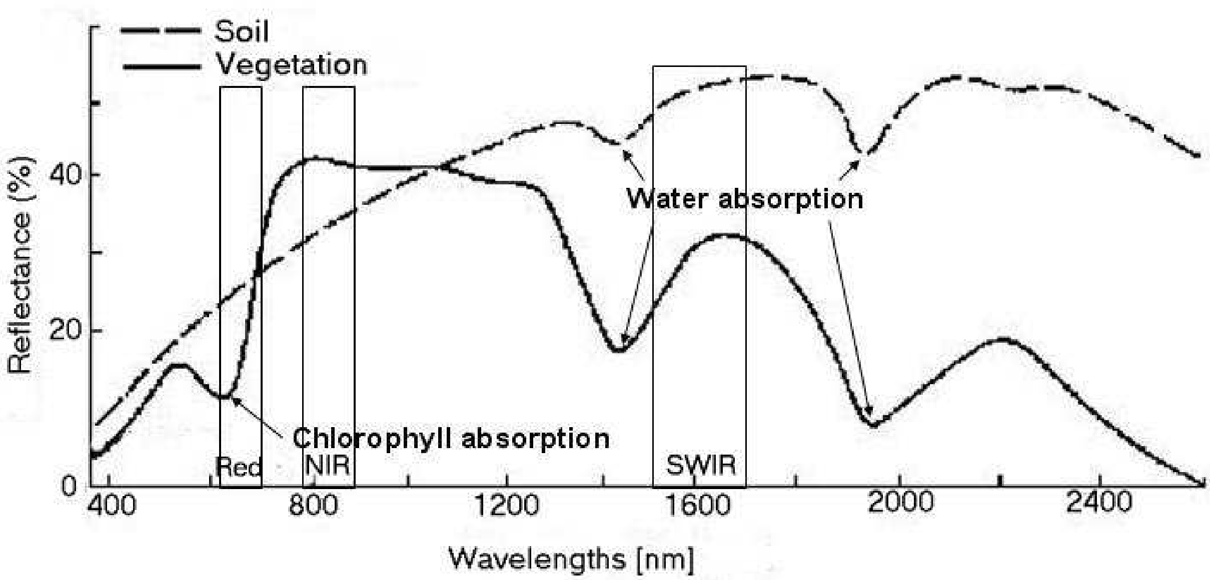


Figure 1. Landsat wavelength bands (Red, NIR, SWIR) superimposed to the reflectance curves of healthy vegetation and bare soil. Adapted from Lillesand and Kiefer (1994).

2. Study area

The study area is located in Slovenia, a few kilometres from the Italian border, and from the structural point of view it is part of the “anticlinal Karst area”.
Karst is positioned in a climatic transition zone, which sits between the Mediterranean and the continental Prealpine region. The zone is characterized by rainy winters, relatively dry summers and extremely short spring and autumn seasons. The two most peculiar physic-geographical characteristics of the Karst are: the discontinuous elevation (between 300-400 m amsl) and the predominant presence of carbonate rocks. Karst area has shallow soils, poor in *humus* and often moderately productive. Morphologically and lithologically the Karst is characterized by poor presence of superficial water.
In the study area two forest typologies are prevalent: the Karst woodland and the black (or Austrian) pine (*Pinus nigra*) planted forest. In the Karst region deciduous woodlands are very common: nowadays the prevailing one is the hornbeam and oak woodland (*Ostryo-Quercetum pubescentis*) (Poldini, 1989); the following species are also always present: *Quercus pubescens* (downy oak), *Ostrya carpinifolia* (hop hornbeam), *Quercus petraea* (sessile oak) and *Fraxinus ornus* (flowering ash). Black pine forests are also very significant in the Karst; they all have an anthropic origin, since they have been planted under the Austro-Hungarian dominance from the middle of the 19^{th} century in order to reforest the Karst. The pine forests in the test polygons (Figure 2) were partially planted after World War II and partially originated from natural forest expansion.
A forest fire occurred on the 29^{th} July 2003, burning an area of 10.45 km^2 with the following topographical characteristics: altitude 161.42 m, slope 12.48% and aspect 174˚ (southern exposure) (Figure 2).
The Slovenian forest authority began in 2004 a restoration program. In the research areas the following tree species were planted: *Pinus nigra* (black pine), *Acer platanoides* (Norway maple),

Tilia sp. (lime), *Prunus avium* (wild cherry), *Acer monspessulanum* (Montpellier maple), *Acer campestre* (field maple) (11200 saplings and 92.3 kg of seeds on a total surface of 69.5 hectares).

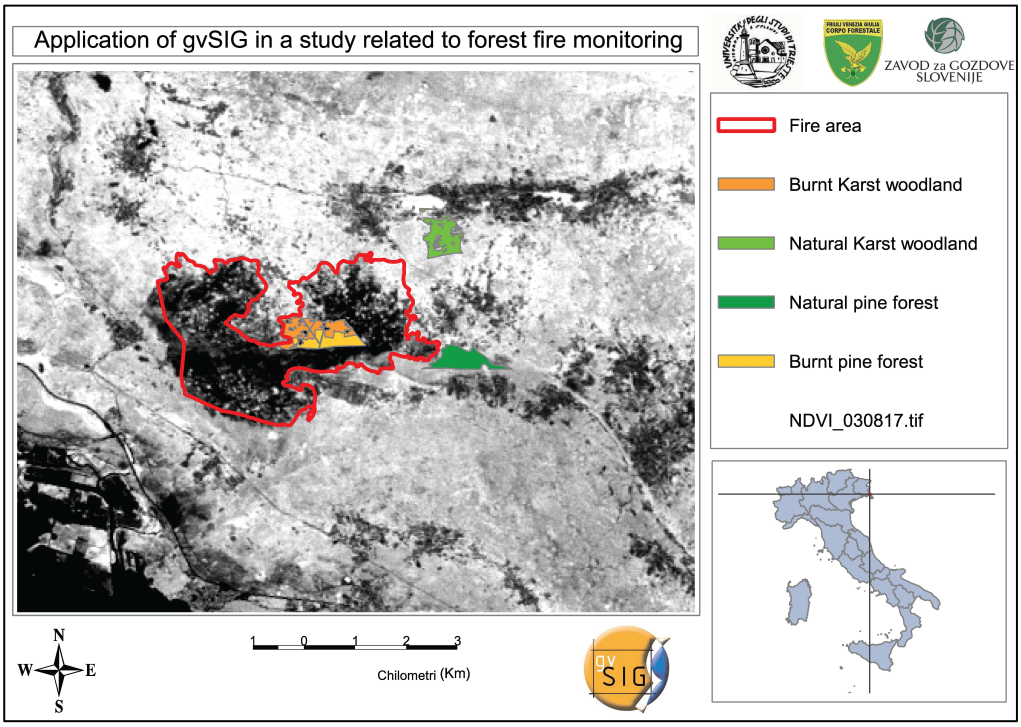


Figure 2. NDVI image (17th August 2003) with superimposed fire area (red line) and the four test polygons.

3. Materials and methods

Four areas have been selected for this research (Figure 2, Table 1). Two of these are covered with Karst woodland, the other two with planted pine forest. One of the Karst woodlands and one of the pine forests were exposed to the fire.

	Altitude (m)	**Slope (%)**	**Aspect (degrees)**	**Area (ha)**
Burnt Karst woodland	223.13	7.92	145.61	40.32
Natural Karst woodland	293.34	7.99	206.94	40.95
Burnt pine forest	237.80	9.58	142.74	28.62
Natural pine forest	188.00	29.76	181.72	39.60

Table 1. Topographical characteristics of the 4 test areas.

Landsat images

In order to follow the evolution of the vegetation in the burnt areas, we have used a series of multi-temporal Landsat images (2003-2009) from Landsat 5 Thematic Mapper (TM) and Landsat 7

Enhanced Thematic Mapper Plus (ETM+) (Table 2) downloaded from the Glovis website (http://glovis.usgs.gov). The images chosen were the following: 16/07/03 (TM5), 17/08/03 (TM5), 08/06/04 (ETM+), 29/07/05 (ETM+), 14/06/06 (ETM+), 19/07/07 (ETM+), 19/06/08 (ETM+), 24/07/09 (ETM+).

Characteristics	**Landsat 5 TM**		**Landsat 7 ETM+**	
Launch date	1 March 1984		15 April 1999	
Swath width	185 km		185 km	
Orbit type	Heliosynchronous		Heliosynchronous	
Temporal resolution	16 days		16 days	
Radiometric resolution	8 bits		8 bits	
Spatial resolution	30 m for bands 1, 2, 3, 4, 5 e 7 120 m for band 6		30 m for bands 1, 2, 3, 4, 5 e 7 60 m for band 6 15 m for Panchromatic band	
Acquisition bands	Spectral resolution (µm)	Spatial resolution (m)	Spectral resolution (µm)	Spatial resolution (m)
Band 1 (Blue)	0.45-0.52	30	0.45-0.52	30
Band 2 (Green)	0.52-0.60	30	0.53-0.61	30
Band 3 (Red)	0.63-0.69	30	0.63-0.69	30
Band 4 (Near InfraRed, NIR)	0.76-0.90	30	0.78-0.90	30
Band 5 (Short Wave InfraRed, SWIR)	1.55-1.75	30	1.55-1.75	30
Band 6 (Thermal InfraRed, TIR)	10.40-12.50	120	10.40-12.50	60
Band 7 (Middle InfraRed)	2.08-2.35	30	2.09-2.35	30
Band PAN (Panchromatic b/n)	-	-	0.52-0.90	15

Table 2. Summary of Landsat TM/ETM+ characteristics. From Campbell (2002).

gvSIG

From the wide range of free and open source GIS software available, gvSIG 1.9 version (produced by Generalitat Valenciana) has been chosen, due to its remote sensing extension. Sextante, a set of 239 free geospatial analysis tools included in gvSIG and distributed under GPL license, has also been repeatedly used.

The geographic data were handled in the following way:

• importation of burnt area polygon and Slovenian data for land cover;

• individuation of 4 reference areas: a burnt and analogous non burnt area, both for pine forest and Karst woodland;

• destriping of Landsat 7 ETM+ images with striping noise: these images have been treated replacing missing values with a mean local value calculated by a moving window of 5x5 cell dimension;

• importation of Aster DEM image (15 m resolution) and calculation, with Sextante, of aspect and slope ratio;

• calculation with Sextante of vegetation indices NDVI, NDWI on bands of the Landsat images, from 2003 to 2009;

• calculation, with Sextante, of grid statistics from NDVI, NDWI images in the polygons of the 4 areas of interest, obtaining maximum, minimum, mean and variance values of these vegetation indices.

Vegetation indices

Once corrected the striping noise on the downloaded Landsat images, the data could be analyzed to obtain the green biomass index (NDVI) and the leaf-soil water content (NDWI).
Bands B3, B4 and B5 from the spectral reflectance curve were used to obtain these indices values and their images. The NDVI values were obtained by combining bands 3 and 4 while the NDWI values by combining bands 4 and 5:

$$NDVI = (B4-B3)/ (B4+B3)$$
$$NDWI = (B4-B5)/ (B4+B5)$$

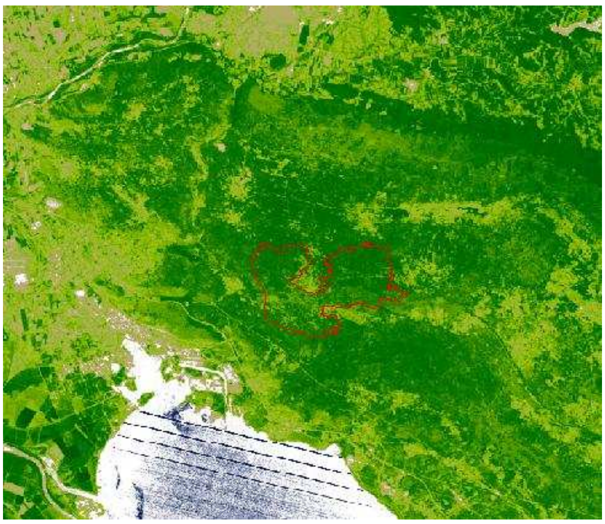
Where: B3 = band 3 (Red), B4 = band 4 (NIR), B5 = band 5 (SWIR)

Statistical analysis

The non parametric U-Mann Whitney test was used to test the differences between indices of NDVI and NDWI in burnt and unburnt areas on a random sample for each year and for each vegetation type. The non parametric test has been selected because the indices were not normally distributed.
Statistical analysis has been carried out by the free software R (http://www.r-project.org).

4. Results and discussion

With the gvSIG software the Landsat data has been analyzed and 16 images were obtained, 8 for NDVI index values (Figures 3, 4) and 8 for NDWI index values (Figures 5, 6) (two for 2003 (2003a is before fire and 2003b is after fire) and one per year from 2004 to 2009).
The comparison of the reflectance values before and after the fire broke out, pointed out these aspects: a) the damage caused by fire on both vegetation typologies leads to a strong signal loss in the near infrared (NIR) and a decrease of NDVI index, due to leaf tissue degradation; b) leaf tissue dehydration and the development of a hydrophobic soil layer (MacDonald and Huffman, 2004) are the main causes of reflectance increase in short wave infrared (SWIR) and of the consequent decrease of NDWI index.
Signals of recovery for both vegetation typologies appear from spring 2005, almost two years after the fire.



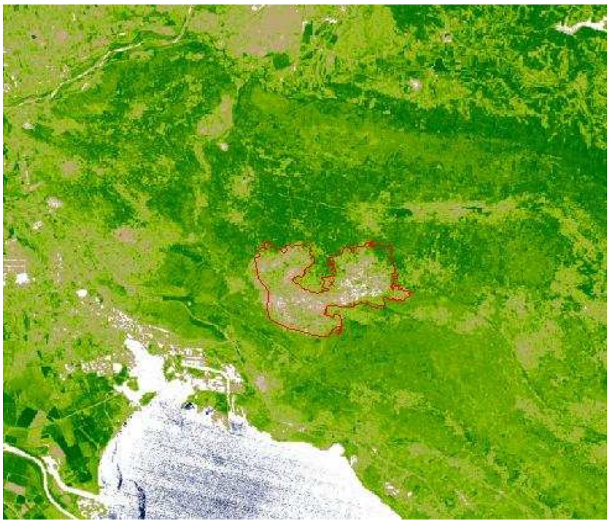


Figure 3. NDVI 16th July 2003

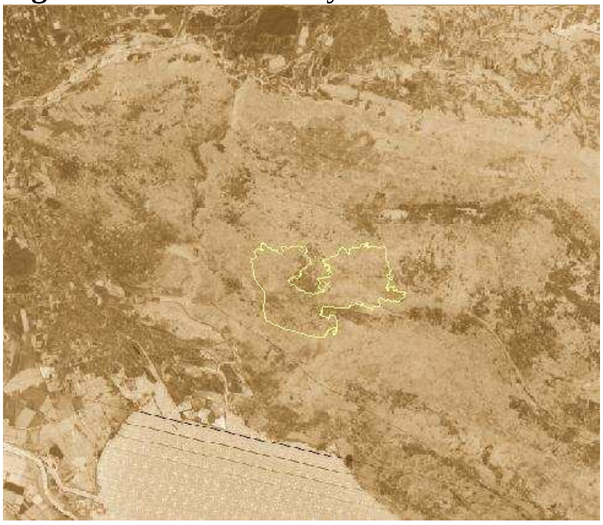


Figure 4. NDVI 17th August 2003

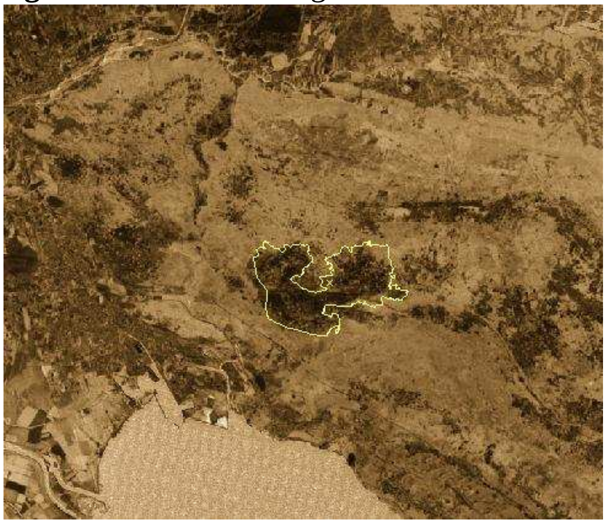
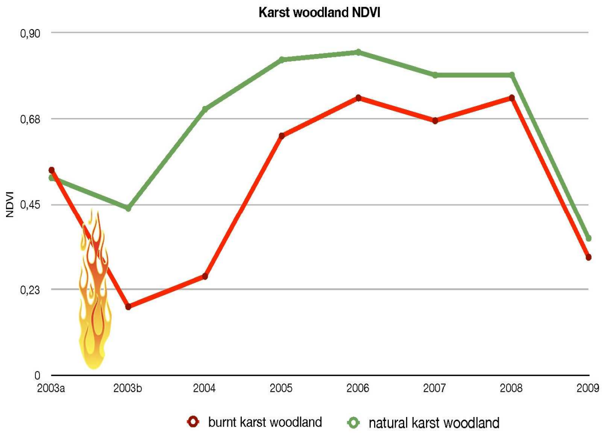


Figure 5. NDWI 16th July 2003

Figure 6. NDWI 17th August 2003

NDVI data trend observed in Figures 7-8 could be due to recovering time of the green biomass, set to about 5 years. Although the vegetation structure, verified during a field trip, is still different from the original one, the present CO_2 balance seems to be similar.



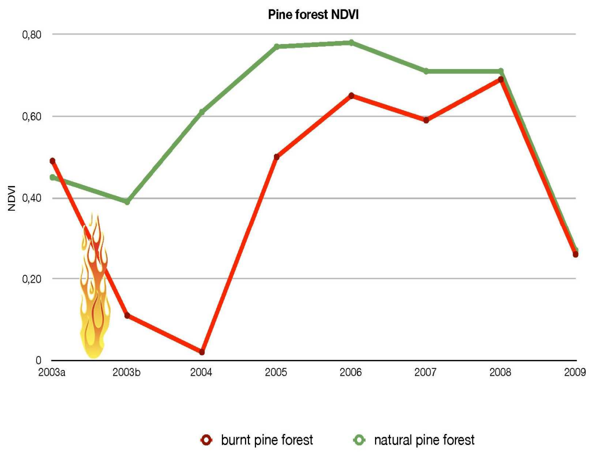


Figure 7. Karst woodland NDVI values (2003a is before fire and 2003b is after fire)
Figure 8. Natural pine forest NDVI values (2003a is before fire and 2003b is after fire)

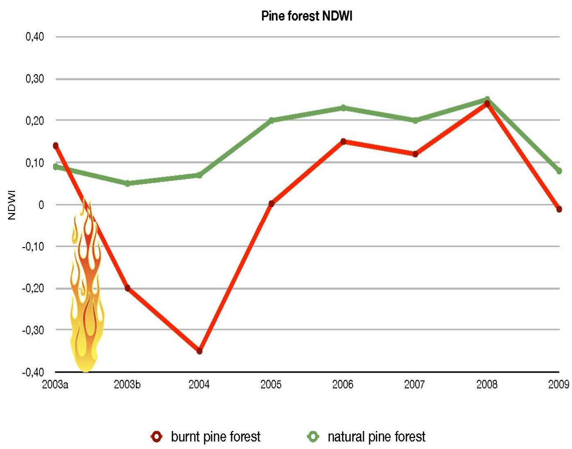


Figure 9. Karst woodland NDWI values (2003a is before fire and 2003b is after fire)
Figure 10. Natural pine forest NDWI values (2003a is before fire and 2003b is after fire)

In Figures 9-10 the NDWI trends are similar to those of the NDVI index (Figures 7-8). These results suggest that the humidity content of leaves and soil return to “normal conditions” when the vegetation cover is regenerated, although the structure of the forest is not the same as before.
After a forest fire, the damage to the ecosystem is such that its whole structure is changed or destroyed. This is shown by red lines in the graphs, where it is well displayed as a steep drop of the NDVI and NDWI values.
It is also important to highlight that just after the fire (August 2003) and one year later (2004) the soil water absorption was very low, due to the lack of vegetation and the formation of a hydrophobic sheet above the superficial soil layer. This “crust” blocks the water infiltration and furthermore causes soil erosion due to water run-off (MacDonald and Huffman, 2004).

Cumulated rain data, 60 days before the time the satellite images were taken, has been used to correlate the amount of rainfall with the NDVI and NDWI indices values (Figures 11-12). The rainfall histogram and the green lines (unburnt areas) have a similar trend, while the trend is different for the burnt areas (red lines).
The NDWI index falls immediately after the fire and it starts rising again two years later (Figure 12). As mentioned before, this suggests that the soil in the burnt areas has difficulties in absorbing rain water; this is particularly evident in the pine forest.
It must be noted that meteorological conditions in 2003 were extreme: summer temperatures were especially high, with scarce precipitations.

a)

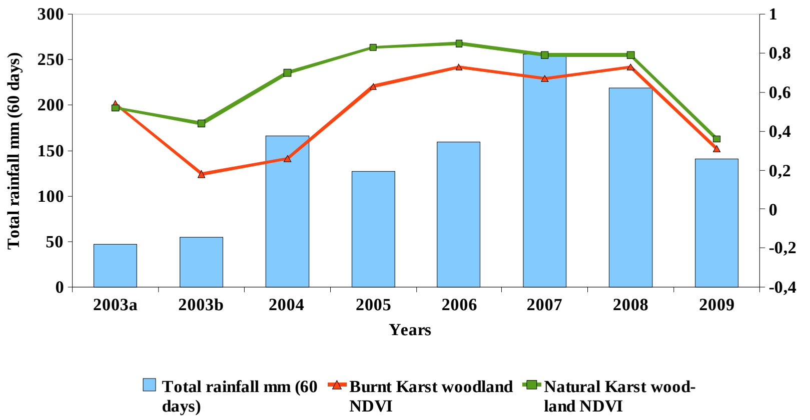
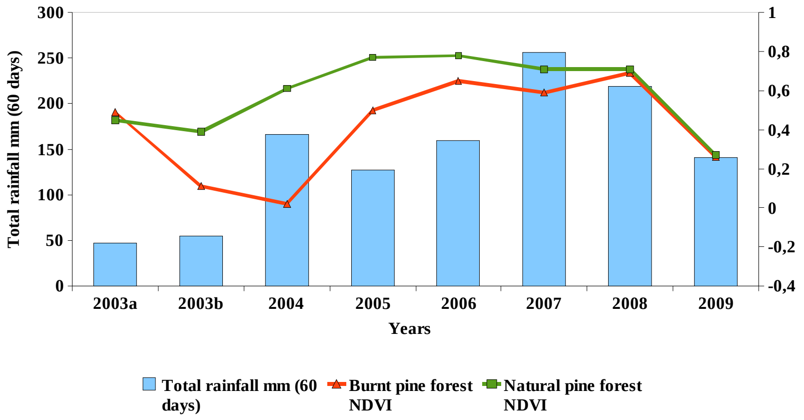


Figure 11. Total rainfall: **a)** Karst woodlands NDVI, **b**) Pine forest NDVI. (2003a is before fire and 2003b is after fire)

b)



a)

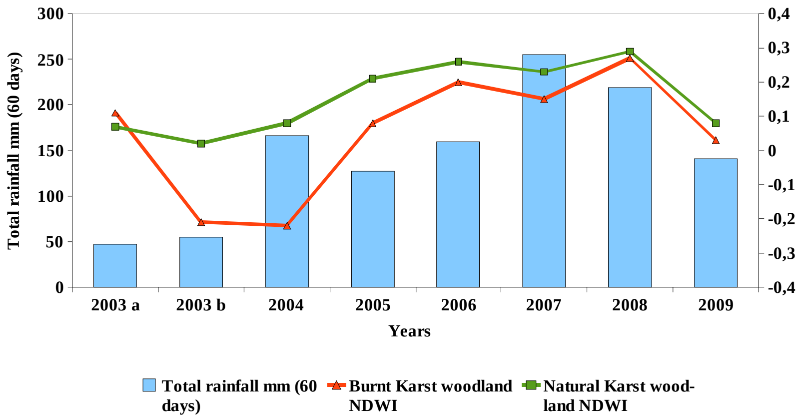


Figure 12. Total rainfall: **a)** Karst woodlands NDWI, **b)** Pine forest NDWI. (2003a is before fire and 2003b is after fire)

b)

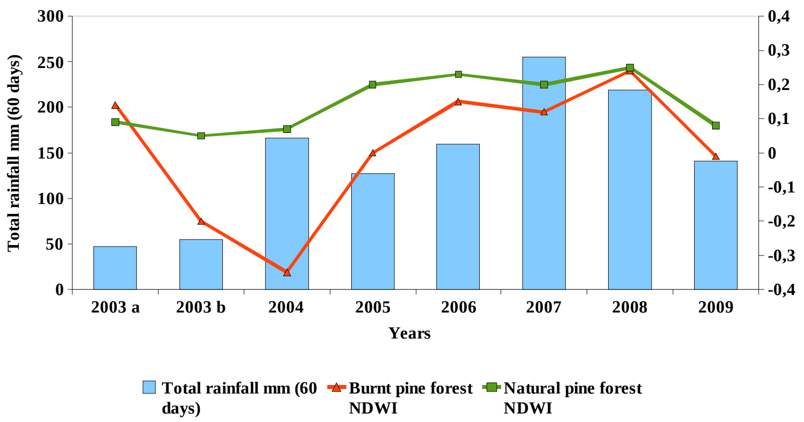


Table 3 shows the values of U-Mann Whitney test applied to the NDVI and NDWI indices of two sampled areas for each year (2003-2008), comparing burnt and unburnt areas for each vegetation typology.

			2003a	2003b	2004	2005	2006	2007	2008	2009
NDVI	**Karst woodland**	**U**	***742.0***	106.0	0.0	44.0	64.5	140.0	173.0	328.0
		p	***0.580***	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	Pine forest	**U**	268.5	0.0	0.0	5.0	75.0	183.0	***550.0***	***602.5***
		p	0.000	0.000	0.000	0.000	0.000	0.000	***0.237***	***0.543***
NDWI	**Karst woodland**	**U**	***722.5***	78.5	22.0	63.0	107.0	108.5	436.0	156.0
		p	***0.459***	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Pine forest	**U**	141.0	0.0	0.0	0.0	163.0	45.0	***656.5***	39.0
		p	0.000	0.000	0.000	0.000	0.000	0.000	***0.987***	0.000

Table 3. U-Mann Whitney indices (U) with two-tailed probability (*p*) applied to random pixels of the test areas for each year. Non significant values are in italics (2003a before the fire, 2003b after the fire).

The NDVI differences between the burnt and unburnt Karst woodlands are always statistically significant after the fire, although they considerably diminish in 2008 and 2009. Only before the fire (July 2003) the NDVI difference is not significant, confirming the expected similarity of the green biomass of the two woodlands. For the pine forests the NDVI values result significantly different already before the fire. This significant difference could be due to the slope (29.76%) of the natural pine forest area that does not allow an abundant growth of the vegetation cover. The differences become not significant in 2008 and 2009, meaning that the quantity of green biomass in the burnt pine forest has reached the value of the unburnt one. The observed trends (Figures 7-8, Table 3) suggest that in few years after 2009 the NDVI index will probably return to its original values.
NDWI statistical results are very similar to those of NDVI, except for the pine forest in 2009. In this year the NDWI difference is significant, probably because the amount of rainfall was low (Figure 12) and the vegetation cover is still on a developmental stage.

5. Conclusions

This study has been conducted using open source software and free images. Using gvSIG, it has been possible to analyze satellite images and rapidly obtain useful results for ecosystem monitoring. The consequences of the forest fire occurred in the study area in 2003 have been studied through multi-temporal satellite images. NDVI and NDWI indices have been calculated to detect the time needed for the vegetation to recover after the fire.
Although after five years the vegetation has not achieved its original structure, it is reasonable to conclude that, in ecological terms, it can already accomplish some of its biological roles such as photosynthetic activity, CO_2 and water absorption. According to the statistical analysis the whole study period (six years) is insufficient to reach the original NDVI and NDWI values, however from the values trend it can be assumed that this will happen in the next few years.

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