FOREST FIRES STUDY USING REMOTE SENSING AND METEOROLOGICAL INDICATORS. STUDY CASE.

Paula FURTUNĂ[1], Iulian-Horia HOLOBÂCĂ[1]

ABSTRACT:
Fires are the most spectacular natural disturbances affecting forest ecosystem composition, having a devastating effect on the landscape. These can be monitored and analyzed over large areas in an efficient manner in a short time and at low cost by using satellite images and the affected area can be defined using satellite imagery through geographic information systems technology (GIS). The aim of this study is to detect, analyze and quantify land cover changes from production forest fires using Landsat TM imagery, one of the pre-fire and post-fire, studied area corresponds District Forest Cluj. Changes were identified by calculating two indices, NDVI (Normalized Difference Vegetation Index) and NDBR (Normalized Difference Burning Ratio). The causes may be natural or anthropogenic, but weather conditions can have significant contributions to their propagation.

Key-words*: forest fires, satellite images, Carrega Index I85/90, remote sensing.*

1. INTRODUCTION

Fires are seen as "the greatest disaster suffered by the forest" (Nanu, 1984) because the role has changed from forest shelter and wood production to manufacturing complex functions, protection, recreation, etc.

Forest fires occupy an important issue for Europe, especially for the southern Mediterranean Basin respectively.

Historical data on forest fires in Europe reveals that in 1990, "about 50,000 fires have destroyed more than 600,000 hectares of forest area that doubles as affected by the fires recorded in the period 1970-1990" (Ciobanu, 2007). The risk of forest fires is a very complex concept in which meteorological factors play a key role (Carrega & Jeronino, 2007) this risk can be expressed by calculating risk indicators, the last 20 years were created over 20 such indices. The calculation of these indices involves combining variables essential weather, the degree of forest fuel (wind speed and direction, humidity, soil water deficit, temperature, etc.). The existence of forest fire risk requires the development and implementation of risk management strategies in the prevention and reduction. Forest Fire Management includes three stages (Mateescu, 2006):

- The pre-fires phase - involves prevention and risk assesment
- Effect fire phase -response and mitigation
- The post fire phase – demage assessment and rehabilition policy

The first research on forest fire risk models referred to the fire, they were based on fire history of the region analyzed, and strictly limited their statistical analysis.

[1] *Babeş-Bolyai University, Faculty of Geography, Cluj-Napoca, Romania,*
paula.roxana.furtuna@yahoo.com , holobaca@ubbcluj.geografie.ro

Landsat satellite images were used quite early for analysis of forest fires. Thus, Tanaka et al. (1983) used Landsat MSS images for classification and estimation of fire-ravaged areas of Japan and Kritikos (1992) applied supervised and unsupervised classification for assessing fire damage at Mount Athos in Greece.

Kailidis and Pantelis (1988) cited by Zhao et al. (2011) determined the relationship between fire and climate conditions using statistical data on fires. The relationship between weather variability and the start of fires were studied and by Vasques and Moreno (1993). Also in 1993 Antoninetti et al. used the topographic data and satellite images to identify fire risk.

In recent decades, a variety of systems in fire risk assessment based on different meteorological variables were developed in different locations such as Forest Fire Danger Index (FDI) (McArthur, 1967), quantified by Noble et al. (1980) , Fire Weather Index (FWI) (Van Wagner, 1977), (cited by Ali Husain, Matakala & Zagdaa, 2008). A method based on remote sensing using Landsat images TM and introduction of indicators for measuring the severity of the combustion, similar to NDVI was developed for the U.S. National Park Service (Key & Benson, 2003, cited by (Mateescu, 2006).

A study by (Polychronaki & Mateescu, 2007) shows the forest fire evaluation using open source software, tools used in this study BAS2 (Burnt Area Statistics) and validated by applying the same analysis using ArcGIS for forest fires in Greece since Kassandra Island 2006.

National level research has been undertaken using satellite images to study changes in forest landscapes (Boboc et al, 2006). Regarding the analysis of forest fires in Romania there were many concerns, especially among silviculturist, a study that should be mentioned is that of (Adam, 2007) conducting the fire risk map based on statistical analysis of fires from 1990-2003.

2. DATA SOURCES AND METHODS USED

2.1 Studied Area

The District Forest Cluj is located in the middle basin of Somesul Mic in the Transylvanian Plainin the north and the Transylvanian Plateau. The forests are located in the Transylvanian Plain and the Feleacul Hills in the basins of the Somes Mic river. The divisions of the area i are distributed in four production units (UP), numbered from UP1 to UP IV as follows: UP I Vaida-Mociu, U.P. II-Chinteni-Faget, U.P. III Săvădisla and U.P. IV Baciu-Sard, (**Fig. 1**).

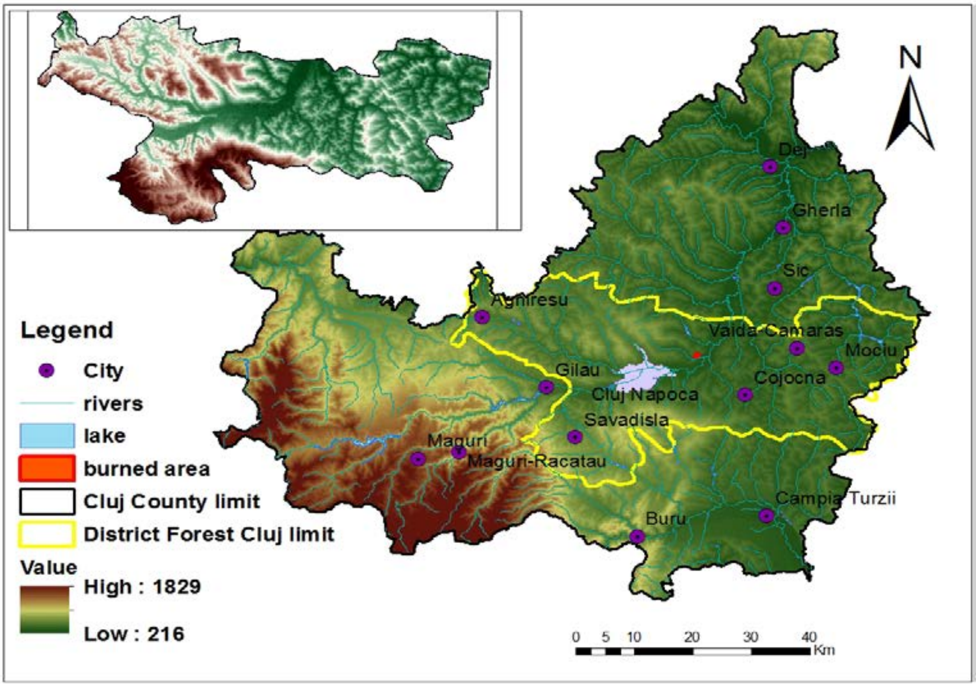

Fig. 1 The location of District Forest Cluj inside of Cluj County.

2.2 Data sources and methodology

2.2.1. Data sources

1. A set of images Landsat 7 TM (with 7 spectral bands and 30 m spatial resolution,) from different data: before the forest fire occurred and right after it occurred. Landsat 7 TM images were downloaded for free from the website (http://glovis.usgs.gov/). The two images were acquired in the same season to minimize the impact of vegetation in different seasons (**Table 1**).

Table 1. Characteristics of the images used

Fire Date	Path/Row	Lat/Long	Datum	Projection	Pre-fire	Post-fire
25.III.2011	185/27	47.4/23.4	WGS84	UTM	29.VIII.2010	26.III.2011

2. The terrain's digital model Aster Gdem was also used, it being available for free on *(http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html)*, at a 30m resolution.
3. Meteorological data from Weather Station Cluj.
4. Reports of forest fire issued by District Forest Cluj.

2.2.2. Methods used

Fire propagation speed is influenced by a number of factors determined by atmospheric situation (wind direction and speed, air temperature and humidity, solar radiation). To characterize the weather conditions in the pre-fire stage was due by determining the reference evapotranspiration. This was based on Peanman-Monteith equation (Allen et al, 1998) and calculated using ETO program which is a program developed by the FAO Land and Water Division, whose main function calculating reference evapotranspiration (Eto).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where,

ET_o – *reference evapotranspiration* [mm day^{-1}],
R_n - *net radiation at the crop surface* [MJ m^{-2} day^{-1}],
G - *soil heat flux density* [MJ m^{-2} day^{-1}],
T - *mean daily air temperature at 2 m* height [°C],
u_2 - *wind speed at 2 m height* [m s^{-1}],
e_s – *saturation vapour pressure* [kPa],
e_a – *actual vapour pressure* [kPa],
e_s - e_a - *saturation vapour pressure deficit* [kPa],
Δ - slope vapour pressure curve [kPa °C^{-1}],
g - *psychromatic constant* [kPa °C^{-1}

Program input data required for ETO were, daily data: the name of climatic station, the latitude and longitude, the altitude in meters above sea level, the maximum, mean and minimum air temperature, mean wind speed, mean relative humidity, hours of bright sunshine .

The Carrega I85 /90 Index of Forest Fire uses data on humidity, soil water storage and wind speed, it can be calculated both daily and hourly, the index formula is shown below.

$$I85/90 = (500 - (R^{0.5} * H/V))/25,$$

were R = ground water reserve, H = relative humidity and V = wind speed

Daily soil water storage was calculated as the algorithm used by a team of researchers from the University of Lorraine Nancy IUFMs program, with Christiane Haguenaur as coordinator, (http://acces.ens-lyon.fr/biogeo/hydrolog/doceco/ecoalgor.htm). The calculation algorithm takes into account the actual amount which is in the ground, daily evapotranspiration and daily amount of precipitation. Practically the useful reserve is the result of the process of decreasing the daily consumption and adding amounts of precipitation to the already existing reserve at the begging of the day.

The relationship between soil water storage and the need of the plants is strong in the growing season, but decreases at the end of summer to winter becoming insignificant when vegetation is dormant. The evolution of filling of soil water reserve is slow in the absence of precipitation, with the appearance of exponential decrease (without going to zero).

To highlight the area affected by the fire, were calculated two satellite indices NDVI and NDBR and then was made the difference and percentage between them with "Change Detection" tools from Erdas Imagine program.

NDVI is defined as the rapport between the subtraction of the infrared-red bands, and the sum of the two respectively.

NDVI = *(NIR-R)/(NIR+R) = (Band TM 4 – Band TM 3)/(Band TM 4 + Band TM 3*),

Where:
NDVI – Normalized Difference Vegetation Index
NIR – Near Infra Red Band – band 4 Landsat TM and ETM+)
R – Red spectral band (visible, Red-band 3 Landsat TM and ETM+)

The interpretation implies the delimitation of the areas in tones of different colors, which obviously shows characteristics of the vegetation. NDVI was calculated for the imagines taken before and after fire occurred, **Fig. 2** is shown the NDVI difference.

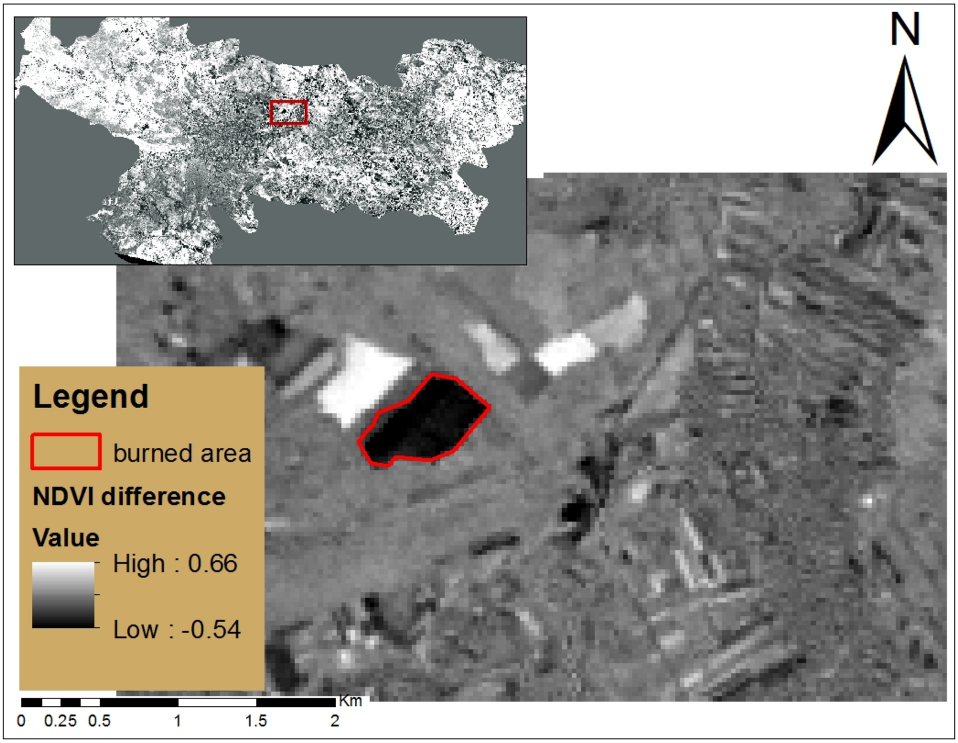

Fig. 2 Land cover change detection using NDVI as input by difference.

The highest values of NDVI are correspondent to the tones of white, and reaches up to 1, these are associated with the thickest and healthiest forests.

The darkest tones, close to black, show the exact opposite of what was mentioned above. The lack of vegetation, of chlorophyll, is expressed by the bare soil, or rock, which absorb the near infrared more.

The medium values are in tones of lighter or darker grey. They can be associated to the broadleaf forest and coniferous forest when the tones are of light-grey, the darker-grey showing inconsistent grassland which does not cover everything.

The NDVI percentage is shown in **Fig. 3**, affected area is evidenced by the color red, the legend shown that in this area the vegetation decreased.

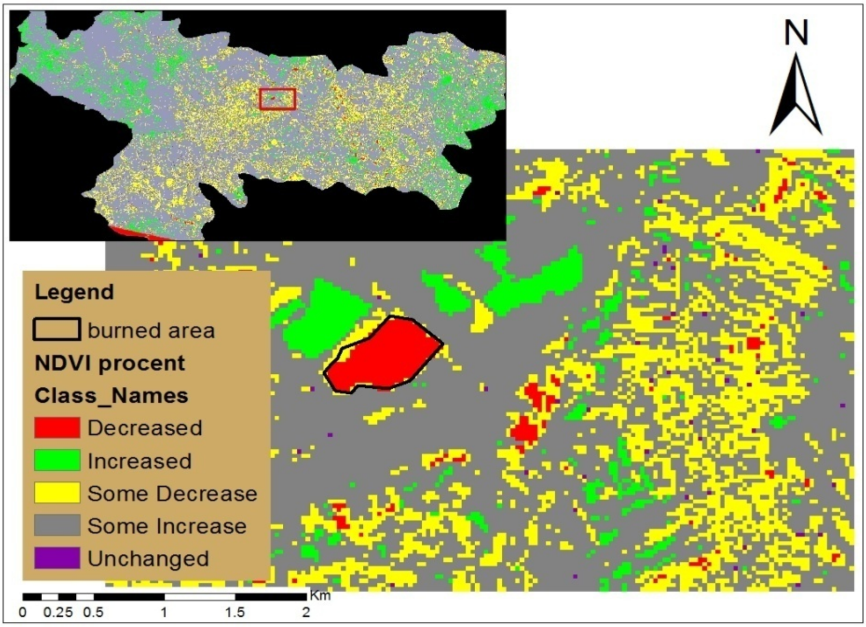

Fig. 3 Land cover change detection using NDVI as input by percentage.

NDBR is particularly useful in the context of areas susceptible to such phenomena, such as mountain forests in areas that meet the intense foehn air masses. The report uses the bands in which spectral response of the not burned vegetation (near infrared) and burned vegetation (middle infrared 2-2.5 µm) are the most powerful, and generally, applies on series of multitemporal images.

NDBR = *(NIR- MIR) / (NIR+MIR) = (Band 4 –Band 7) / (Band 4+ Band 7)*,
where

NDBR –*Normalized Difference Burning Ratio*
NIR – *Near Infra Red* –(band 4 on Landsat TM and ETM+)
MIR –*Infra Red* – (band 7 Landsat TM and ETM+).

NDBR calculated for the images of before and after the fire occurrence is shown in **Fig. 4**, where there the affected area is evidenced by dark tones. In **Fig. 5** is shown the percentage fo NDBR.

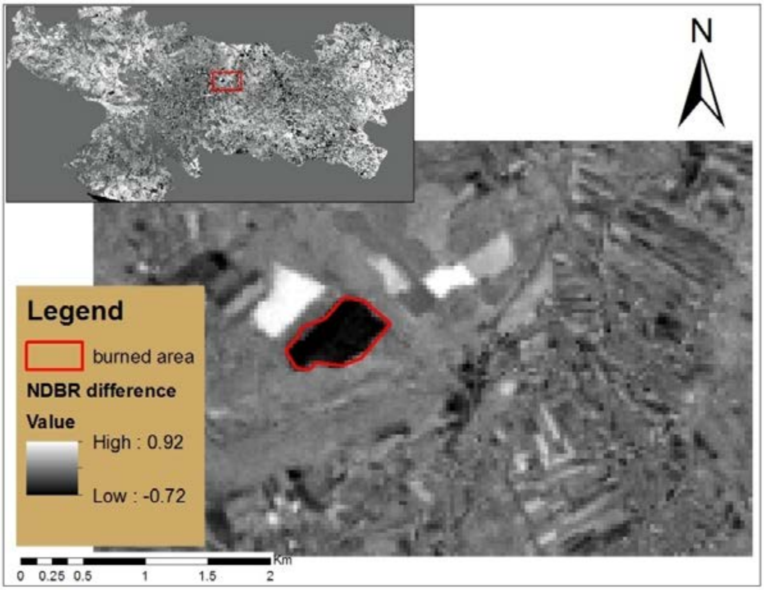

Fig. 4 Land cover change detection using NDBR as input by difference.

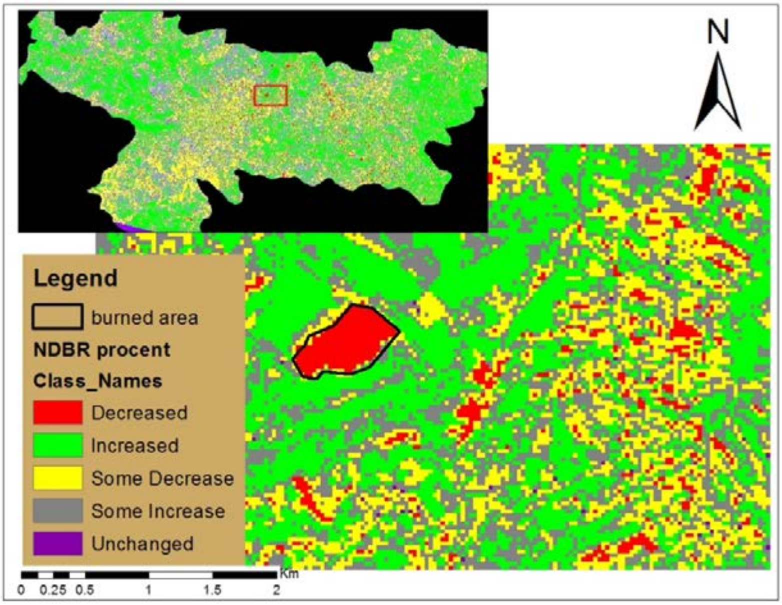

Fig. 5 Land cover change detection using NDBR as input by percentage.

The next stage implies the recording of the image, which is a raster map in only two values: 0 – for the areas that do not show any changes, do not show the effect of fire, and 1 – to the burned areas. Then the raster map was "flattened" by the application of the tool "Majority" from Arc Map, the result being presented in **Fig. 6 (a)**.

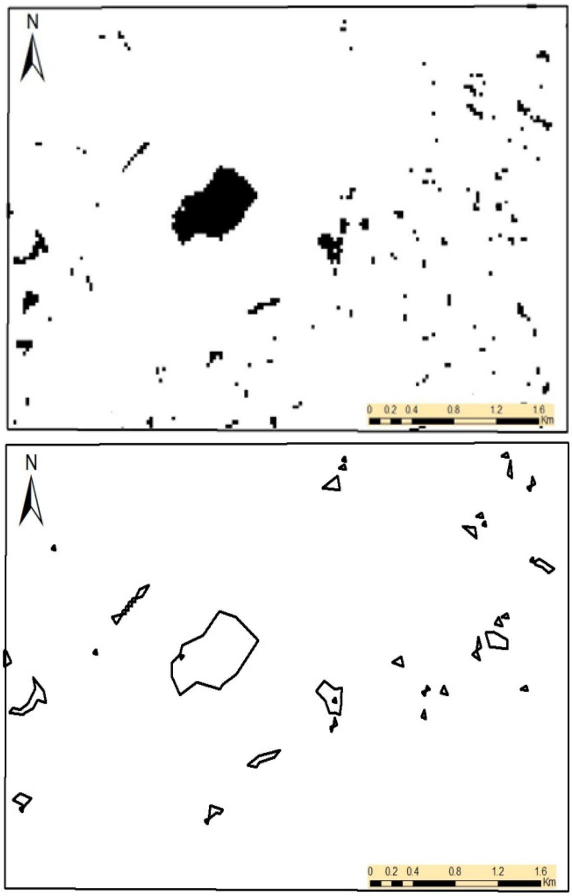

Fig. 6 „The flattened” with „Majority” tools of 1- bit raster map, -(a); polygon vector leyer obtined by changing the representation of raster to vector, - (b).

For the geo-spatial analysis a switch from the raster representation mode to the vector representation was made. The result is a polygon type ground, presented in **Fig. 6 (b)**. In this way the vector limit of the polygons was marked at the limit between pixels with different values (in this case with values 0 and 1).

3. RESULTS AND DISCUSSIONS

An analysis of the causes of forest fires was made by Adam in (2007), he observed that 59.7% of all fires and 66.8% total of the area burned are due to accidental fires from grassland and farmland neighboring forest. The same author has shown that most fires occur in spring (51%) and summer (26%).

The large number of fires in spring and even summer, largely due to arson practices in grassland and stubble is to “clean” them, of course correlated with climatic conditions. During the long winters, high humidity in the air and litter moisture in March and April when pastures can't be burnt and litter combustion is low the number of forest fires is reduced.

3.1 Analysis of the meteorological causes which have favored the spread of fire.

Fires causes can be natural related to weather, higher temperatures, a more pronounced drought, high potential evapotranspiration, soil water deficit, etc.

A first important climatic parameter in the analysis of meteorological factors that may favor the fire is the pluviometric deficit or excess. The values of this parameter are important for surface "preparation" before the fire. In March 25, the day of fire occurrence, there was a pluviometric deficit of -3 mm, highest value recorded in the entire month of March (**Fig. 7**).

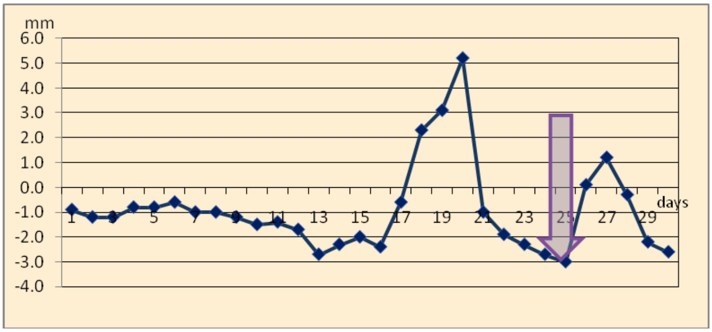

Figure 7. Pluviometric deficit, calculated by subtracting evapotranspiration of the amount of precipitation.

Another climatic parameter which can favor the forest fire propagation is the wind speed. On the day of the fire occurrence the wind was blowing at a speed of 2.4 m / s (that is 8.6 km / h). Wind gusts intensified throughout the day, reaching a speed of 3.3 m / s (or 11.8 km / h).

In **Fig. 8** is shown in graphical form wind speed between the hours in which the fire occurred, mean wind speed for 2 minutes and the mean wind speed for 10 minutes. From the graph there is an increase in the wind speed from 13:00 until it was extinguished at around 2:30 p.m.

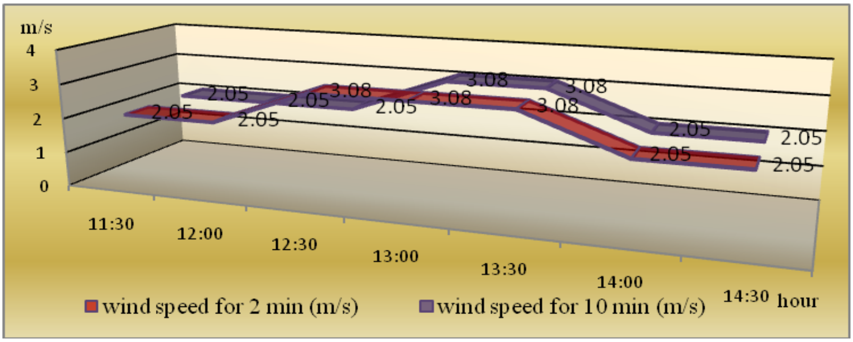

Fig. 8 Wind speed between the hours in which the fire occurred.

The pluviometric deficit in the affected area by the fire is well highlighted in **Fig. 9**, where there were shown the precipitation amounts for 5 days in the month of March 2011, so we can see that in the day of the fire occurred was accumulated a deficit of 10,9 mm.

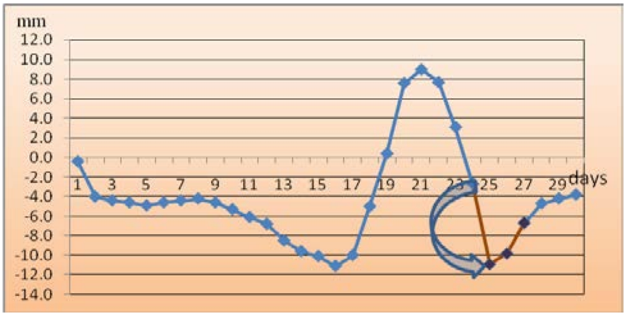

Fig. 9 Dragging the five day precipitation amounts for March 2011.

The pre-fire period is characterized by the deficiency of precipitation and high evapotranspiration, high wind speed. All these factors can favor the spread of a forest fire on a wide surface in a relatively short period of time and can make the fire fighting much harder.

The concept of risk of forest fires, as well as other risks, natural or antropogenic, is ambiguous, describing the probability of an event and also the danger and consequences of this event, associated with humans and his influence on the environment, and therefore vulnerability thereof. Forest fire risk indices correlated with meteorological factors trying to answer this vulnerability, one of them is the index of forest fire weather risk Carrega I85/90.

This index value varies from 0 (no hazard) to 20 (maximum risk) are shown in **Fig. 10** index values calculated for March 2011.

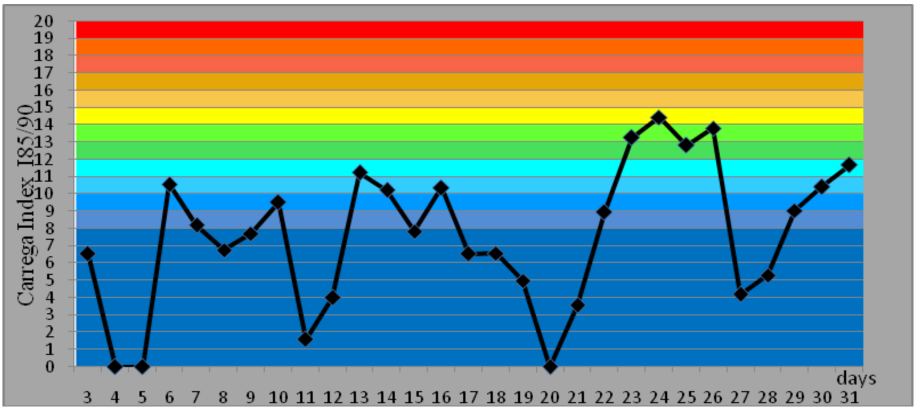

Fig. 10 Carrega Index I85/90 for March 2011.

According to Carrega IndexI85/90 in the time preceding the fire of March 25 increased risk of forest fires since the 20th, when the index value was 0, reaching the value 13 in the day of the fire occurred.

Table 2 summarizes the characteristics meteorological variables from before fire period, the temperature tended to increase from 20 to 25 March, humidity fell was produced, and the deficiency of precipitation has increased the evapotranspiration values. All these features have made the weather of the day 25 March to favorable rapid fire spread.

Table 2. Meteorological variables that characterized the period pre-fire

Day	Maximum Temperature (°C)	Minimum Temperature (°C)	Relativ humidiy (%)	Wiind speed (m/s)	Evapotranspiration (mm/zi)	Precipitation (mm)
20	5.6	2.4	97.7	1.5	0.7	6
21	6.7	1.9	88.4	2	1	0
22	12.1	1.4	63.1	2.1	2.1	0
23	13.6	5.6	61.4	3.3	2.5	0
24	15.1	1.2	56.2	3.6	3	0
25	19	2.1	49.5	2.4	3.3	0
26	18.1	6.4	58.7	3.3	3.2	3

3.2 Analysis burned areas based on morphometric parameters

Exposure is an element of natural potential and has an important role in the analysis of forest fire, the slope exposure map showing in the **Fig. 11**.

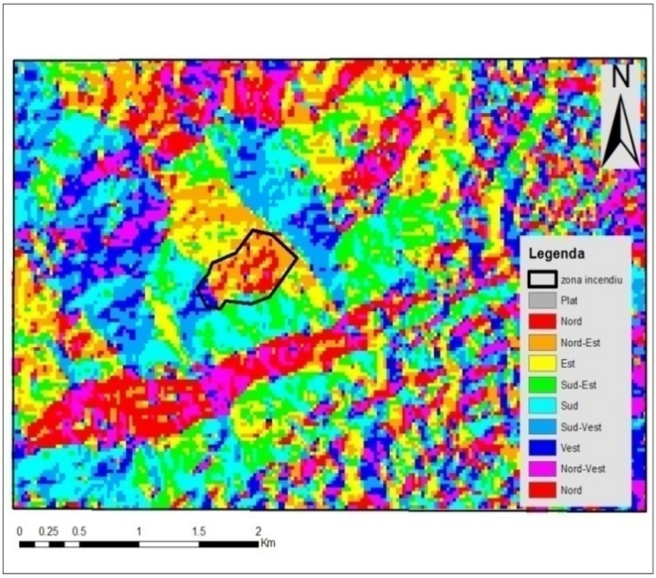

Fig. 11 Map slopes exposure.

Fig. 12 (a) showing that the mainly oriented towards N (25%), NE (28) and E (23%) slope orientation.

Besides slope exposure, another important factor is slope. Slope is understood as the size of altitude increasing with distance, in the direction where it is highest.

Table 3. Slope categories

Slope	Type of surface
0°- 5°	slightly inclined
5,1°- 10°	moderately inclined
10,1°- 15°	inclined
15,1°- 25°	pronounced inclined
> 25°	Strongly inclined+craggy

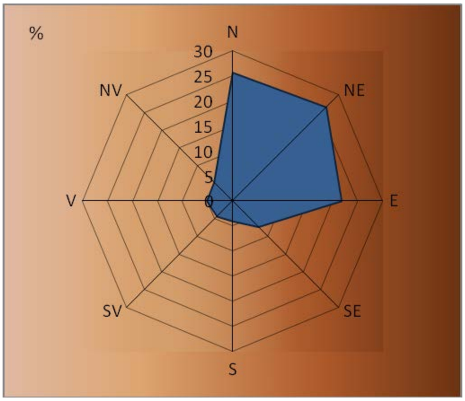

Fig. 12 Affected area reported to slopes (a)- The inclinations classes according to District Forest Cluj Management planning- (b).

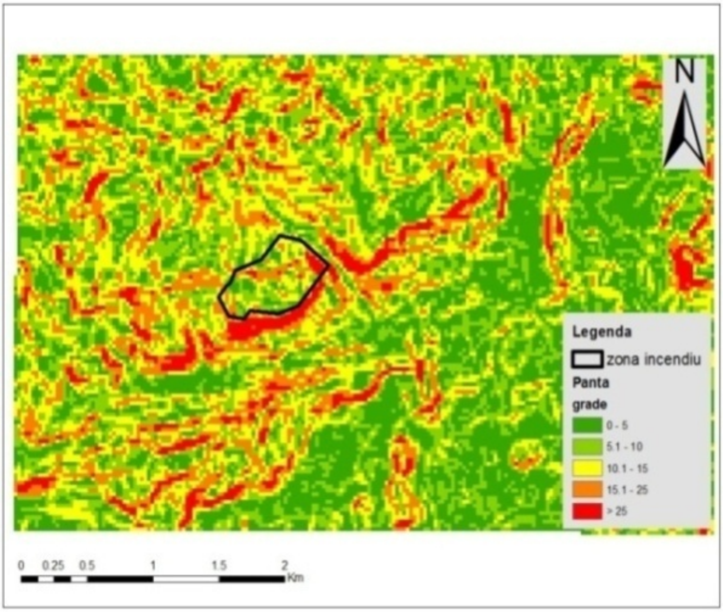

Fig. 13 Map of the inclinations.

For the quantitative analysis, five classes of inclination were chosen and represented grapically (**Fig. 14**), therefore rendering the percentage values for each type of slope.The fire was concentrated on the inclinations with values corresponing to 10.1°-15° classes in proportion of 28%.

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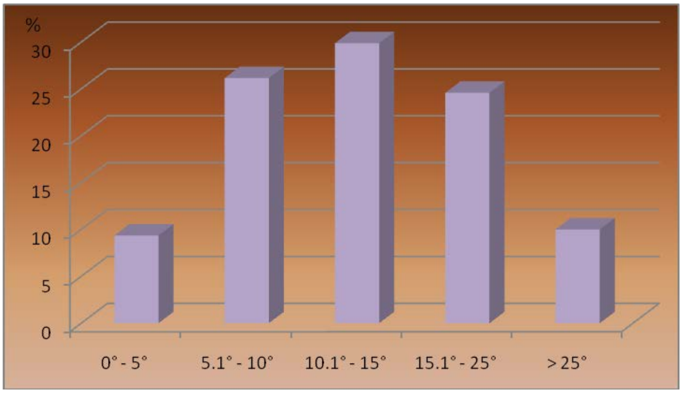

Fig. 14 Affected area by fire, reported to the slope.

Another element with an important role in analyzing forest fire is altitude because determines the accessibility of affected area for intervention and hight area have a low degree of accessibility. To detail the altitude of the affected areas we define 4 classes, between 300 m and 530 m (**Fig. 12**). Thus it is observed that the most affected areas are those between 380m-430 m, with a percentage of 33%. Also was affected the classes between 430m-530 in proportion of 28%.

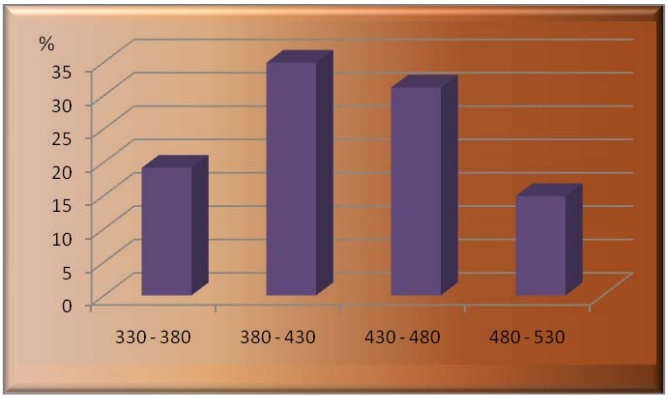

Fig. 15 Affected area by fire, reported to the altitude.

4. CONCLUSION

Forest fires area complex phenomena that which can be caused by a variety of causes, climatic factors play an important role in the production and spread of fire in a large area.

Forest fire is a complex and unpredictable phenomena which can propagate in an uncontrolled way in space and time.

Although the studied fire was caused one, important are the weather conditions which favored the spread of fire over a large area in a short time.

The pre-fire period analyzed is characterized by a lack of precipitation, high evapotranspiration, pluviometric deficit, high wind speed, parameters that favored the spread of fire over a area of 6 hectares. The Carrega I85/90 forest fire rixk Index had the value 14 in the day of the fire, placing the study are in a high risk zone.

The Carrega I85/90 Index could be used to obtain forest fire occurrence data, and therefore to ensure an efficient and effective management regarding risk and opportunities associeted enabiling planning, identification, assessment, quantification, response, monitoring and control the potential risk. This would have to be taken into account the climatic characteristics, which combined with uncontrolled actions of people are factors taht expose the forest areas at high risk of fire. Even in the regions that seem to be non-vulnerable should be taken measures to ban population to using „clean” methods for farmland via arson or unsupervised use of fire near forest fire area.

Fire protection measures, considered in determining the risk of fire, are designed to reduce, neutralize and eliminate fire hazards, or to limit, localization and liquidation of the fire and where it was produced.

Detection of affected areas include essentially quantify phenomena using satellite images. The literature shows, however, that change detection using satellite images is a difficult task and requires validation in the field.

Geographical analysis gave us data on the orientation and the exposure of slopes. Thus the area affected by fire had west orientation with sunny slope aspect. If the slopes and meteorological parameters are correlated appears another favorable factor for fire.

The choosing of 5 classes of inclinations allowed the observation of the concentration of affected area on the class between 10.1° - 15°.

The definition of 4 classes of altitude between 330 m and 530 m allowed us to highlighting affected area by fire reported at altitude, so the area with the highest percentage is the class with altitudes between 380 m and 430 m.

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