

### III. ECOMONITORING

#### INVESTIGATION OF FOREST VEGETATION DYNAMICS BEFORE AND AFTER A FIRE BY USING AEROSPACE DATA

Nataliya Stankova, Roumen Nedkov

**Abstract:** The aim of this study is to investigate the forest vegetation dynamics before and after a fire that took place in the summer of 2007 on the territory of Haskovo region, Bulgaria. To achieve this goal, NDVI and VCI indices have been generated once every year during the vegetation period by means of Terra MODIS imagery. The variations of NDVI and VCI indices have been examined before and after the fire by means of satellite images. The differences in NDVI and VCI variations have been analyzed for the period 2005–2014. The correlation between the two indices has been assessed on the basis of the obtained results. The evaluation of the obtained results has been validated by means of aerial images of the territory of the fire.

**Keywords:** forest fire, post-fire recovery, remote sensing, NDVI, VCI, MODIS.

#### INTRODUCTION

Forest fires can be considered as one of the most important environmental hazards. The large-scale and long-term impact of the forest fires on the environment in big territories determines the relevance of the studies of their effect. Aerospace remote sensing methods and technologies have become irreplaceable tool for operational, reliable and large-scale study of the post-fire recovery process. Remote sensing technology can be used in different phases of fire management which are risk estimation, detection and assessment. Remotely sensed data provide rapid, accurate and reliable information for post-fire damage analysis with being spectrally sensitive to surface vegetative characteristics and structure [1].

In this paper, we use the Normalized Difference Vegetation Index (NDVI) [2, 3] and the Vegetation Condition Index (VCI) [4] for the post-fire recovery monitoring of the study forests.

NDVI is widely used for estimation of green biomass and for assessment of post-fire vegetation regrowth. This is appropriate as long as direct change in green vegetation cover is the main ecological process being measured. Several studies have applied NDVI and similar spectral indices to remotely assess post-fire effects [5, 6, 7].

NDVI is defined by the following equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \quad (1)$$

where  $\rho_{NIR}$  and  $\rho_{RED}$  indicate the reflectance of the near infrared and red bands, respectively. The sum  $(\rho_{NIR} + \rho_{RED})$  represents (twice) the average reflectance in this wavelength range. Division by this factor reduces the effect of non-uniform illumination, such as that due to aspect, and thus

helps to make for better comparability of the vegetation index (VI) across an image.

Since most vegetation indices do not tend to unity at high Leaf Area Index (LAI) (or zero for bare soil), it is frequently useful to “scale” the NDVI or other vegetation index to give scaled VI [8]. The Vegetation Condition Index is mostly used for drought detection.

The VCI is defined as follows:

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (2)$$

where NDVI,  $NDVI_{min}$  and  $NDVI_{max}$  are the NDVI, NDVI minimum and NDVI maximum values, respectively, for the corresponding year. The subscripts max and min refer, to the values for dense vegetation and for bare soil, respectively, sometimes estimated from images as the maximum and minimum positive values detected within an image. Low values of VCI indicate poor/stressed vegetation due to unfavorable weather conditions, and high values of VCI indicate healthy vegetation conditions. The pixel-based normalization is performed to minimize the effect of spurious or short-term signals in the data and to amplify the long-term ecological signal [9].

Vegetation indices, such as NDVI and VCI, have been used to assess the damages [10] and to monitor the recovery of the vegetation after a fire. The use of these indices is justified because of their sensitivity to the vegetation condition which suffers from significant changes after a fire.

#### STUDY AREA

The study area is located in southeastern Bulgaria, Haskovo region, where a significant fire occurred in July, 2007. As a result of heat and dry climate, several

large fires took place between the middle of July and September on the territory of the Balkans [11]. The study fire occurred in the summer of 2007 in an area bounded by the coordinates 4651600m - 4634000m

and 424000m - 438200m, UTM 35T, north of the city Svilengrad. The burnt area has a total length of 17.6 km and a width of 14.2 km. The fire affected a total of 114 km<sup>2</sup>, 11 km<sup>2</sup> of which are forests (Fig. 1).

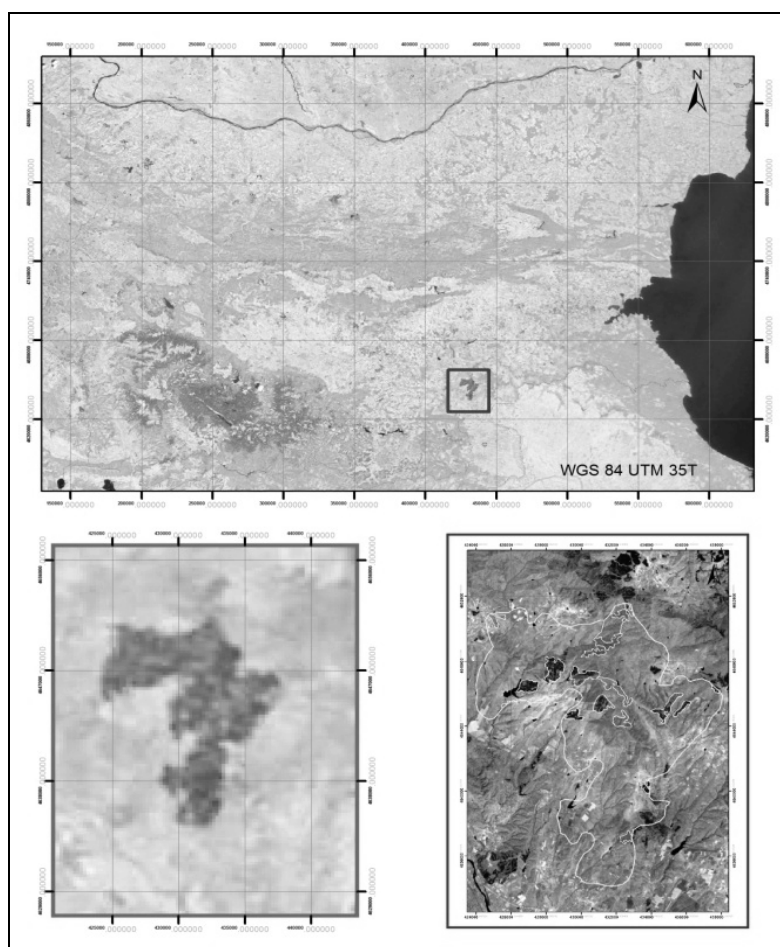


Fig. 1. Study area - a) National boundary of Bulgaria and the location of the burnt area – Terra MODIS imagery acquired on 25/07/2007, 7-2-1 bands; b) The perimeter of the burnt area; c) Landsat image of the burnt area with the study forests, 07/2007, 4-5-3 bands.

In this study, we have selected the test areas to be the forest areas with deciduous, coniferous and mixed forests damaged by the fire. The forests are heterogeneous formations composed mainly of different types of oak trees - *Quercus cerris* L., *Quercus frainetto*, *Quercus pubescentis*, *Quercus virgiliana*. The other forest formations include *Querceto-Carpineta betuli* forests and *Carpinus orientalis* [12].

The region manifests moderate continental climate with a strong Mediterranean influence which is characterized primarily with higher annual average temperatures and hot dry summers. This area is especially prone to forest fires. In the recent years the number of fires and the perimeter of the areas destroyed by fires have reached critical levels

and have no equivalent in the history of forestry in Bulgaria [13].

According to the Habitats Directive [14], the test areas are located in the protected area Sakar and most of them are included in a protected area also called Sakar, this time according to the Birds Directive [15].

## DATA AND METHODS

In this paper we use several Terra MODIS images from 2005 to 2014 with resolution 250 m. The images are composed of band 7, 2 and 1 (Tabl. 1).

The imagery acquisition was performed taking into account the period of the year characterized with the most vegetation and the absence of clouds. The dates of the images are shown in Tabl. 2.

Table 1 – MODIS bands used for image composition

| № Band | $\lambda$ , $\mu\text{m}$ | Spatial Resolution, m |
|--------|---------------------------|-----------------------|
| B1     | 0.620 – 0.670             | 250                   |
| B2     | 0.841 – 0.876             | 250                   |
| B7     | 2.105 – 2.155             | 500                   |

Table 2. MODIS images used to derive vegetation indices

|            |            |            |            |
|------------|------------|------------|------------|
| 23/06/2005 | 25/07/2007 | 21/06/2010 | 22/06/2013 |
| 20/06/2006 | 19/06/2008 | 21/06/2011 | 23/06/2014 |
| 22/06/2007 | 22/06/2009 | 21/06/2012 |            |

After the acquisition, the images have been georeferenced in UTM 35T Zone. Using Corine Land Cover classification (CLC 2006), the different types of forests – deciduous, coniferous, and mixed forests, have been united in a common class of forests. Areas occupied only by this class have been extracted from the images.

NDVI and VCI have been calculated in the middle of June once every year during the examined period (Fig. 3, Fig. 5). An assessment of the recovery process for the study period has been made.

Based on the results obtained, diagrams assessing the dynamics of the average NDVI (Fig. 4) and VCI (Fig. 6) have been created for evaluating the recovery of the forest ecosystems.

The deviations of the mean value of the two indices (Fig. 7, Fig. 8) for each year of the study period excluding the year of fire and the correlation coefficient have been calculated.

Aerial images from one year before (2006) and four years after the fire (2011) have also been used for verification and validation of the methodology.

Fig. 2 shows the methodology followed in this study.

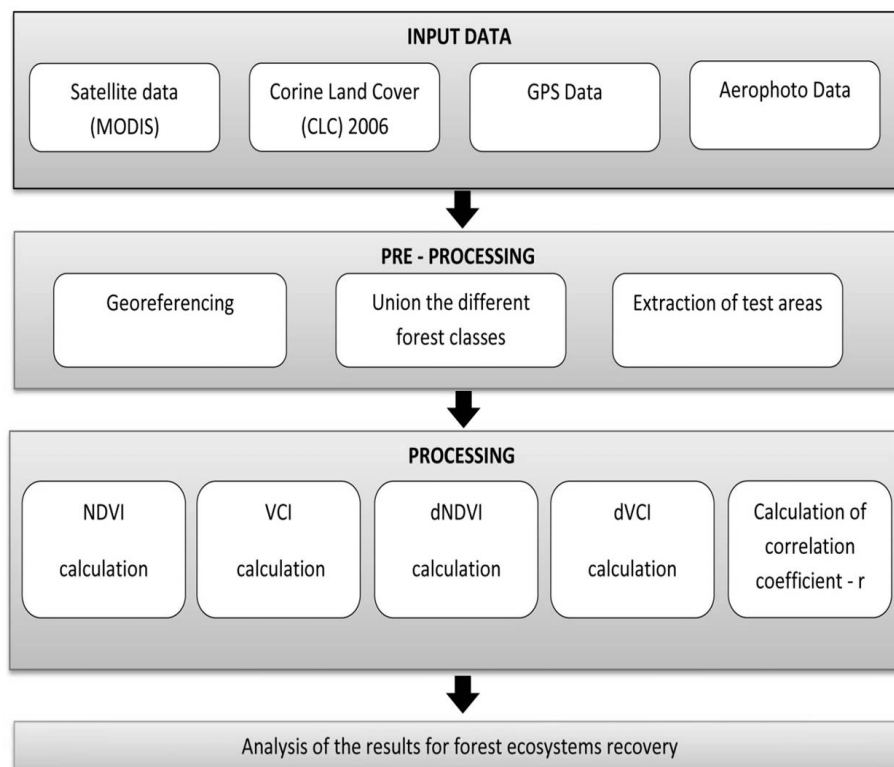


Fig. 2. Flow diagram of the methodology followed in this study

## RESULTS

### *Normalized Difference Vegetation Index (NDVI)*

In order to monitor the post-fire recovery, NDVI for the territory of the forest areas has been calculated once every year in the middle of June, between three years before and seven years after the fire (Fig. 3). NDVI shows high average values during the period before the fire. A month before the fire (June, 2007), a decrease in the index can be detected which persists for two years after the fire occurrence. The aerial images from 2006 reveal a tendency for drought which is related to moisture decrease around the crowns of the trees and to decrease of the chlorophyll. Stressed forest vegetation can be distinguished from the healthy one by interpreting of aerial images in the green band of the spectrum one year before the fire. Those areas exhibit low NDVI values one year before

the fire and after the fire forest vegetation in them has been completely destroyed.

A few days after the fire, there is a drastic decrease of the index values as expected. Almost the whole burnt area shows negative NDVI values. The only positive once a few days after the fire can be seen in the forest areas.

NDVI reaches its highest values in 2010 and 2014 – in the third and the seventh year after the fire (Fig. 4). The fluctuation ranges of the index are narrow due to the influence of external factors such as air temperature, precipitation, etc. which accompany the regenerative process. The sudden change in NDVI values during the regeneration period after the fire may be due to the appearance of invasive species as a result of the variety of secondary effects that occurred [16, 17].

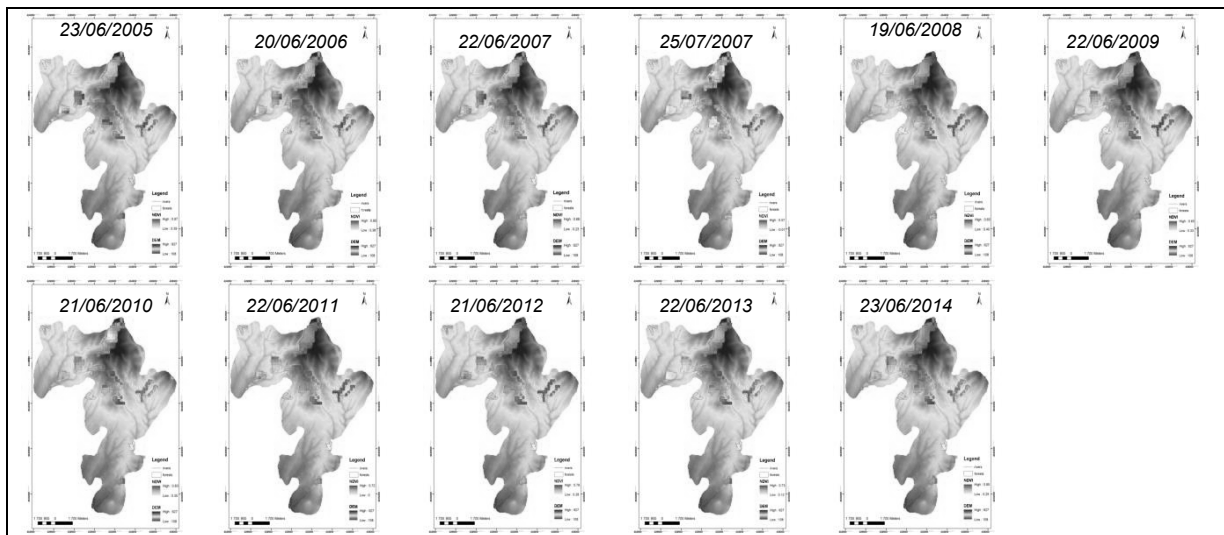


Fig. 3. The burnt area with NDVI of the study forests – between three years before and seven years after the fire

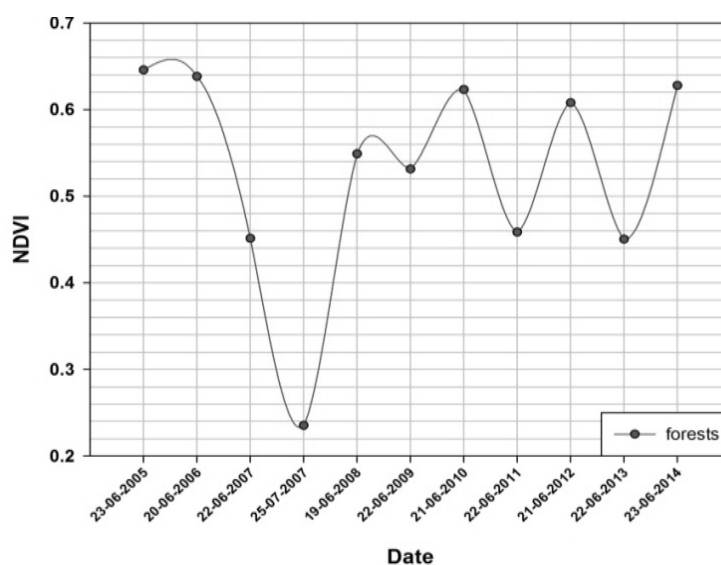


Fig. 4. Average NDVI values for the study areas during the examined period

### *Vegetation Condition Index (VCI)*

In order to monitor the regenerative process after the fire, to detect drought, and to determine the vegetation status of the study forests, VCI has also been calculated in the middle of June once every year on the territory of the forest areas starting three years before until seven years after the fire (Fig. 5).

The shape of the VCI curve in most of the cases resembles the one of the NDVI. VCI shows high average values during the period before the fire which indicates healthy vegetation conditions except

for the areas with stressed vegetation that can be observed on aerial images from 2006.

There is a drastic decrease in the values of the index a few days after the fire. VCI reaches its highest values in 2012 – in the fifth year after the fire (Fig. 6). The index fluctuations which accompany the regenerative process are also within narrow ranges. In fact, the values of the index follow the same trend as the ones before the fire. During the regeneration process VCI exhibit even higher values than the values before the fire.

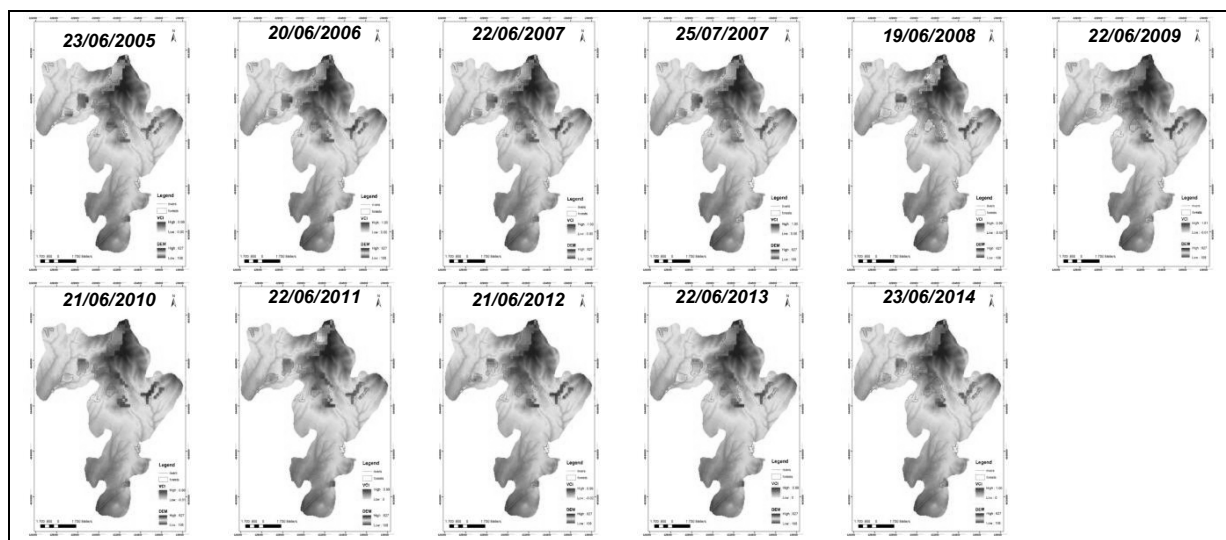


Fig. 5. The burnt area with VCI of the study forests – between three years before and seven years after the fire

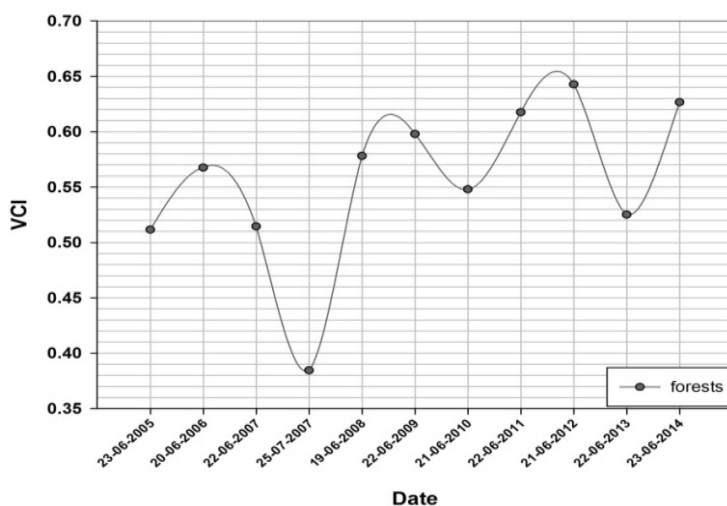


Fig. 6. Average VCI values for the study areas during the examined period

In 2010 NDVI approached a higher value and VCI a lower value when compared to the previous and the following years. This lower VCI value in 2010 is due to the higher minimum value of NDVI which proves that most of the vegetation has recovered after the disaster.

### *NDVI and VCI variations*

The deviations from the mean values of the vegetation indices, dNDVI and dVCI, indicate unstable recovery process (Fig. 7, Fig. 8). The deviations from the mean values are pronounced

which confirm the unsustainability of the recovery process of the forest ecosystems. The quantitative assessment of the regenerative process of the forest ecosystems is more clearly expressed by dNDVI and dVCI than by their absolute values (NDVI and VCI).

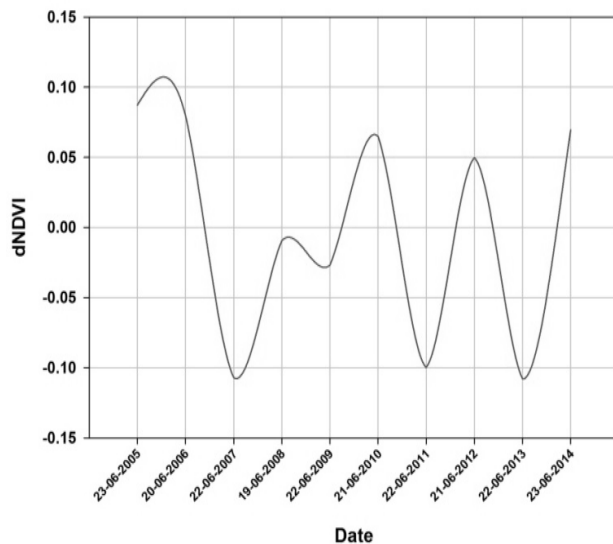


Fig. 7. The deviations from the mean NDVI value (dNDVI) excluding the fire

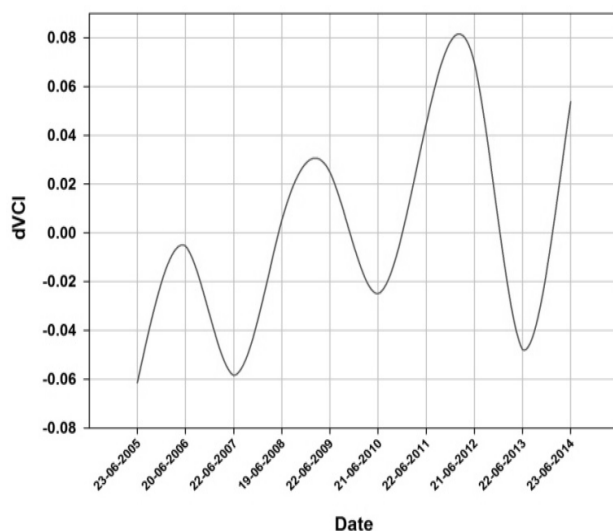


Fig. 8. The deviations from the mean VCI value (dVCI) excluding the fire

The correlation coefficient between the vegetation indices (NDVI and VCI) is  $r = 0.68$  and the correlation coefficient between the deviations from the mean values (dNDVI and dVCI) is  $r = 0.81$ . Since the correlation between the deviations is stronger than the correlation between their absolute values, in this case it is better to use the deviations for monitoring the recovery process.

## CONCLUSION

NDVI and VCI show high average values for the study period before the fire. A month before the fire, there is a decrease in these indices that persists for two years after the fire (Fig. 4, Fig. 6). There is a trend of drought-related reduction of moisture around the crowns of the trees which is observed on aerial images from 2006. This trend negatively affects the foliage of the forest ecosystem which is related to the reduction of the chlorophyll amount, and also to reduction of the water content and to changes in the structure of the cells. By visual interpretation in the green range of the spectrum, forests under the influence of this stress can be distinguished from the green healthy forest vegetation. This is observed during the interpretation of aerial images taken one year before the fire which was a result of drought. After the fire in these areas the forest ecosystems have been completely destroyed. In fact, the beginning of the recovery process is observed in 2009 since the indices follow the same trends as the ones from the period before the fire.

An unsustainable trend of the recovery process of the forest ecosystem is detected which can be seen in Fig. 4 and Fig. 6. In some areas forest ecosystems have been practically completely destroyed by the fire and have not recovered. The areas of forest ecosystems in which no stress is observed, have a shorter recovery period and this corresponds to higher values of the vegetation indices (NDVI and VCI). The recovery process can be seen on the graphs with the deviations from the mean value (dNDVI and dVCI) the fluctuations of which are even stronger than the ones of the vegetation indices absolute values.

**ACKNOWLEDGEMENTS:** This work was supported by the Operational Program Human Resources Development of the Bulgarian Ministry of Education, Youth and Science funded by the European Social Fund (ESF), CONTRACT BG051PO001-3.3.06-0051.

## REFERENCES

1. Alganci U., Sertel E., Ormeci C. (2010) - *Forest Fire Damage Estimation Using Remote Sensing and GIS*. Proceedings of EARSeL Symposium 2010, ISBN 978-3-00-033435-1, 423-430.
2. Rouse J.W., Haas R.H., Schell J.A., Deering D.W. and Harlan J.C. (1974) - *Monitoring the vernal advancement and retrogradation (greenwave effect)*

of natural vegetation. NASA/GSFC Final report, Greenbelt, MD, USA

3. Tucker C.J. (1979) - *Red and Photographic Infrared Linear Combinations for Monitoring Vegetation*. Remote Sensing of Environment, 8: 127-150. doi: [http://dx.doi.org/10.1016/0034-4257\(79\)90013-0](http://dx.doi.org/10.1016/0034-4257(79)90013-0).

4. Kogan F., Sullivan J. (1993) – *Development of global drought-watch system using NOAA/AVHRR data*. Advances in Space Research, 13: 219-222.

5. Fiorella M., Ripple W.J. (1993) - *Analysis of Conifer Regeneration using Landsat Thematic Mapper Data*. Photogrammetric Engineering and Remote Sensing, 59, 9: 1383-1388.

6. Henry M.C., Hope A.S. (1998) - *Monitoring post-burn recovery of chaparral vegetation in southern California using multi-temporal satellite data*. International Journal of Remote Sensing 19, 16: 3097-3107.

7. Diaz-Delgado R., Lloret F., Pons X. (2003) - *Influence of fire severity on plant regeneration through remote sensing imagery*. International Journal of Remote Sensing 24, 8: 1751-1763.

8. Jones H., Vaughan R. (2010) - *“Remote sensing of vegetation. Principles, techniques, and applications”*, OXFORD University Press, ISBN: 978-0-19-920779-4.

9. Wardlow B.D., Anderson M. C., Verdin J.P. (2012) – *Remote sensing of drought. Innovative monitoring approaches*. CRC Press, Taylor and Francis Group, ISBN 978-1-4398-3557-9.

10. Lee B., Kim S. Y., Chung J., Park P. S. (2008) - *Estimation of fire severity by use of Landsat TM images and its relevance to vegetation and topography in the 2000 Samcheok forest fire* - J For Res, 13:197–204

11. Nedkov R., Dimitrova M., Zaharinova M., Ivanova I. (2008) - *Web-based monitoring of the fires in the Balkans using satellite data during July and August 2007*. Ecological engineering and environmental protection, No1: 13-19. (in Bulgarian)

12. Bondev I. (1991) - *The vegetation of Bulgaria*, Sofia, University Press, “Kliment Ohridski”: 184. (in Bulgarian)

13. Dimitrova M., Ivanova I., Zaharinova M., Nedkov R. (2011) - *Application of aerospace methods of monitoring of forest fires and evaluation of burned area in Haskovo region in the summer of 2011*, Seventh Scientific Conference with International Participation - Space, Ecology, Safety, 87-98. (in Bulgarian)

14. Habitats Directive, 92/43/EEC

15. Birds Directive, 2009/147/EC

16. Thomas C.M., Davis S.D. (1989) - *Recovery Patterns of Three Chaparral Shrub Species after Wildfire*. Oecologia, 80: 1432-1939.

17. Hilty J.H., Eldridge D.J., Rosentreter R., Wicklow-Howard M.C., Pellant M. (2004) - *Recovery of Biological Soil Crusts following Wildfire in Idaho*. Journal of Range Management, 57: 89-96.

## ИЗСЛЕДВАНЕ ДИНАМИКАТА НА ГОРСКАТА РАСТИТЕЛНОСТ ПРЕДИ И СЛЕД ПОЖАР ЧРЕЗ ИЗПОЛЗВАНЕТО НА АЕРОКОСМИЧЕСКИ ДАННИ

Наталия Станкова, Румен Недков

**Резюме:** Целта на настоящото изследване е проследяване динамиката на горската растителност преди и след пожар, състоял се лятото на 2007 г. на територията на област Хасково, България. За постигане на тази цел, веднъж годишно по време на вегетационния период са генерирани NDVI и VCI индекси на базата на изображения от Terra MODIS. С помощта на сателитни изображения са изследвани колебанията на индексите NDVI и VCI преди и след пожара. Разликите в отклоненията от средните стойности на индексите NDVI и VCI са анализирани за периода 2005–2014 г. На базата на получените резултати е оценена корелацията между двата индекса. За валидиране на получените резултати се използват аерофото изображения на територията на пожара.

**Ключови думи:** горски пожар, възстановителни процеси, дистанционни изследвания, NDVI, VCI, MODIS.

**Nataliya Stankova**

**Prof. Dr. Eng. Roumen Nedkov**

Space Research and Technology

Institute – BAS

Acad. Georgi Bonchev Str. Bl. 1

Sofia 1113, Bulgaria

e-mail: [natalia\\_hs@space.bas.bg](mailto:natalia_hs@space.bas.bg)

**Наталия Станкова**

**проф. д-р инж. Румен Недков**

Институт за космически изследвания

и технологии – БАН

ул. Акад. Георги Бончев бл. 1

София 1113, България

e-mail: [natalia\\_hs@space.bas.bg](mailto:natalia_hs@space.bas.bg)