I. MAN AND BIOSPHERE

RESEARCH MODEL OF MONITORING THE RECOVERY OF AN ECOSYSTEM AFTER FIRE BASED ON SATELLITE AND GPS DATA

Nataliya Stankova, Roumen Nedkov

Abstract: The aim of this study is to monitor the post-fire recovery of an ecosystem. The test area is located in Southeastern Bulgaria, Haskovo region, where a significant fire took place in the summer of 2007. To achieve this goal, satellite images from Landsat 5 (TM), Landsat 7 (ETM+), and Landsat 8 (OLI) have been used. The model that has been developed is built on three main components – Disturbance Index (DI), Vector of Instantaneous Condition (VIC), and Direction Angle (DA). Tasseled Cap transformation (TCT) has been used and Tasseled Cap components have been generated as input data for the model. Normalized Difference Vegetation Index (NDVI) has also been generated and the correlation coefficient between DI and NDVI has been calculated. The model has also been validated by means of aerial images with high resolution on the territory of the fire.

Keywords: remote sensing, post-fire recovery, TCT, DI, VIC

INTRODUCTION

Wildfires are a common disturbance factor, especially in areas characterized primarily with higher annual average temperatures and hot dry summers. The study 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 [1]. The detection of disturbance and monitoring of post-fire ecosystem recovery are vital for ecological research and calculation of Disturbance Index (DI). The DI was designed [2] to highlight the unvegetated spectral signatures associated with stand-replacing disturbance and separate them from all other forest signatures. The DI is a linear combination of the three Tasseled Cap indices [3, 4].

The Tasseled Cap transformation (TCT) offers a way to optimize data viewing for vegetation studies. Research has produced three data structure axes which define the vegetation information content [5]:

- Brightness (BR) – a weighted sum of all bands, defined in the direction of principal variation in soil reflectance;
- Greenness (GR) – orthogonal to brightness, a contrast between the near-infrared and visible bands. Strongly related to the amount of green vegetation in the scene;
- Wetness (W) – relates to canopy and soil moisture [6].

The DI simply quantifies how close in tasseled cap space a pixel is to the areas in the scene having the highest brightness and lowest greenness and wetness. However, when viewed in sequence, DI images provide a direct way to highlight pixels that move from an average forest condition to a disturbed forest condition [2].

Based on the three Tasseled Cap components (BR, GR and W), a vector describing the current condition of the ecosystem has been obtained and we call it Vector of Instantaneous Condition (VIC). VIC represents the condition and the relation between the tree main elements of the study ecosystem. VIC shows the change in the correlation between the components in case of disaster.

We call Direction Angle (DA) the angle between the Greenness component from the TCT and the Vector of Instantaneous Condition. This angle shows the direction of the change of the Greenness component in relation to the VIC. This enables the assessment of the recovery rate of the Greenness component.

The aim of this study is to monitor the post-fire recovery of an ecosystem. The model that has been developed for monitoring the recovery of an ecosystem after fire is built on the following components – Disturbance Index (DI), Vector of Instantaneous Condition (VIC), and Direction Angle (DA).

STUDY AREA

The study area is located in Southeastern Bulgaria, Haskovo region, where a significant fire took place in July, 2007 [7]. As a result of heat and dry climate several large fires occurred between the middle of July and September on the territory of the Balkans [8]. The location and the perimeter of the burnt area have been determined by means of two Landsat imageries, the first taken a few days before (20/07/2007) and the other a few days after the fire (28/07/2007). The fire affected a total of 10989.8 ha. The study area is bounded by the coordinates N4651600m - E424000m and N4634000m - E438200m, UTM 35T, North of the town of Svilengrad. The region has a total length of

17.6 km and a width of 14.2 km. The elevation of the area ranges between 108 and 627 metres. According to the Habitats Directive [9] the study area is located in the protected area Sakar and half of the study area is included in a protected area also called Sakar this time according to the Birds Directive [10].

The principal vegetation in this area consists of pastures, shrubs, agricultural lands and forests. The forests are heterogeneous formations composed mainly of different types of oak trees - *Quercus cerris L.*, *Quercus frainetto*, *Querceta pubescentis*, *Quercus virgilianae*. The other forest formations include *Querceto-Carpineta betuli* forests and *Carpinus orientalis*. The shrubs consist mainly of *Paliurus spina-christi*. The pastures comprises of xerothermic grasslands dominated by *Dichantieta ischaemii*, *Poaeta bulbosae*, *Jasminum fruticans L.*, *Ephemereta* [11].

DI has been calculated for the territory of the whole burnt area while for VIC and DA calculation a test area comprised mainly of forest that has been selected.

DATA AND METHODS

In this paper we use several images from Landsat 5 TM (Thematic Mapper), Landsat 7 ETM+ (Enhanced Thematic Mapper plus), and Landsat 8 OLI (Operational Land Imager) taken once per year during the study period - between 2007 and 2014. These data were provided by the USGS. The imagery acquisition was performed taking into account the period of the year with the most vegetation and the absence of clouds when it is possible. Areas of clouds and cloud shadows have been removed from the images. The dates of the images are shown in Tabl. 1.

Table 1 – Image acquisition dates

Dates of acquisition	Sensor
20/07/2007	ETM+
28/07/2007	TM
22/07/2008	ETM+
17/07/2009	TM
04/07/2010	TM
23/07/2011	TM
17/07/2012	ETM+
12/07/2013	OLI
15/07/2014	OLI

After the acquisition, the burnt area has been extracted and Tasseled Cap transformation, Disturbance Index, Vector of Instantaneous Condition, and Direction Angle have been calculated for the recovery monitoring using the model.

For assessing the ecosystem after the fire, a method of linear spectral transformation in multidimensional space has been used in order to reduce the space of the signs. This type of transformation is called Tasseled Cap transformation (TCT). Tasseled Cap components have been generated as input data for the model.

The first step is decomposition of each of the TC components – BR, GR and W (Fig. 1). The second step is calculation of the mean and the standard deviation values for each of the TC components. The third step is

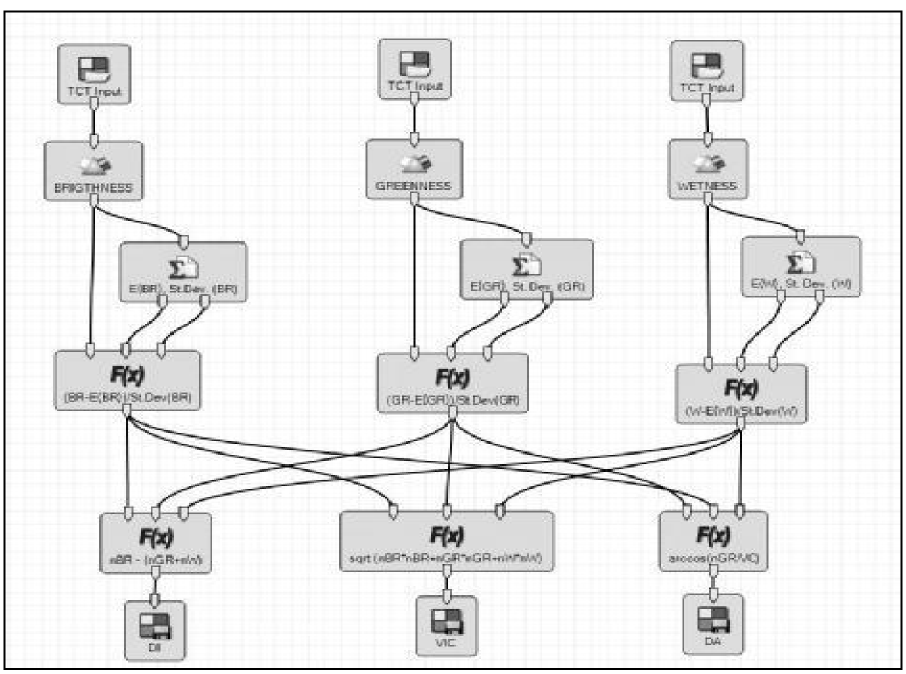

Fig. 1. Model for calculation of Disturbance Index, Vector of Instantaneous Condition and Direction Angle

calculation of the normalized values of the three TC components. These spectral normalization steps should be taken in order to normalize radiometric change. The normalization was conducted as follows:

$$nBR = (BR - E\{BR\}) / St.Dev(BR)$$
$$nGR = (GR - E\{GR\}) / St.Dev(GR) \quad [1]$$
$$nW = (W - E\{W\}) / St.Dev(W)$$

where E{BR}, E{GR} and E{W} represent the mean Tasseled Cap Brightness, Greenness and Wetness, respectively. St.Dev (BR), St.Dev (GR) and St.Dev (W) are the corresponding standard deviations, and hence nBR, nGR and nW indicate the normalized Brightness, Greenness and Wetness, respectively. After normalization, the three component indices were combined linearly to acquire the DI as follows:

$$DI = nBR - (nGR + nW) \quad [2]$$

The next step is calculation of the Vector of Instantaneous Condition (VIC) based on the normalized values of the TC components. The calculation was conducted as follows:

$$VIC = sqrt(nBR*nBR + nGR*nGR + nW*nW) \quad [3]$$

The last step is calculation of the Direction Angle (DA) – the angle between the Greenness (GR) component from TCT and the VIC for every moment of the study period. It was acquired as follows:

$$DA = \arccos(nGR/VIC) \quad [4]$$

NDVI [12, 13] has also been generated for assessing the recovery of the ecosystem after the fire. The correlation coefficient between DI and NDVI has been calculated which validates the approach used to assess the condition and recoverability of the ecosystem. Furthermore, the approach and the results have been validated on the basis of high-resolution aerial images taken before the fire and in the end of the study period.

RESULTS

Disturbance Index (DI)

The calculation of DI is based on the observation that disturbed areas generally have a higher Tasseled Cap Brightness value and lower Greenness and Wetness values than undisturbed forest areas [2]. Thus, disturbed areas that have high positive nBR, low negative nGR and nW will be with high DI values. Conversely, an undisturbed area should present low DI values [14].

Fig. 2 shows the values of DI for the territory of the burnt area during the study period - between 2007 and 2014. Areas of clouds and cloud shadows have been removed from the images. A few days after the fire (28/07/2007) DI shows very high values for the territory of the whole burnt area. After the fire, in the areas where recovery processes begin, the values of the index are decreased. This is also observed in the increase of the NDVI values (Fig. 5). Values of DI increase in the years when some anthropogenic influence is observed. In 2013-2014, when there is a tendency of recovery processes DI values decrease but they remain high in the permanently affected areas.

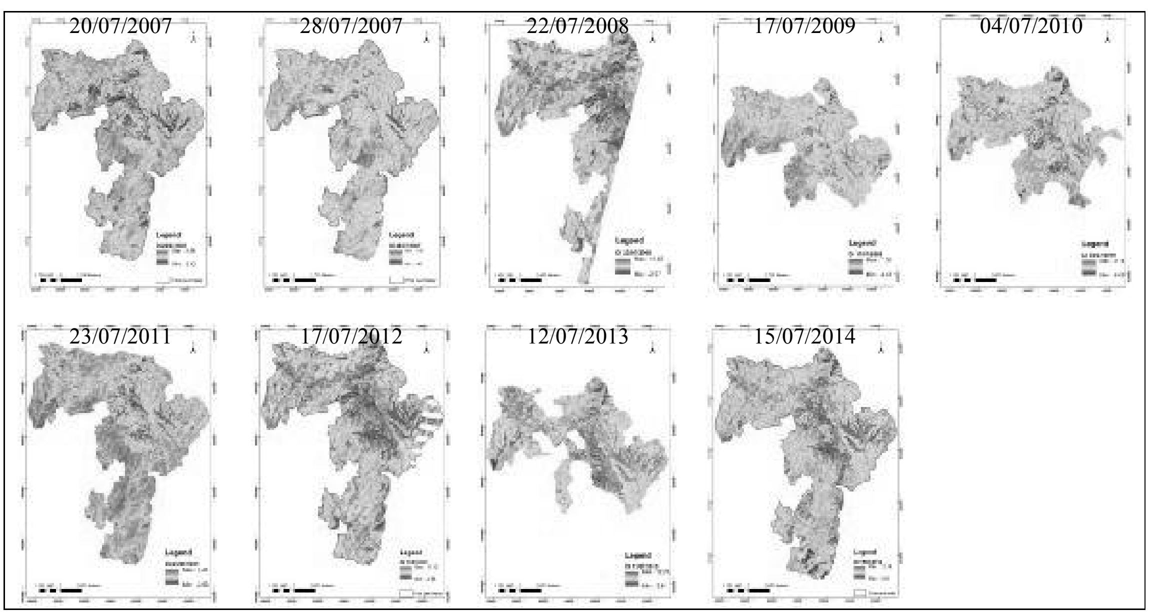

Fig. 2. The DI of the burnt area during the study period – between 2007 and 2014. Areas of clouds and cloud shadows have been removed from the images

Vector of Instantaneous Condition (VIC)

Fig. 3 shows the values of the spatial distribution of VIC during the study period. The first 3-D scatter diagram represents the condition of the ecosystem before the fire. On the second 3-D scatter diagram, the distribution of VIC after the fire is shown in red compared to VIC before the fire, which is in green. Over the next few years after the fire, there is no significant trend of recovery since most of the burnt areas have not changed. A decrease in the recovery processes is established in 2012 because of anthropogenic impact. In 2013-2014, a tendency for more quickly recovery is observed which is seen in the prevalence of the green over the red color (Fig. 3). In general, the burnt areas seriously affected by the fire have not recovered throughout the study period.

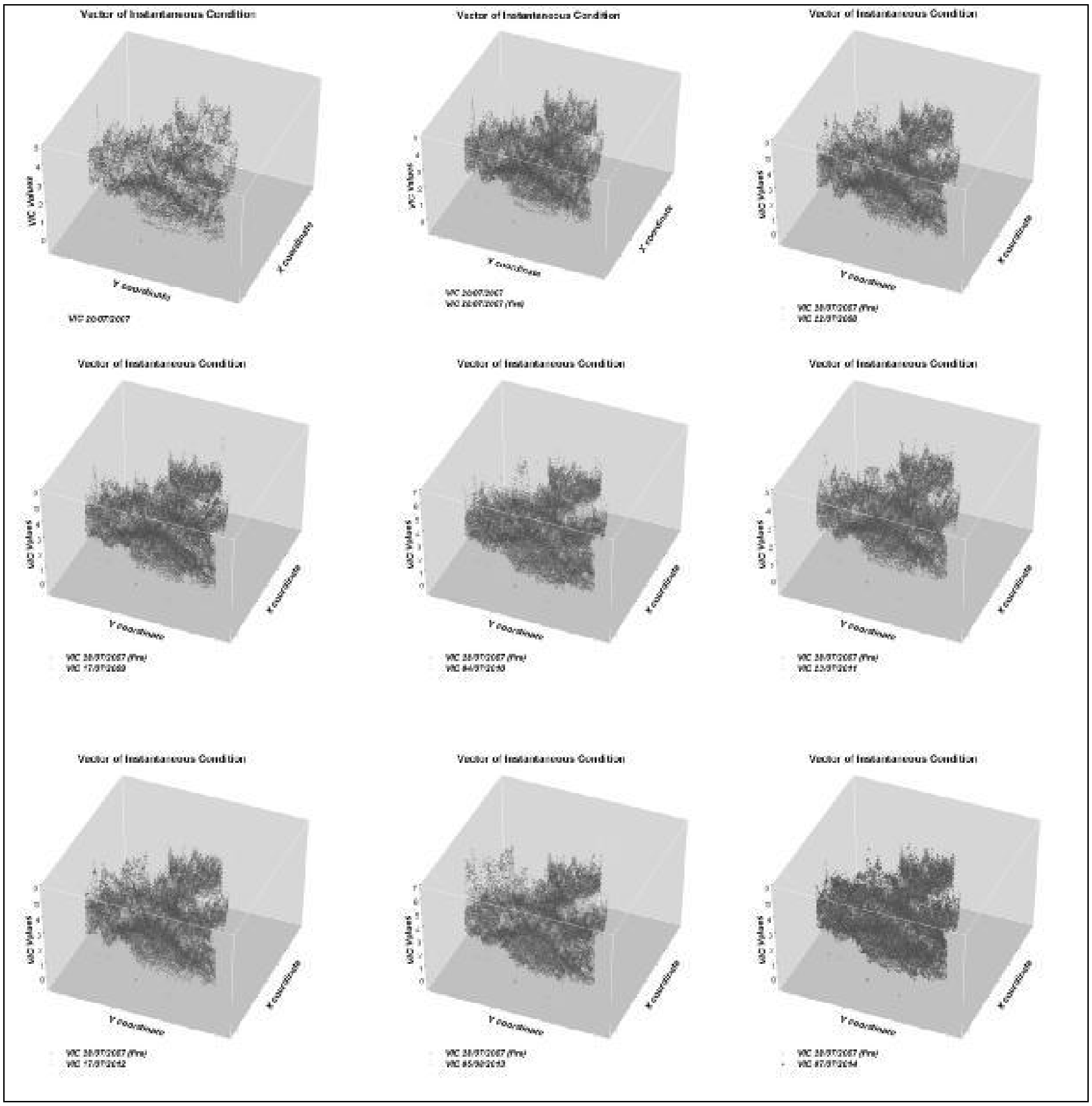

Fig. 3. 3-D scatter diagrams of VIC

Direction Angle (DA)

Fig. 4 shows the values of the spatial distribution of DA during the study period. In general, DA follows the trends of VIC change and it represents more clearly the changes of the Greenness component during the study period. Under anthropological impact, there is an increase of DA after the fire in comparison to its values before the fire.

2-D Scatter diagrams of DI and NDVI

Normalized Difference Vegetation Index (NDVI) has also been generated and the correlation coefficient (R) between DI and NDVI has been calculated (Fig. 5). The correlation has been calculated by means of linear regression based on the spatial data for NDVI and DI. The correlation coefficient has been calculated based on the Pearson's correlation coefficient. A strong correlation between DI and NDVI has been observed during the study period. The correlation coefficient between the two indices show negative values and with the increase of DI, NDVI decreases. During the fire, R is low due to the decreasing NDVI values. This proves that calculation of the correlation between DI and NDVI could be a good approach for ecosystem monitoring in the case of a negative impact.

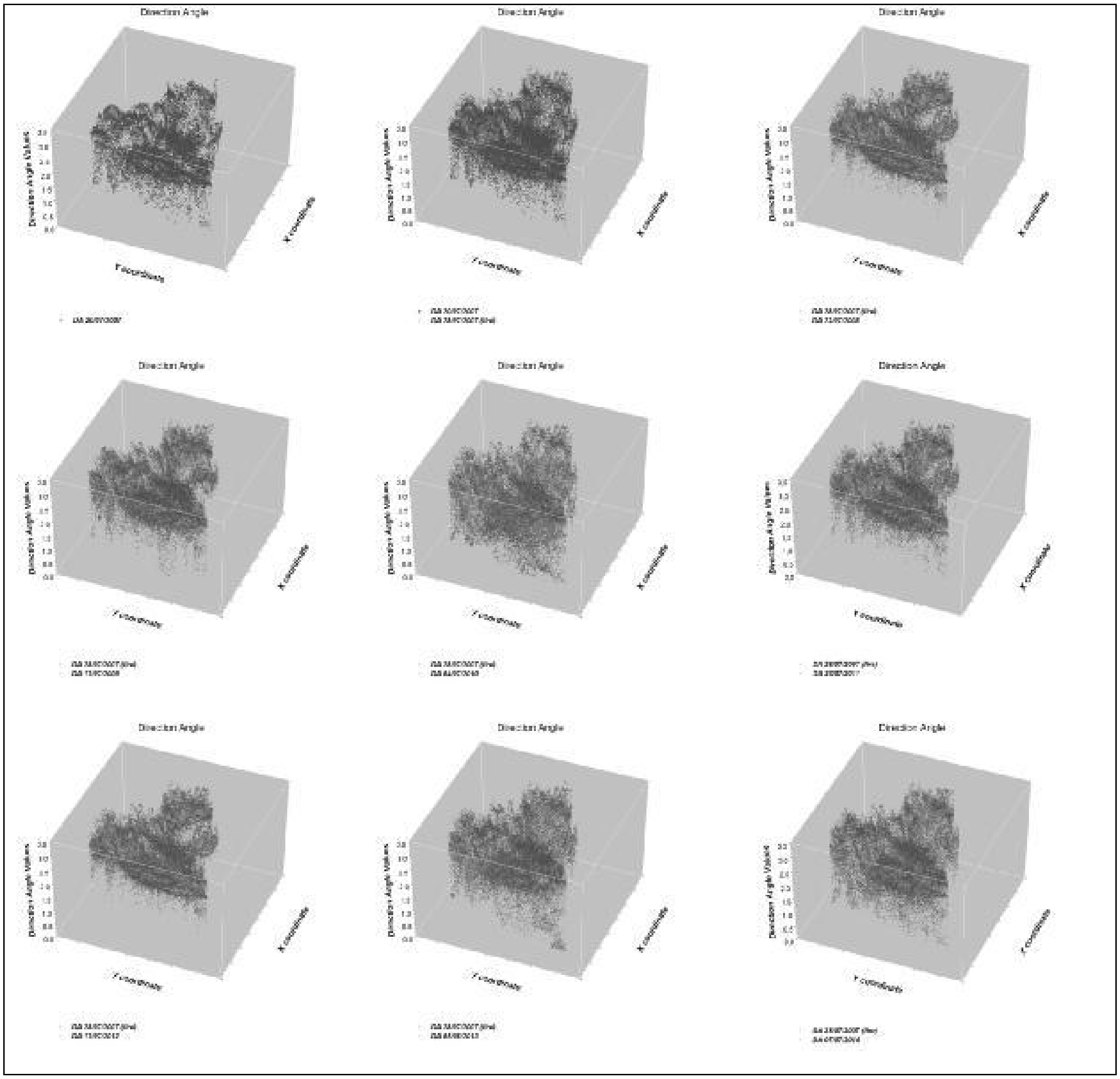

Fig. 4. 3-D scatter diagrams of DA

CONCLUSION

The obtained results give an objective assessment of the recovery of an ecosystem after a fire. Using the proposed model, based on the tree main TC components a quantitative assessment for DI, VIC and DA has been made. Results for VIC and DA show that they are appropriate for monitoring the ecosystem condition in case of disaster. The disadvantage of the introduced VIC and DA is that they indicate the instantaneous condition of the ecosystem. As indicators for assessing the degree of recovery of the ecosystem, they give an objective assessment not only of the degree of recovery, but also of the presence of affected areas that cannot recover. The proposed model can be used in processing other satellite data (MODIS, SPOT), which allows for more detailed assessment of the degree of ecosystem recovery after fire.

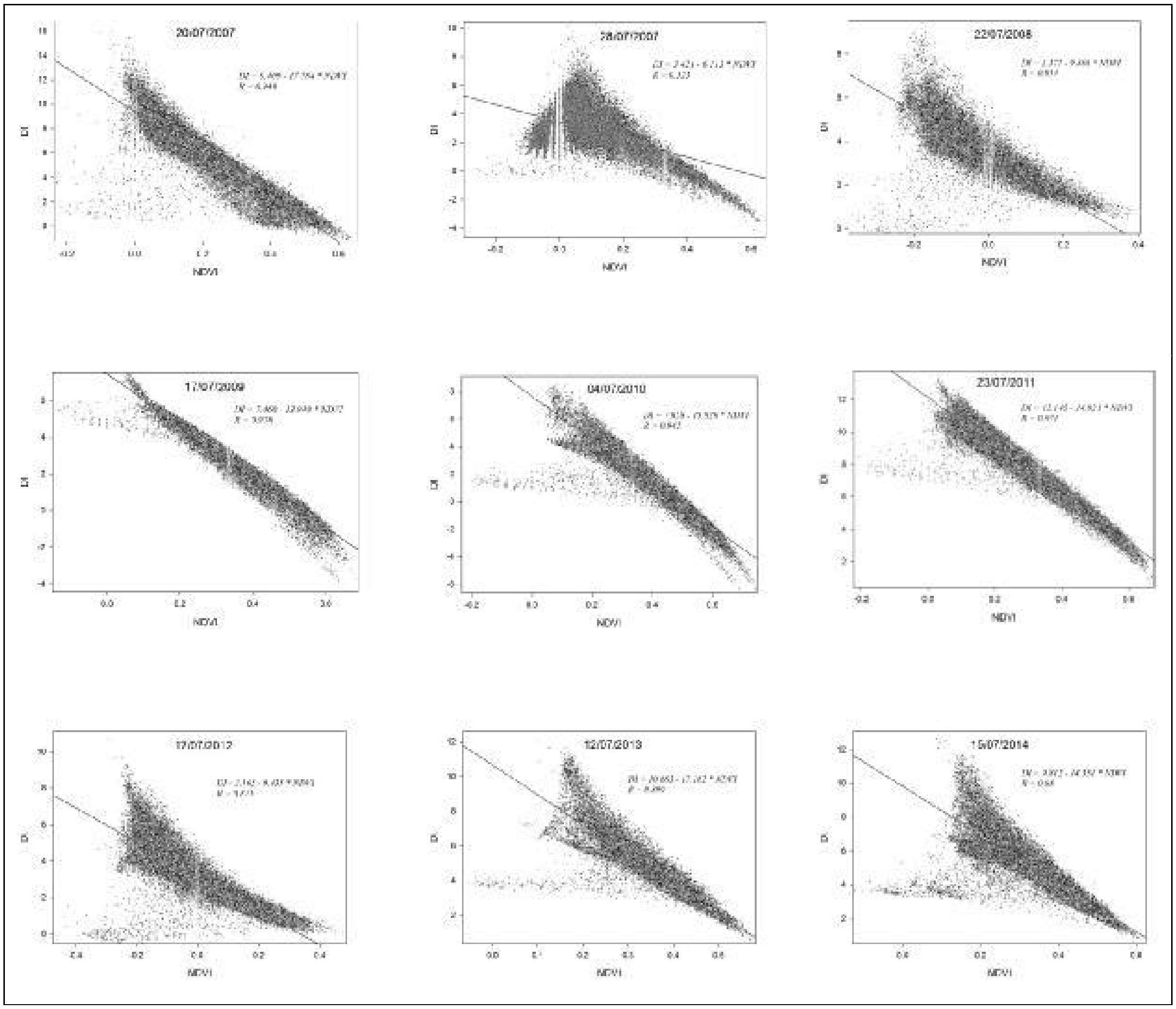

Fig. 5. 2-D Scatter diagrams of DI and NDVI

REFERENCES

1. 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.

2. Healey S.P., Cohen W.B., Yang Z.Q., Krankina O.N. (2005) - *Comparison of Tasseled Cap-based Landsat data structures for use in forest disturbance detection*. Remote Sensing of Environment, 97: 301-310. doi: http://dx.doi.org/10.1016/j.rse.2005.05.009.

3. Crist E.P., Cicone R.C. (1984) - *A physically-based transformation of Thematic Mapper data-the TM Tasseled Cap*. IEEE Transactions on Geoscience and Remote Sensing, 22: 256-263. doi: http://dx.doi.org/10.1109/TGRS.1984.350619.

4. Kauth R.J., Thomas G.S. (1976) - *The Tasseled Cap – a graphic description of the spectral – temporal development of agricultural crops as seen by Landsat*. Proceedings second ann. symp. machine processing of remotely sensed data. West Lafayette' Purdue University Lab. App. Remote Sensing.

5. Crist E.P., Kauth R.J. (1986) - *The tasseled cap de-mystified*, Photogrammetric Engineering & Remote Sensing, 52: 81-86.

6. Lillesand T.M., Kiefer R.W. (1987) - Remote Sensing and Image Interpretation. Wiley, New York, 1987.

7. Stankova N., Nedkov R (2015) - *Investigation of forest vegetation dynamics before and after a fire by using aerospace data*. Ecological Engineering and Environment Protection, No 1/2015, p.p. 40-46, ISSN 1311 – 8668.

8. 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.

9. Habitats Directive, 92/43/EEC

10. Birds Directive, 2009/147/EC

11. Bondev I., *The vegetation of Bulgaria*, Kliment Ohridski University Press, Sofia, 1991.

12. 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

13. 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

14. Chen W., Moriya K., Sakai T., Koyama L. and Cao C. (2014) - *Monitoring of post-fire forest recovery under different restoration modes based on time series Landsat data.* European Journal of Remote Sensing, 47: 153-168. doi: http://dx.doi.org/10.5721/EuJRS20144710.

МОДЕЛ ЗА ИЗСЛЕДВАНЕ НА ПРОЦЕСИТЕ НА ВЪЗСТАНОВЯВАНЕ НА ЕКОСИСТЕМА СЛЕД ПОЖАР НА БАЗАТА НА СПЪТНИКОВИ И GPS ДАННИ

Наталия Станкова, Румен Недков

Резюме: Целта на настоящата работа е изследване на възстановителните процеси, протичащи в екосистема след пожар. Изследваната територия се намира в югоизточна България, област Хасково, където през лятото на 2007г. избухва значителен пожар. За постигане целта на изследването са използвани спътникови изображения от Landsat 5 TM, Landsat 7 ETM+ и Landsat 8 OLI . Разработеният модел е изграден на базата на три основни компонента - Disturbance Index (DI), вектор на моментното състояние (VIC) и посочен ъгъл (DA). Използвано е Tasseled Cap преобразуване (TCT) и като входни данни за модела са генерирани трите основни Tasseled Cap компонента. Генериран е Normalized Difference Vegetation Index (NDVI) и е изчислен корелационният коефициент между DI и NDVI. Предложеният модел е валидиран на базата на аерофото изображения с висока пространствена разделителна способност на територията на пожара.

Ключови думи: дистанционни изследвания, възстановяване след пожар, TCT, DI, VIC

Наталия Станкова, Румен Недков

Институт за Космически Изследвания и Технологии – Българска Академия на Науките
ул. Георги Бончев, бл. 1, София 1113, България
e-mail: natalia_hs@space.bas.bg

Nataliya Stankova, Roumen Nedkov

Space Research and Technology Institute – Bulgarian Academy of Sciences
Acad. Georgi Bonchev Str., Bl. 1, Sofia 1113, Bulgaria
e-mail: natalia_hs@space.bas.bg