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Application of Tasseled Cap Transformation of Sentinel-2—MSI Data for Forest Monitoring and Change Detection on Territory of Natural Park "BLUE STONES" †

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Abstract: The goal of the present research is to monitor the forest vegetation's condition and detect the changes that occurred in the territorial disturbance of the forest cover in the area of Natural Park "Blue Stones", located in Bulgaria, by the use of a combinative approach of Remote Sensing's methods. Tasseled Cap Orthogonal Transformation is applied to the selected satellite images, resulting in three segmented TCT components: *"brightness"*, *"greenness"* and *"wetness"*. On the basis of the *"greenness"* component from different temporal points (satellite scenes), the Normalized Differential Greenness Index has been calculated, which gives accurate and precise data on the dynamics of forest vegetation for short-term and long-term time periods.

Keywords: forest monitoring; Sentinel-2; Tasseled Cap Transformation; *greenness*; NDGI

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1. Introduction

The Natural Park "Blue Stones" is situated in the Balkans, in the southeastern part of Bulgaria, above the town of Sliven, over an area of 11,380 ha (Figure 1). The specific climate and lay conditions of the park determine the great diversity of flora and fauna. The territory of the park is covered with mono-dominant and mixed broadleaf forests (9000 ha), and 600 ha are covered with conifers [1]. It was created in 1980 as a national park to preserve and protect the forest formations of the species *Fagus sylvatica* ssp. *moesiaca* and *Fagus orientalis*. Other forest formations in the park are presented by species of: *Qvercus sessiliflora*, *Carpinus betulus*, *Qvercus cerris*, *Qvercus conferta*, *Acer pseudoplatanus*, *Carpinus orientalis* and *Tilia tomentosa* [1].

The aim of the following study is to identify the advantages of the proposed TCT model for segmenting Sentinel-2 imagery [2], which is used to identify the needs of forest vegetation monitoring and to detect the changes in the spatial disturbance of forest cover. Short-term and long-term temporal periods, when the forest vegetation's phenophase is most active (from April to August), were chosen as a different time frame suitable for the application of NDGI and to analyze its quantitative values.

The Tasseled Cap Transformation (TCT), first developed by Kauth and Thomas, was initially applied as a data compression and visualization tool from the Landsat-1 Multispectral Scanner (MSS) to extract information about the features and characteristics of agricultural lands [3]. Kauth and Thomas envisioned the creation of TCT by comparing the phenological characteristics of vegetation from a given image with the overall structure and shape of the reflectance data represented in a multidimensional spectral space [3]. The main advantage of TCT is its ability to visualize multi- and hyperspectral data from satellite imagery in a condensed and meaningfully defined feature space [4]. TCT can also be used as a vegetative index, which is an indicator for evaluating the "healthy" state of vegetation and for evaluating changes that have occurred on the Earth's surface [5,6].

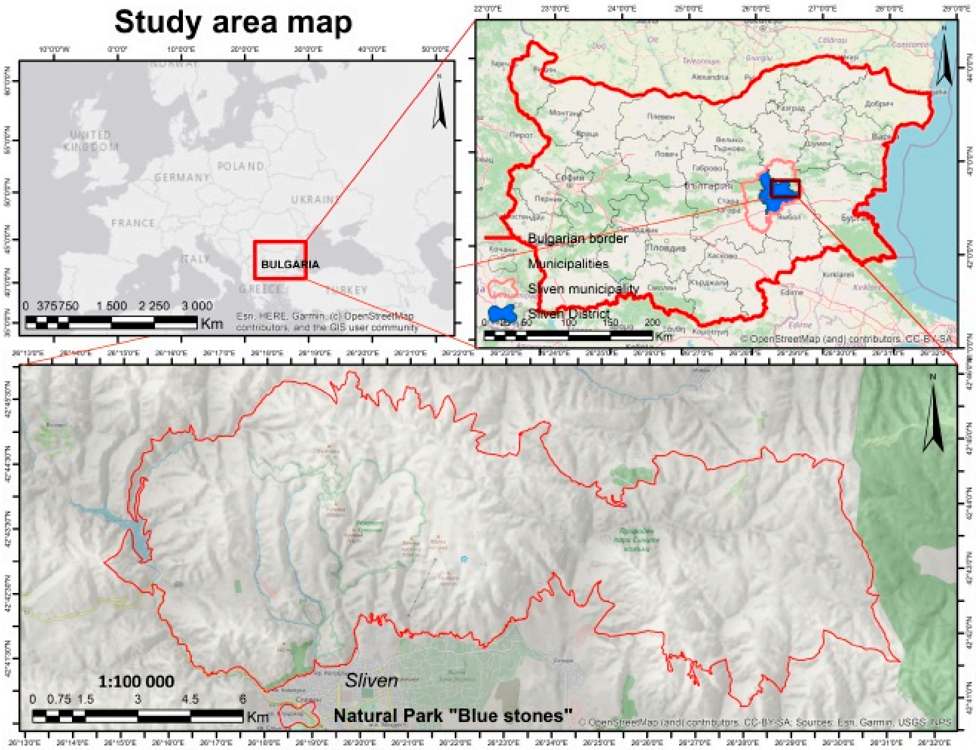


Figure 1. Study area map.

2. Materials and Methods

In the following research, imagery data from mission Sentinel 2-MSI of the European Space Agency (ESA) are used [7], including Multi Spectral Instrument (MSI) register data on the optical bands with variable spatial and spectral resolutions. For the MSI, the 13 spectral bands span from the visible (VIS) and the near-infrared (NIR) electromagnetic spectrum regions to the short-wave infrared (SWIR) one (Table 1).

Table 1. Satellite imagery used.

Satellite, Sensor	Date of Aquisition	Spectral Band	GSD (m)
Sentinel 2-MSI	10 June 2017 24 August 2017 31 May 2018 19 August 2018 25 April 2020 15 May 2020 28 August 2020 25 May 2021 08 August 2021	All spectral channels [7]	10×10 20×20 60×60

The proposed Tasseled Cap Transformation model for the orthogonalization of satellite images from Sentinel-2 has been proven as a highly effective method for the interpretation, classification, and analysis of phenomena and processes related to the dynamic changes of the main Earth surface's components: *soil*, *vegetation* and *water* [2,5]. The matrix of TCT for Sentinel 2 was developed and created by Roumen Nedkov [2]; it extracts the information contained in all 13 spectral channels of the MSI sensor, resulting in three clusters: *"brightness"*, *"greenness"* and *"wetness"*.

Normalized Differential Greenness Index (NDGI) (Equation (1)) was created on the basis of the *greenness* component, derived through decomposing optical satellite images by the applied orthogonal TCT matrix [8]. NDGI reflects the vegetation's change in dynamics, depending on the temporal period. The index has ranging values from −1 to +1, which correspond to the vegetation's negative and positive changes that have occurred [8].

$$\text{NDGI} = \frac{GR_n(t_2) - GR_n(t_1)}{|GR_n(t_2)| + |GR_n(t_1)|}, \tag{1}$$

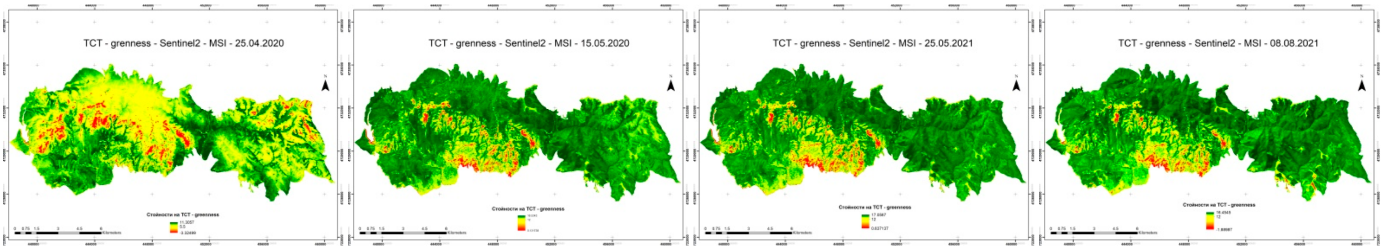
where GR_n (t_1) and GR_n (t_2) represent the normalized values of the *greenness* component at time points t_1 and t_2, and $|GR_n (t_1)|$ and $|GR_n (t_2)|$ represent the absolute values of the same components [8].

The most commonly used vegetation indices (e.g., NDVI) are not sufficiently sensitive to the minimal changes in the state of the vegetation that have occurred, which is most noticed in the studies on the restoration processes of forest ecosystems after a fire [9]. The three differentiated classes obtained as a result of the applied orthogonalization are highly sensitive to the minimal changes that occur in the requirements of the vegetation. When NDGI values are less than 0, it indicates that negative changes in vegetation condition have occurred. When they are above 0, there are positive changes, and the degree of changes corresponds to the obtained index values. Extreme values—NDGI = −1 reflect the complete degradation of vegetation, while NDGI = +1 indicates an intensive increase in leaf biomass or growth of vegetation. This indicates that the positive and negative values of the index represent a quantitative scale that can be used to assess the changes in vegetation that have occurred [8].

Based on the *greenness* component, of each selected time point, NDGI values were generated for short-term periods: between the "spring" and "summer" images for each of the years 2017, 2018, 2020 and 2021, including one super short-term period of 20 days (25.04.20–15.05.20) as a showcase "capturing" the leaf growth of forest vegetation in areas around 600–700 m a.s.l.; for long-term periods: between the "spring" and "summer" images for each of the years.

3. Results and Discussion

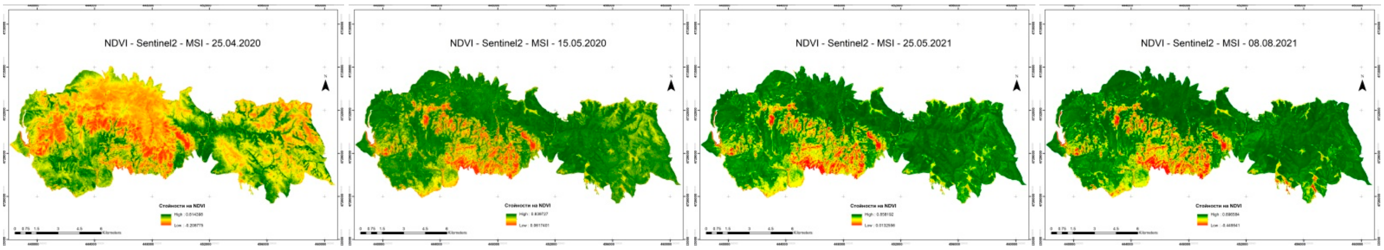
On Figure 2, maps with the *greenness* component of *spring* and *summer* temporal points, serving as input data for generating NDGI, are shown as a showcase for the years 2020 and 2021.



(**a**) (**b**) (**c**) (**d**)

Figure 2. Maps of the TCT–*greenness* component values from: (**a**) 25 April 2020; (**b**) 15 May 2020; (**c**) 25 May 2021; (**d**) 08 August 2021.

On Figure 3, maps with the NDVI values of the same temporal points from Figure 2 are shown, which serve as reference data for interpretation and as a base for comparative analysis between the values of the TCT–greenness component and those of NDVI. The TCT–greenness values show slightly more detailed information about the territorial distribution of vegetation compared to that of the NDVI values.

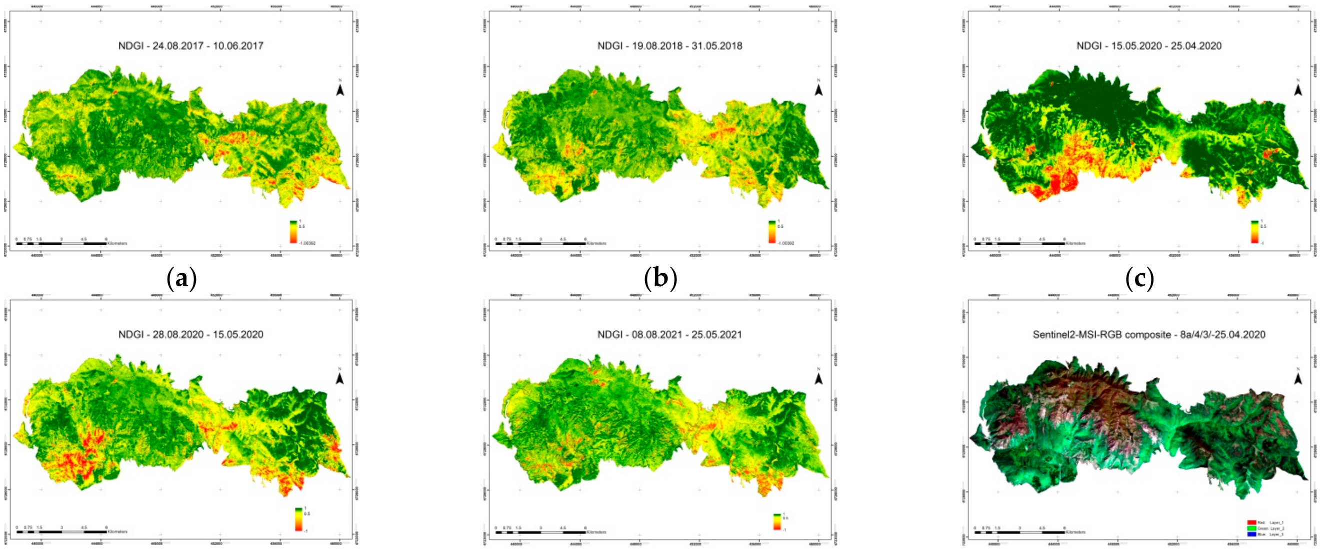


(**a**) (**b**) (**c**) (**d**)

Figure 3. Maps of NDVI values from: (**a**) 25 April 2020; (**b**)15 May 2020; (**c**) 25 May 2021; (**d**) 08 August 2021.

3.1. Short-Term Temporal Periods of NDGI

On Figure 4, maps with the spatial distribution of the NDGI values for short-term temporal periods are shown. The values of NDGI represent the spectral reflectance characteristics (SRC) of the vegetation recorded by the sensor, indicating the maximum and minimum changes that occurred. After a long comparative and visual analysis of the histograms (including those in the *visible* spectrum) and using the borderline between grassland and forests as a benchmark, an optimal threshold of 0.5 was set in order with pixels with values above it to correspond with the areas covered by forest vegetation. This was also carried out for values of the TCT–*greenness* component. All pixels in green (NDGI > 0.5) represent areas of the Earth's surface where positive changes in forest vegetation status occurred during the period, and the new vegetation that developed during the given period (including vegetation on streams and river valleys, low bushes, etc.). Pixels in yellow (NDGI $\geq 0 \leq 0.5$) represent areas where minimal or no positive changes in vegetation status occurred during the period. Pixels in red (NDGI < 0) represent areas of the Earth's surface where negative changes in the state of vegetation have occurred (due to drought, logging, dried grass formations, etc.) or correspond to terrains occupied by rock formations, where vegetation is absent. Regarding the 20-day period case (Figure 4c), saturation of the green color is due to the defoliation of the forests in the high-altitude areas that occurred during the period.

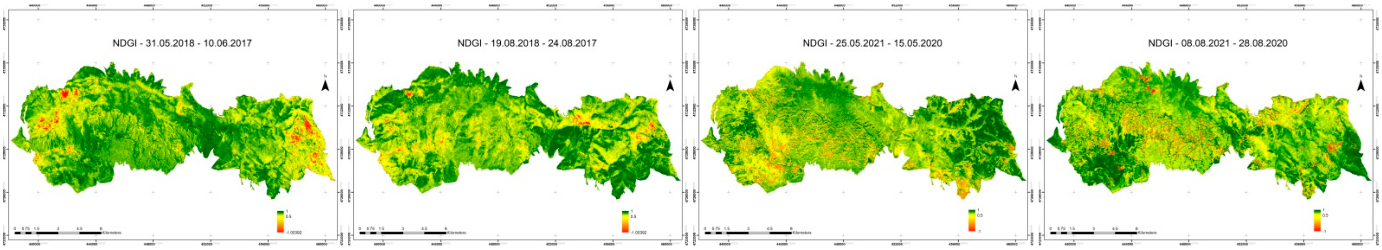


(**a**) (**b**) (**c**)
(**d**) (**e**) (**f**)

Figure 4. Maps with NDGI values for short-term periods: (**a**) 10 June 2017–24 August 2017; (**b**) 31 May 2018–19 August 2018; (**c**) 20-day period 25 April 2020–15 May 2020; (**d**) 15 May 20–28 August 20; (**e**) 25 May 21–8 August 21; (**f**) RGB composite in band combination 8a/4/3 from 25.04.20.

3.2. Long-Term Temporal Periods of NDGI

The used approach for monitoring vegetation is more suitable for studies whose time periods are short-term because it allows for the tracking of vegetation dynamics in very short time intervals. This approach can also be used to monitor the development of agricultural crops (with a shorter growing season), fires, droughts, soil moisture calculation, etc. [10–12]. However, the presented results in Figure 5, including the one-year periods, show what changes occurred in the current state of vegetation in comparison with that of the previous year.



(**a**) (**b**) (**c**) (**d**)

Figure 5. Maps with NDGI values for long-term periods (**a**) 10 June 2017–31 May 2018; (**b**) 24 August 2017–19 August 2018; (**c**) 15 May 2020–25 May 2021; (**d**) 28 August 2020–08 August 2021.

In Figure 6, the change detection map is shown—the green pixels show the restoration in the forest vegetation and in the forest road after legal logging occurred in 2014 for the period 2015–2021; the denser red lines are new forest roads, the red spot below the peak of Karaborun is a new logging site developed in 2020.

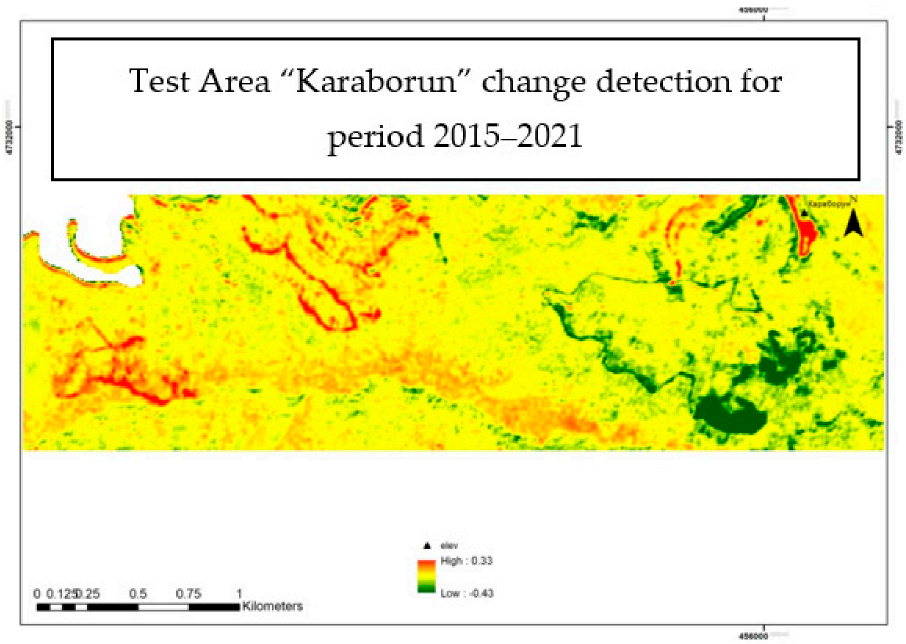


Figure 6. Map of change detection in forest vegetation for the period of 2015–2021.

4. Conclusions

The applied methodology for forest monitoring can be used for accurately and precisely determining the spatial distribution and quantitative assessment of the forest cover on the territory of the Natural Park "Blue Stones" for the selected temporal periods. The use of matrix for orthogonal transformation is another way of extracting and processing satellite imagery for the purpose of monitoring the Earth surface's main components: soil, vegetation and water. Setting the threshold of the NDGI values for masking-out the forest vegetation, and interpreting and validating the results, are still in the experimenting level, and in the future, they will still undergo development. The proposed forest-monitoring method can be integrated into forest management, forestry and forest resource inventory.

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