NDVI CHANGES AND THEIR RELATIONSHIPS WITH CLIMATIC PARAMETERS FOR THE SOUTH-EASTERN PART OF BULGARIA

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ABSTRACT - *The Normalized Difference Vegetation Index (NDVI) has been successfully used for vegetation dynamics monitoring and evaluating vegetation responses to climatic changes and natural disasters at different scales. NDVI sequences covering the south-eastern part of Bulgaria in relation to temperature and precipitation during the month of August for the time period of 2003 to 2015 have been collected and compared in order to assess the area and time period for a forest fire risk occurrence. The images from Landsat 5 (TM) and Landsat 8 (OLI) were used for the NDVI calculation. The datasets consisting of the monthly mean temperature and monthly precipitation data were collected for two regional stations. The studied area was affected by two forest fires in years 2008 and 2013, respectively. Negative NDVI trends were documented for this time period for both studied regions – Svilengrad and Haskovo - with coefficients equal to -0.025 and -0.038, respectively. A more pronounced decrease in the corresponding NDVI values were observed immediately after the forest fires that occurred in August 2008 and August 2013. The NDVI trends for this month exhibited significant correlations with the mean precipitation and weak or no correlation with the temperature recorded during the same periods. Different vegetation types showed distinct spatial responses to climatic changes.*

Keywords: *Normalized Difference Vegetation Index (NDVI), Forest fires, Landsat, South-eastern part of Bulgaria*

INTRODUCTION

Disturbances affecting large portions of forest ecosystems occur mainly in response to climate extremes. Changes in climate in the absence of extreme climate events (and the forest disturbances, which they may trigger) result in an increased forest productivity, but extreme climate events can potentially overturn such events [1]. Damage is already occurring, and threatening conditions are projected to increase. Forests are already experiencing climate-related impacts, such as drought, water stress, high temperatures, insect pests, and pathogens. Future disturbance in forests will mainly depend on changes in the frequency of extreme events as well as the underlying changes in average climate conditions [2], [3]. Of a particular concern is the potential for increased forest disturbance as the result of droughts accompanied with higher temperatures, which could cause both wildfires and trees´ death. According the European Forest Fire Information System [4], despite the climatic conditions in the Mediterranean, the Balkan region and North Africa, where very high-to-extreme fire danger levels and prolonged fire seasons have been recorded. The impact of climate change on the increasing duration of the fire season, the size of burnt area each year and the number of wildfires have been reported [5], [6], [7]. A warmer climate also leads to earlier snowmelt, which causes soils to be drier for longer periods of time. The higher temperatures increase evaporation means that the atmosphere draws more moisture from soils, thus making the land drier [8].

So far, the normalized difference vegetation index (NDVI) has been widely used for assessing the net primary productivity of vegetation (NPP) [9], and to improve predictions and impact assessments related to disturbances, such as droughts [10], floods [11] and forest fires [12], [13].

The relationships between the NDVI and climatic factors have been explored at local and regional scales worldwide [14], [15], [16]. However, the mechanisms of the vegetative response to climate change are uncertain, and the results from previous studies have varied due to different vegetation characteristics, regions, and study methods [17], [18], [19], [20] reported that vegetation coverage in the arid, western regions of north-eastern Asia exhibits a strongly positive correlation with precipitation, while spatial changes in the NDVI, which are influenced by temperature in the region, are less pronounced. A study on variability of NDVI over semiarid Botswana during the period 1982-1987 demonstrated a linear relationship between precipitation and NDVI when precipitation was about 500 mm/yr or 50-100 mm/month [21]. Similar results were also found by [22] who examined the temporal responses of NDVI to precipitation and temperature in the central Great Plains, Kansas, USA and concluded that the relationship between precipitation and NDVI was strong and predictable when viewed at the appropriate spatial scale. The Normalized Difference Vegetation Index (NDVI) has been successfully used for vegetation dynamics, monitoring and evaluating vegetation responses to forest fires for some territories of Bulgaria [23] [24] and to a lesser extent to climatic parameters at different scales [25]. It is also known that the fire occurrences and propagation are strongly related to particular meteorological conditions such as the solar radiation, air temperature, relative humidity, precipitation, wind (its speed and direction) and vertical structure of the atmosphere [26]. The forest fires occur and spread more quickly in hot and dry summer months with long rainless periods [27], [28], [29]. Therefore, the current study aims at exploring the long-term changes (2003 to 2015) of the NDVI sequences covering the south-eastern part of Bulgaria in relation to temperature and precipitation during the month of August in order to assess the vulnerable area and time period for a forest fire risk occurrence.

MATERIALS AND METHODS

The study region covers the terrestrial surface of the south-east part of Bulgaria, Haskovo and Svilengrad region, where a significant fire took place during summer periods from 2003 to 2015 [30], [31], [32], [33] (Fig. 1). Object 1 was representative for fire affected area in Mineralni bani Municipality region. The main tree species is Austrian pine (*Pinus nigra* Arn.). Within Svilengrad Municipality region, the studied area is located in southern part of Sakar Mountain. Object 2 is representative for mixed coppice stand with dominant Downy oak (*Quercus pubescens* Willd.) tree species. In Object 3, the main tree species, affected by fire was Scots pine plantation (*Pinus sylvestris* L.) The climate- and vegetation-related variables, are registered using the WGS 1984 geographic coordinate system.

The region is characterized with moderate continental climate with a Mediterranean influence (higher annual average temperatures and hot dry summers), thus the area is prone to forest fires. In the recent years the number of fires and the territory destroyed by fires have reached critical levels for forestry in Bulgaria [30]. Landsat TM images were used as the criteria in determining the fire risk period and fire affected territories [33], [34].

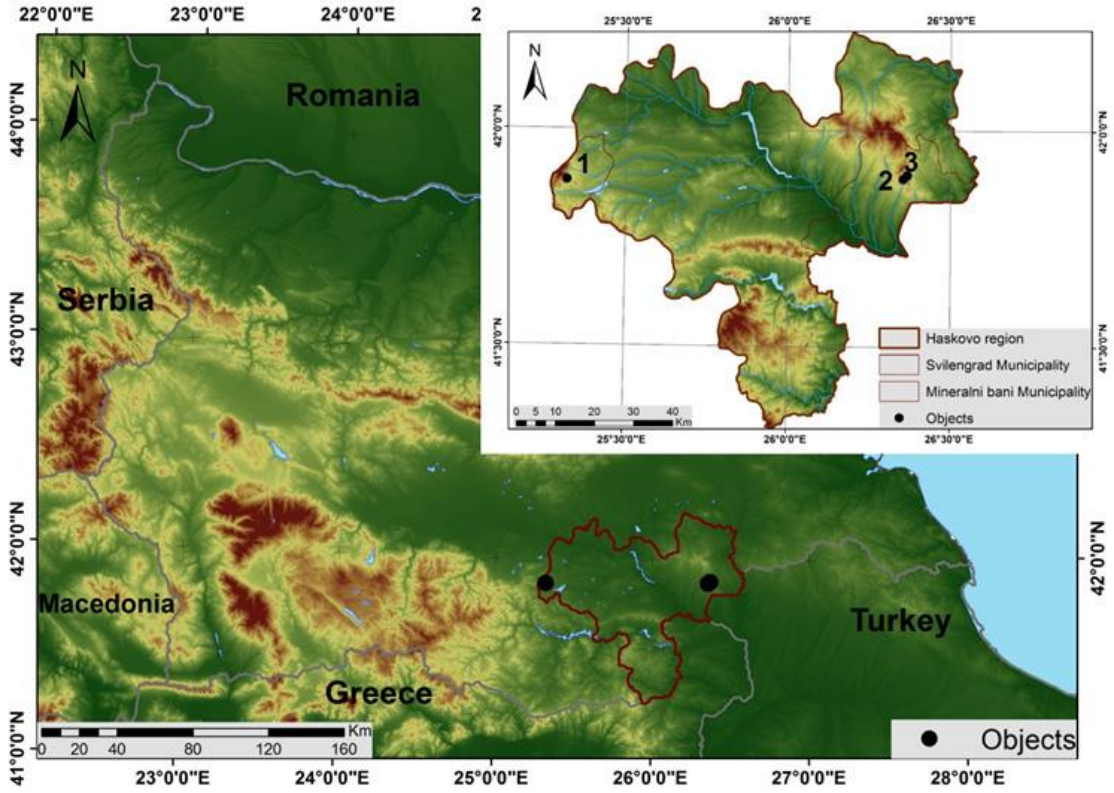

Fig. 1. Location of the studied area: Object 1 – Haskovo region; Object 2 and Object 3 – Svilengrad Municipality region.

The images from Landsat 5 (TM), Landsat 7 (ETM+) and Landsat 8 (OLI) was used for the NDVI calculation for the time period of 2003 to 2015. Then the burnt area was extracted and NDVI was calculated according equation 1.

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

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

Additionally, the datasets consisting of monthly mean temperature and monthly precipitation for month of August were collected for two regional stations, covering studied territory for the same period (2003 to 2015) in order to assess the area and time period for forest fire risk occurrence. The studied area is frequently affected by forest fires, but the biggest affecting large territories were - in year 2007 and year 2013, respectively. Detail data for climatic elements – air temperature and precipitation for summer period of years 2008 and 2013 were also used for depicting the environmental conditions before and after forest fire event. The affected areas were representative of the main tree-covered ecosystems in South-eastern part of Bulgaria so that the results could be extrapolated in the future to other fires in the region.

RESULTS

A set of Landsat images with different spectral bands and 30 m spatial resolution, for areas with forest vegetation are presented in Table 1. For Haskovo region, the values of NDVI vary from +0.307 (±0.049) to + 0.551 (±0.076). Lowest values were established for month August for period 2013 – 2015, when the forest fires events were registered [35], [36], [37].

Table 1

NDVI for forest vegetation from areas, affected by forest fire

Data of images	Data of fire occurrence	NDVI		
		Average ± SD	Minimal	Maximal
Haskovo				
18.08.2003	08.08.2013	+0.506±0.050	+0.365	+0.612
10.08.2006		+0.541±0.060	+0.288	+0.656
26.08.2006		+0.509±0.058	+0.359	+0.625
13.08.2007		+0.551±0.064	+0.339	+0.695
29.08.2007		+0.532±0.060	+0.393	+0.663
18.08.2009		+0.486±0.054	+0.350	+0.644
24.08.2011		+0.529±0.049	+0.368	+0.652
13.08.2013		+0.323±0.076	+0.068	+0.529
16.08.2014		+0.309±0.067	+0.163	+0.478
04.09.2015		+0.307±0.074	+0.174	+0.475
		min + 0.307 ±0.049		
		max + 0.551 ±0.076		
		average 0.459 ±0.061		
Svilengrad				
18.08.2003	23.08.2007 and 23.08.2013	+0.464±0.055	+0.262	+0.627
26.08.2006		+0.489±0.060	+0.287	+0.653
29.08.2007		+0.511±0.060	+0.266	+0.694
24.08.2008		+0.324±0.195	-0.106	+0.651
02.08.2009		+0.428±0.141	+0.067	+0.667
24.08.2011		+0.438±0.130	+0.124	+0.669
13.08.2013		+0.354±0.067	+0.187	+0.491
16.08.2014		+0.334±0.062	+0.138	+0.476
04.09.2015		+0.309±0.083	+0.121	+0.498
		min + 0.301 ±0.055		
		max + 0.511 ±0.195		
		Average 0.405 ±0.095		

The values of the NDVI for Svilengrad region are keeping the similar trend within the studied period (2003 – 2015) with minimum + 0.301 (±0.055) and max + 0.511 (±0.195). The lower value for average NDVI +0.405 (±0.095) in comparison with that for Haskovo region +0.459 (±0.061) are most probably duo to prevailing part of deciduous forests and shrub vegetation. On the other hand, the NDVI values, close to 0.4 are assumed to be a threshold, dividing well-functioning forest vegetation from sparse vegetation, grasslands, and bare soil [25], [38]. Disturbance of forests by fires during summer period of 2013 – 2015 were noted with lower, however positive average values of NDVI for the region at whole in comparison with

Table 2

Statistical analysis of NDVI for all types of vegetation from studded areas

Data of images	NDVI		
	Average ± SD	Minimal	Maximal
Haskovo			
18.08.2003	+0.406±0.138	+0.102	+0.612
10.08.2006	+0.455±0.126	+0.156	+0.655
26.08.2006	+0.418±0.130	+0.122	+0.625
13.08.2007	+0.450±0.145	+0.125	+0.694
29.08.2007	+0.444±0.126	+0.140	+0.662
18.08.2009	+0.413±0.107	+0.153	+0.643
24.08.2011	+0.452±0.112	+0.190	+0.652
13.08.2013	+0.269±0.099	+0.068	+0.529
16.08.2014	+0.305±0.057	+0.163	+0.478
04.09.2015	+0.289±0.069	+0.147	+0.475
	min + 0.269 ±0.057		
	max + 0.455 ±0.145		
	average 0.390 ±0.111		
Svilengrad			
18.08.2003	+0.275 ±0.126	-0.111	+0.627
26.08.2006	+0.287 ±0.134	-0.100	+0.653
29.08.2007	+0.307 ±0.136	-0.020	+0.693
24.08.2008	+0.201 ±0.151	-0.106	+0.651
02.08.2009	+0.341 ±0.106	-0.033	+0.666
24.08.2011	+0.301 ±0.127	+0.018	+0.669
13.08.2013	+0.273±0.077	+0.038	+0.491
16.08.2014	+0.305±0.048	+0.089	+0.485
04.09.2015	+0.250 ±0.068	+0.023	+0.498
	min + 0.201 ±0.048		
	max + 0.341 ±0.151		
	Average + 0.282 ±0.108		

The presented NDVI values for the whole vegetation (Table 2) vary from +0.282 ±0.108 for Svilengrad region to +0.390 (±0.111) for Haskovo region and exhibit lower average values in comparison with that for forest vegetation (Table 1). Vegetation type for Svilengrad region are presented mainly with deciduous forests, sparse shrubs and grassland, which reflects in higher degree visible light and in less degree near-infrared, resulting in NDVI values, ranging from 0.2 to 0.3 (moderate). Moreover, during the middle and the end of August, the changes in atmosphere and soil heat and the shortage of moisture reflect the vegetation conditions and dynamic and enhance their susceptibility to ignition and forest fires spread. This conditions are more strongly pronounced for Svilengrad region during studied time period (2003 – 2015), were the NDVI indexes are lower.

The trend of the climatic parameters and NDVI is decreasing for both studied regions and the model equation of straight line was established as best fitted (Table 3). This model explains about 60 % for Svilengrad (R^2 = 0.60) and 70% for Haskovo (R^2 = 0.71) of NDVI space variance for area, covered by forest vegetation. NDVI trend for all types vegetation, calculated for Haskovo region is keeping a decreasing trend (R^2 = 0.59). Based on the data mentioned, it could be hypothesised that forests disturbance under climatic elements and extreme events (flooding, forest fires, erosion),

and increasing the areas of sparse and grasslands vegetation, as the climatic parameters for Haskovo region from 2003 to 2015 show negligible downward trend. Calculated values for NDVI for all types of vegetation in Svilengrad region, show a similar trend within the time period (2003 – 2015). For this region we could suppose that there were no significant changes in forests and all types of vegetation.

Table 3. Trend of NDVI, air temperature and precipitation changes from 2003 to 2015

Region	Land use type	Parameters					
		NDVI		Temperature, °C		Precipitation, mm	
		Equation	R^2	Equation	R^2	Equation	R^2
Haskovo	Forest	y = -0.0381x + 0.6164	0.7121	y = -0.1429x + 25.229	0.2151	y = -2.2393x+19.7	0.1245
	all types	y = -0.0247x + 0.4909	0.5853				
Svilengrad	forest	y = -0.022x + 0.5145	0.5972	y = -0.1483x + 26.486	0.4580	y = -4.8183x + 43.1	0.4774
	All types	y = -0.0002x + 0.2834	0.0003				

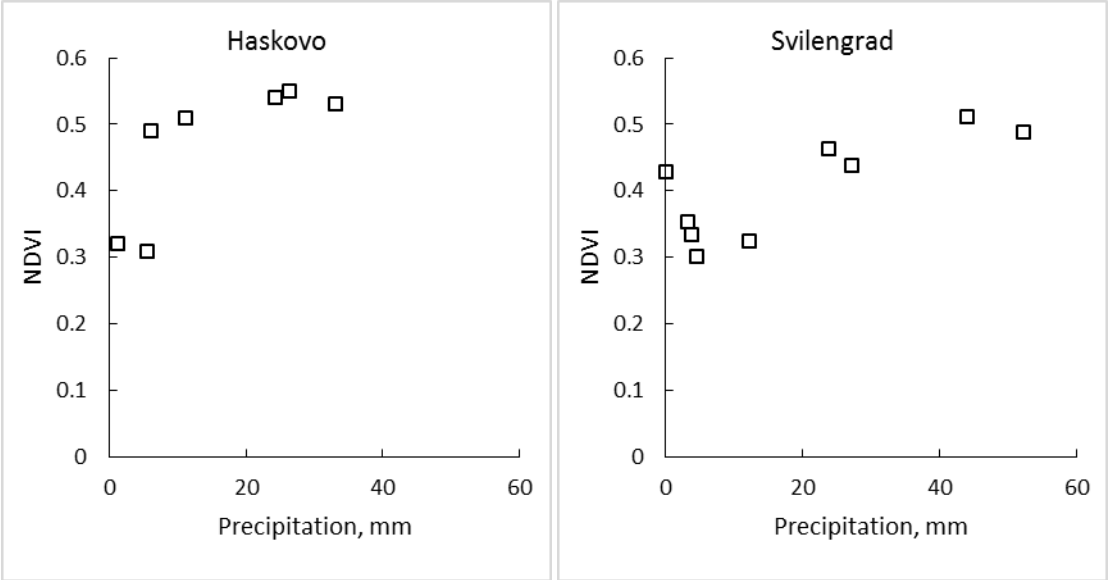

Fig. 2. Correlation model between NDVI of forest with monthly precipitation.

The results for the decreasing trend for temperature and precipitation show a high variability. Other studies also found high variability of spatial vegetation-climate relationship from one location to another duo to physical factors of the environment as vegetation type, soil type and land use [25], [39], [40].

The correlation between NDVI and the precipitations for the studied regions for monthly period (end of August) was modelled (Figure 2). In this model, **x** is the precipitation and **y** is post-fire data for NDVI for monthly period (end of August). The correlation coefficients between NDVI values and precipitation indicates positive correlation with $R^2 = 0.59$ for Haskovo and with $R^2 = 0.64$ for Svilengrad regions. The higher $R^2 = 0.64$ value for Svilengrad indicates that forests in this region are more sensitive to the variations in precipitation and drought periods. The regional severe drought periods have happened in recent decades and provoked conditions for field and forest fires rising and spreading [30], [35]. It was confirmed the inter-annual correlations of NDVI for forest

and grassland with rainfall [41]. They found that forest and grassland NDVI could increase by 0.003 and 0.002, respectively, if there is more 10 mm rainfall. Consequently, the correlation model between climatic index and NDVI could be used to simulate regional NDVI variations, predictions of the vegetation state and forest fires probability.

CONCLUSIONS

By applying NDVI and climatic data from 2003 to 2015, the time series of forests and all type of vegetation and correlation coefficients were developed for Haskovo and Svilengrad administrative regions.

The whole study area is characterized with a decreased trend for values of the climatic elements – monthly temperature and precipitation average for August for the periods from 2003 to 2015.

Negative NDVI trends for forest vegetation were documented for this time period for both studied regions – Svilengrad and Haskovo - with coefficients equal to -0.022 and -0.038, respectively. A more pronounced decrease in the NDVI values were observed immediately after the forest fires that occurred in August 2007 and August 2013.

The NDVI values for the whole vegetation vary from +0.282 (±0.108) for Svilengrad region to +0.390 (±0.111) for Haskovo region and exhibit lower average values in comparison with that for forest vegetation.

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