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Vegetation in Bulgaria according to data from satellite observations and NASA models

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Abstract. *Introduction.* The condition of the vegetation cover can be traced from Space. *Aim of the research.* To assess the condition of the vegetation cover in Bulgaria during the last twenty years – its distribution over the country, its change in connection with the typical climatic changes, its seasonal change. *Material and methods.* The vegetation index NDVI according to NASA data was used to analyze the condition of the vegetation cover in Bulgaria for the years 2000 - 2020. The methods used were: seasonal data decomposition, t-test, GIS methods for spatial representation of data, Fourier analysis. *Conclusions.* 1. During the summer months the vegetation in the eastern parts of the territory of Bulgaria is noticeably weaker than in the western parts. The influencing factors - drought and frequent fires are probably related to global warming. 2. For the territory of Bulgaria there is a seasonal rotation of the horizontal gradient of the vegetation index in a counterclockwise direction - from east to west in summer, from northeast to southwest in autumn and from north to south in winter. 3. There is a winter increase in vegetation for Northern Bulgaria and to the greatest extent for Northeastern Bulgaria, as well as for Southwestern Bulgaria. Together with the decreasing snow cover, the winter vegetation contributes to the drought in the eastern parts of the country.
Keywords: NASA, Terra, MODIS, NDVI, Bulgaria

Abbreviations

NASA	**N**ational **A**eronautics and **S**pace **A**dministration (USA)
NASA GES DISC	NASA Goddard Earth Sciences Data and Information Services Center
GIOVANNI	**G**ES DISC **I**nteractive **O**n-line **V**isualization and **AN**alysis **I**nfrastructure
MODIS	**MOD**erate Resolution **I**maging **S**pectroradiometer aboard the Terra and Aqua satellites
NDVI	**N**ormalized **D**ifference **V**egetation **I**ndex

1. Introduction

Dynamic climate change in the last decades requires measures to adapt the national economy to climate change [1]. An important stage in the adequate response to the challenges posed by climate change is scientific research, in particular the agro-climatic study of soil moisture. Soil moisture is a resource of paramount importance for non-irrigated agriculture in Bulgaria, susceptible to climate change. Both long-term planning and operational decisions on irrigation measures depend on its change during the

year and over the years. In this regard, a large-scale agro-climatic study is being conducted, uniting the efforts of scientists from tree Bulgarian scientific organizations - the Agricultural University – Plovdiv, the National Institute of Meteorology and Hydrology (NIMH), Sofia and the Faculty of Agriculture of the Trakia University – Stara Zagora. The study is funded by the national scientific program "Improvement of irrigation systems in accordance with climate change in Bulgaria", with a period of implementation June 2019 - May 2021.

One of the factors influencing soil moisture is the vegetation cover on the earth's surface. Vegetation changes soil moisture – on the one hand by shading the soil reduces soil heat and as a consequence evaporation, prevents the runoff of surface water thus stabilizing the moisture content in the soil, but on the other hand through transpiration draws soil moisture. The condition of the vegetation cover is an indicator of the conditions for the development of the vegetation, in particular of the cultivated vegetation. This condition can be traced by tracing the vegetation on the territory of the country.

2. Aim of the research

To assess the condition of the vegetation cover in Bulgaria during the last twenty years by tracing the vegetation – its distribution over the country, its change in connection with the contemporary climatic changes, its seasonal change.

3. Material and methods

3.1. Vegetation index

Photosynthesis uses solar radiation as an energy source, absorbing its energy in two main bands (regions) of the electromagnetic spectrum – with wavelengths of about 480 nm and about 620 nm. The radiation from these areas (light) appears blue and red, respectively, when is accepted in the human eye. Part of the solar radiation that falls on the photosynthesizing vegetation cover is reflected back up to the atmosphere and space. This part has a reduced energy in the above mentioned bands compared to the reflected radiation from a non-vegetating surface. The reflected radiation in spectral regions other than those mentioned above is not affected by photosynthesis.

This specificity of the reflection of solar radiation from the earth's surface in the presence of photosynthesis makes it possible to introduce a quantitative characteristic of vegetation based on the energy absorbed by photosynthesis. The more intense the photosynthesis, i.e. the illuminated surface vegetates actively, the less the reflected radiation in the above mentioned spectral bands.

One of the characteristics of vegetation on a certain area of the Earth's surface is the vegetation index in the form of a normalized difference in the reflected radiation in two spectral bands – one is the above-mentioned "red" region of the spectrum (600 - 700 nm) and the other is invisible for the human eye near infrared region (700 - 1100 nm) [2, 3].

The choice of these bands in the spectrum takes into account the possibility of both being measured by a device (radiometer) mounted on a satellite passing over the measuring point. The "red" band is preferred to the "blue" band because of the less scattering in the atmosphere of the reflected light with a longer wavelength.

For the purposes of the study, data obtained by measuring with a radiometer mounted on a Terra satellite were used. The Terra satellite orbits the Earth in a helio-synchronous polar orbit (passes over the two geographic poles, orbiting the Earth for 24 hours) at an altitude of 705 km, passing from north to south across the equator in the morning. The MODIS radiometer mounted on the satellite board measures the reflected radiation from the Earth's surface in a strip below the satellite during the day. In the nadir direction (in the direction below the satellite, perpendicular to the Earth's surface), the strip is 1 km wide for the NDVI measurement. The entire Earth's surface is covered by the measurement for no more than 2 days. Terra MODIS measures in 36 spectral bands, covering the spectral range from 400 nm to 1440 nm, with a radiometric sensitivity of 12 bits (distinguishes 4096 degrees of brightness of the reflected radiation).

The vegetation index is calculated [3] as a ratio of identical quantities, i.e. the index is dimensionless, there is no unit of measurement. The numerator of this ratio is the difference between the radiation reflected perpendicular to the Earth's surface in the near-infrared region R_{NIR} and the radiation reflected perpendicular to the Earth's surface in the red band R_{RED}. The denominator of the mentioned relation is the sum of these reflected radiations, i.e.

$$NDVI = (R_{NIR} - R_{RED})/(R_{NIR} + R_{RED}) \ .$$

3.2. Source of information
The source of NDVI information is NASA. Through the GIOVANNI [4] interface, NASA offers free access to time series of data collected through direct satellite measurements (currently time series for 578 parameters are accessible) and processed data in the form of models (782 parameters). NASA uses the International System of Units (SI). NDVI data were calculated for granules with a size of 5600 m (0.05 angular degrees). "Granule" (according to NASA terminology) is the smallest area with the same value of the parameter, in this case NDVI. Data is available from the launch of the Terra satellite (February 18, 2000) to the present. Monthly NDVI data were extracted. For the extracted data for NDVI, the option was selected in GIOVANNI to be time series, averaged by area too.

For the purposes of the study, the territory of Bulgaria was covered with six squares of the same size with a side of 170 km (regions), for each of which separate data were obtained through GIOVANNI (figure 1). In geographical degrees, the dimensions of the regions are respectively: 2.124° longitude and 1.5161° latitude.

The used below names for these 6 regions are:

| 1. North-West region |
| 2. North-Central region |
| 3. North-East region |
| 4. South-East region |
| 5. South-Central region |
| 6. South-West region |

From the above sizes of the granule it can be calculated that in each of the 6 regions fall 920 granules, i.e. GIOVANNI calculates the NDVI for each of the 6 regions as the average of the NDVI values for the granules in the region.

The data obtained from the GIOVANNI interface were subjected to further processing. MS Excel was used for this purpose. After unpacking each of the received files, with a software program developed for this purpose, the data were grouped by seasons: Winter (December, January and February), Spring (March, April and May), Summer (June, July and August), Autumn (September, October and November) and the variation of NDVI was studied separately for each season - region combination. The program was developed with the built-in MS Excel programming language (Visual Basic for Applications).

The distribution of NDVI on the territory of the country was presented graphically. The background of the graphs are satellite images of Bulgaria from Google Earth, georeferenced for the World Geodetic System 1984 via Georeferencer Plugin of QGIS 3.6. Background isolines were plotted using Surfer 10 [5], the minimum curvature interpolation method was used, and the input data for Surfer 10 were the mean NDVI values in the 6 regions.
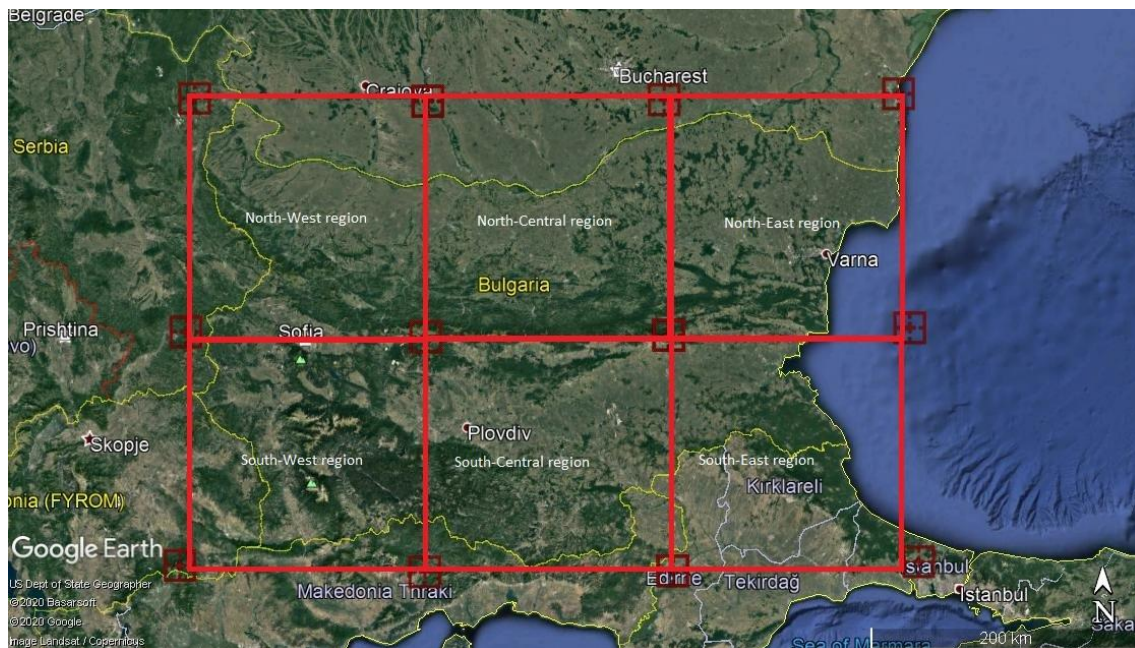
Figure 1. For the purposes of the study, the area of the country was divided into regions. Marine areas are excluded from NDVI data in the eastern regions.

For each combination between season and region, a t-test [MS Excel] was used to test the hypothesis of no change of NDVI values in two sub-intervals of the study interval years, namely 2000 - 2010 and 2011 - 2020. Statistically significant new information is obtained in cases where this hypothesis is rejected, i.e. when is satisfactory low the probability (significance level) that the mean NDVI values for the two subintervals are the same. The lower the level of significance, the more reliably the rejection of the hypothesis of equality between the two means is proved. The criterion for rejecting this hypothesis was the mentioned probability to be less than 5% (significance level 0.05). In the cases when the mentioned hypothesis was rejected, a change was found - increase or decrease of NDVI during the studied interval of years.

For one of the regions with a proven statistically significant change in NDVI – the Northeast, it was assumed that the factors causing the change are cyclical in nature. To identify the factors most strongly influencing the change in NDVI, a Fourier analysis [6] was applied to the NDVI data for the Northeast region in January 2000–2010. Fourier analysis interpreted a number of experimental data as values of linear dependence between NDVI as a dependent variable and a set of cyclic functions with different cycle periods as independent variables characterizing the possible cyclic influencing factors. The largest coefficients (periodograms) in this linear relationship had the functions characterizing the factors with the greatest influence on NDVI.

4. Results and discussion

Figure 2 shows the distribution of NDVI for Bulgaria by regions and seasons, averaged over the years of the survey from 2000 to 2020. As it is expected to be, the vegetation is most active in summer. It can be seen that the vegetation in the summer is markedly most active for the western parts of the country, less active for the central parts of Bulgaria and least active in its eastern parts. Among the probable reasons for this is the ratio between arable land and wild vegetation – in eastern regions wild vegetation has the smallest share, and arable land with cereals is already harvested in the middle of the summer (the photosynthesis is weak). Among the meteorological factors leading to reduced vegetation for the eastern parts of the country are the summer drought, typical for the eastern parts of the country, as well as the frequent summer forest fires, covering large areas, again related to the drought.
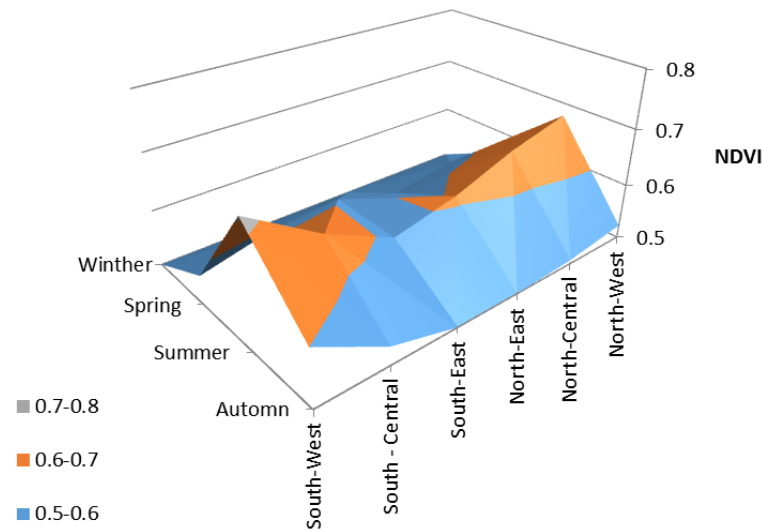
Figure 2. Vegetation index NDVI for Bulgaria, averaged over the area of the 6 regions, by seasons and during the interval 2000 - 2020 for which there are satellite observations (MODIS radiometer of the Terra satellite).

Figures 3, 4, 5 and 6 show the distributions of NDVI for Bulgaria by seasons for the studied interval years 2000 – 2020. There is a seasonal change in the distribution of NDVI in the country, as the horizontal gradient of change (the direction of increase of NDVI across the country) rotates counterclockwise – in spring the gradient is small, NDVI is relatively evenly distributed throughout the country, in summer the gradient is from east to west, in autumn it moves from northeast to southwest and in winter it is from north to south.
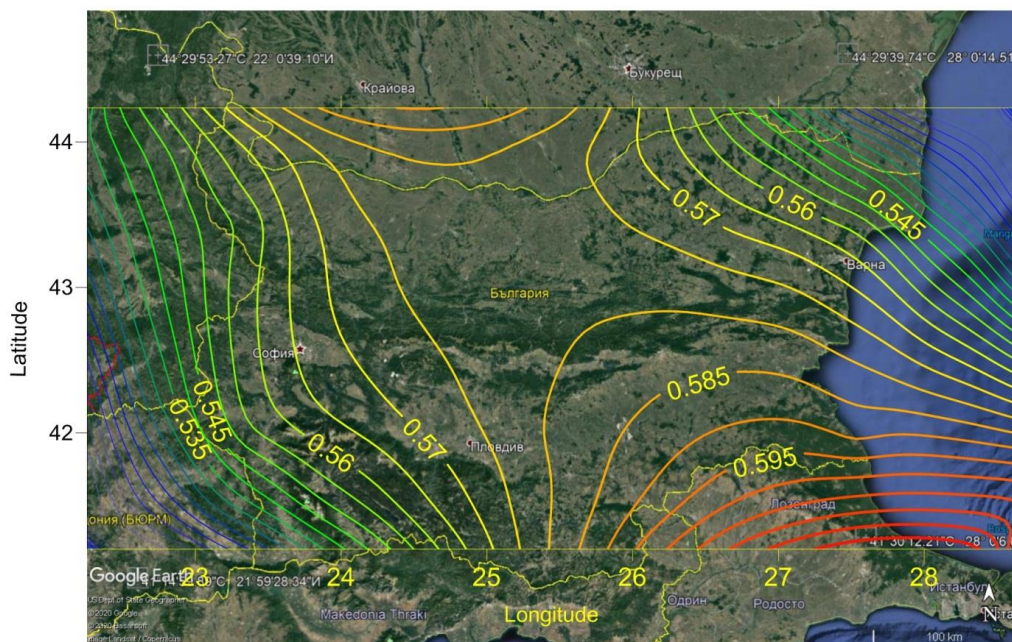

Figure 3. Distribution of NDVI for the territory of Bulgaria in the spring - average values for the interval 2000 - 2020. The vegetation is relatively evenly covering the territory of the country. A slight increase is observed in the Southeast region.
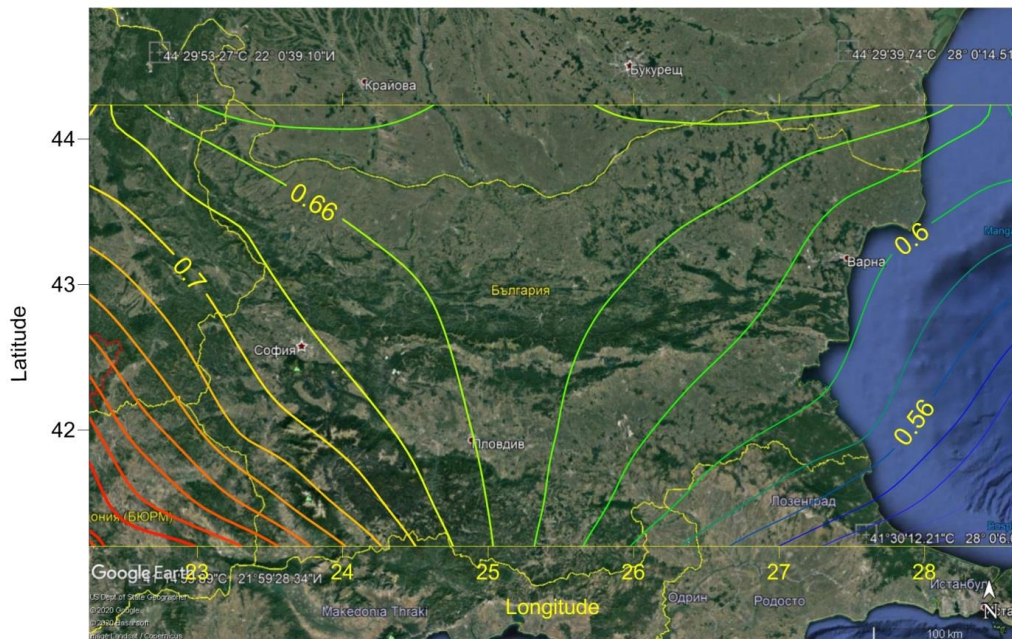
NDVI, Bulgaria, Summer

Figure 4. Distribution of NDVI for the territory of Bulgaria in the summer - average values for the interval 2000 – 2020. The vegetation increases from east to west on the territory of the country (horizontal gradient of NDVI from east to west).
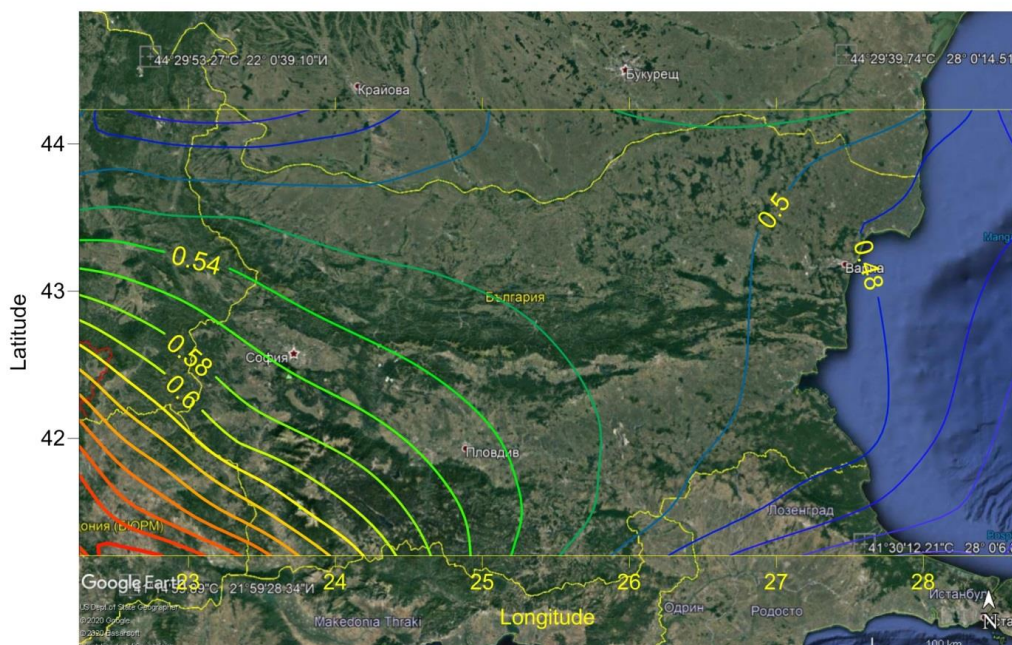
NDVI, Bulgaria, Automn

Figure 5. Distribution of NDVI for the territory of Bulgaria in the autumn - average values for the interval 2000 - 2020. In the autumn deepens the summer tendency for decrease of the vegetation from west to east on the territory of the country (the horizontal gradient of NDVI increases in size as compared to its summer values). It also changes its direction – the direction of the greatest decrease shifts from southwest to northeast.
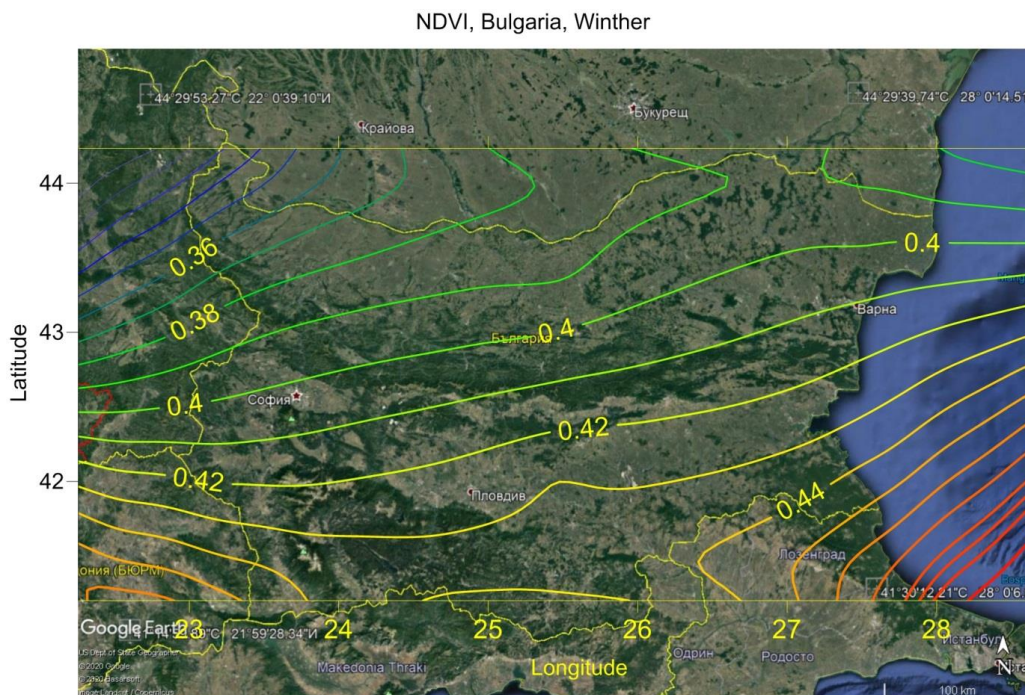
Figure 6. Distribution of NDVI for the territory of Bulgaria in winter - average values for the interval 2000 - 2020. In winter, the direction of increase of NDVI shifts from north to south (the gradient is small in value).

In the studied interval of years, increasing winter vegetation is observed in the northern regions and in the Southwestern region, probably related to the increasing winter temperatures and the decreasing snow cover as a result of global warming.
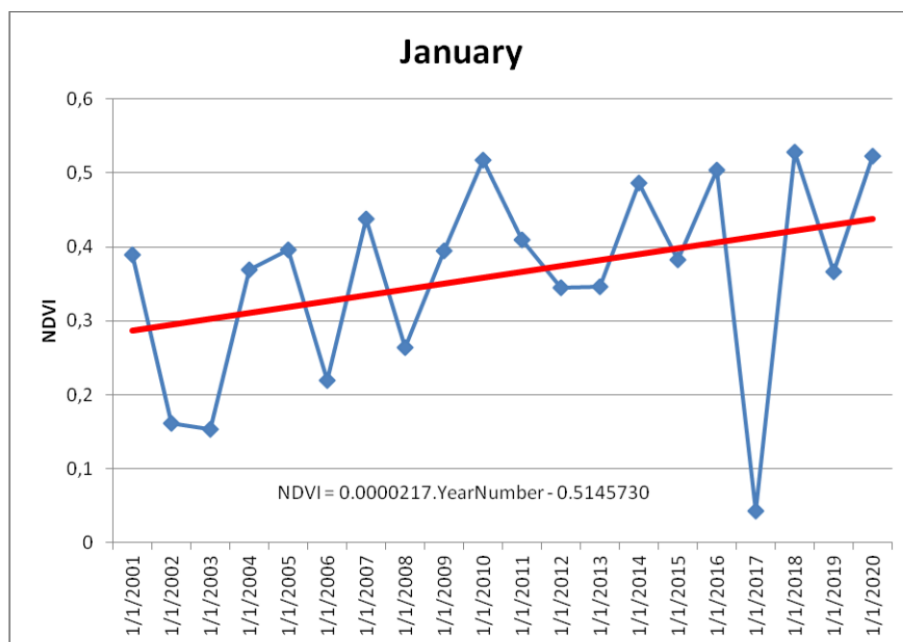

Figure 7. Growing linear trend of the January vegetation index (straight line) for the Northeast region, for which the winter increase of the vegetation index is most noticeable. In the linear trend function, the variable YearNumber is the date converted to a number by means of MS Excel NUMBERVALUE function. For example, 2001/01/01 has a value of 36892, 2002/01/01 is 37257, etc.

Figure 7 shows the change in January NDVI values in the Northeast region, where the increase in vegetation is most noticeable (points connected with a line). The figure also shows the linear trend (straight line) of change of NDVI, as well as the function of the linear trend. With its value, the angular coefficient in the function (in this case +0.0000217) shows the magnitude of NDVI change, and with its sign the direction of change – increase (with a sign +) or decrease (with a sign -).

Figure 8 shows the change of the angular coefficient in the linear trends by regions during the winter. For the northern regions and for the South-Western region, the difference in the winter vegetation index between the first and the second decade of the studied year interval is statistically significant for a significance level of 0.05 (t-test).
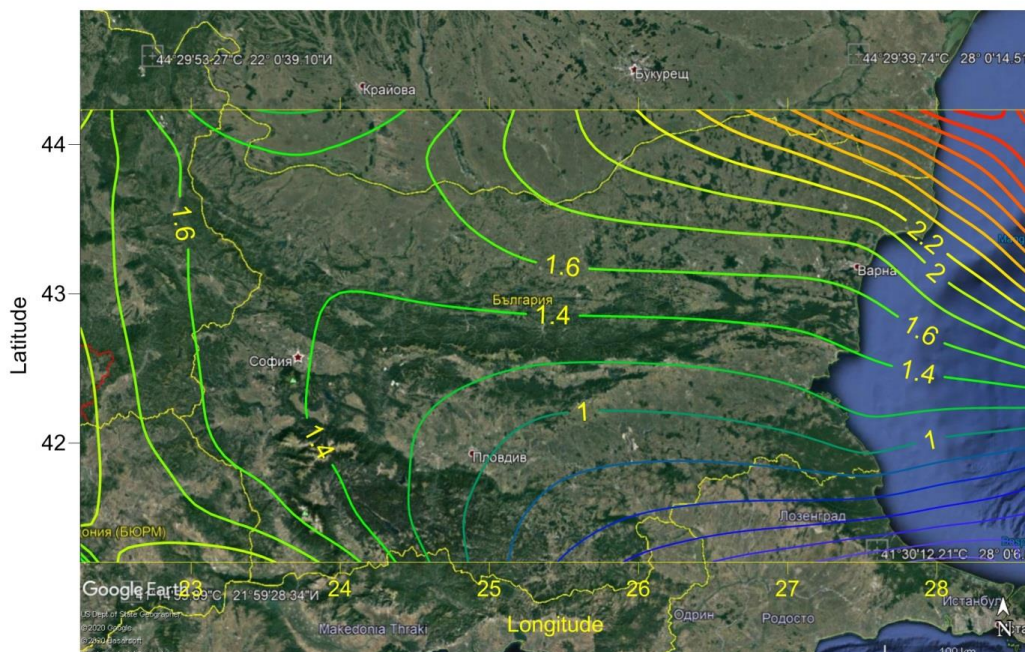

Figure 8. Distribution of the angular coefficients in the linear trends of NDVI by regions in winter. The values shown on the lines are the coefficients multiplied by 10^5. The winter increase of NDVI does not affect the southeastern parts of the country.

Figure 9 shows the distribution of the angular coefficient in the linear trends by regions and seasons. The increase of the winter vegetation is in the direction from west to east – it is most pronounced for the Northeast region.

The NDVI data shown in figure 7 can be interpreted via Fourier analysis as the result of a combination of 3 major cyclic factors of unknown nature, with periods of 2.2, 5 and 2.8 years, respectively.
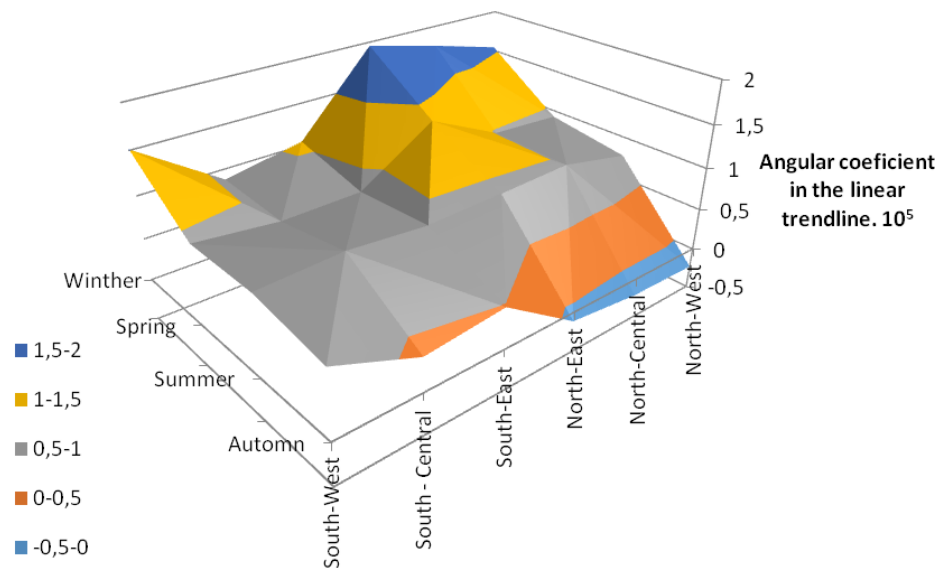
Figure 9. Angular coefficient in the linear trend of the dependence of NDVI on the time by regions for Bulgaria, by seasons and for the studied interval years 2000 - 2020. The winter vegetation is growing, especially in the Northeast region.

5. Conclusions

- During the summer months the vegetation in the eastern parts of Bulgaria is noticeably weaker than in the western parts, probably due to differences in the share of arable land, but also due to reasons related to global warming – drought and frequent fires.
- For the territory of the country there is a seasonal rotation of the horizontal gradient of the vegetation index in a counterclockwise direction – 1. A neutral position in spring, 2. From west to east in summer, 3. From northeast to southwest in autumn, 4. And finally from north to south in winter.
- There is a winter increase in vegetation for Northern Bulgaria and to the greatest extent for Northeastern Bulgaria, as well as for Southwestern Bulgaria. Together with the decreasing snow cover, the early winter vegetation contributes to the drought in the eastern parts of the country, but it also indicates, that the vegetation interval during the year increases, which can be used in agriculture.

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