4. Remote sensing data collection and analysis for vegetation monitoring since 2000 at various scales in Southeast Hungary and Vojvodina

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Introduction

Biomass (land cover) is a fundamental climate variable, therefore accurate and up-to-date information on the state of vegetation is needed, even at global level. As a climate indicator, it refers to short-term and trend-like changes, which could be evaluated applying remote sensing methodology (Ladányi et al. 2011b, Gulácsi and Kovács 2018, Szabó et al. 2019). Changing environmental conditions basically forecast decreasing biological productivity, therefore in environmental researches the key-question is whether the agriculture and forest management will be able to adapt to the constantly changing environmental conditions or not.

As multispectral vegetation monitoring has high temporal sampling resolution, it could support spatial planning by providing real-time data. The studied period between 2000 and 2018 was analysed based on pixel-scale processing of more than 450 images, and this amount of data is increasing with the involvement of current satellite images. Therefore, during data processing it was essential to utilise automation and big data methodology, which were carried out on the freely available Google Engine platform (Kumar and Mutanga 2019). The aim of the study is the spatial analysis of the relationship between drought and vegetation anomaly. The latest results are available on the interactive project website.

The study area is one of the most sensitive regions to climate change from the point of view of drought sensitivity of forest ecosystems. Here, the sustainable land use that can adapt to the climate is closely related to the preservation and state improvement of forest ecosystems (Mátyás et al. 2010). Land covered by woody vegetation can get water from soil layers located close to groundwater, therefore they are suitable for detecting long-lasting dry periods, while the herbaceous vegetation of pastures, meadows and arable land is sensitive to the short dry periods.

Our results are unique for the region, therefore they perfectly complement the spatial results of those European and national drought monitoring GIS systems that study the impacts of climate change at larger time and spatial scale (European Drought Observation, Drought Watch, TEMRE, NATéR).

We analysed the biomass production on agricultural lands based on high time resolution MODIS 250 m images utilising the LUCAS database. Plots where corn was grown were analysed for several years. We also summarise the opportunities of the application of eBee X fixed-wing drone in high spatial resolution vegetation monitoring by analysing its images.

Sampling area and methods

The biomass production for the whole study area was made using low resolution satellite images (Fig 4.1/a). In the last two centuries large areas were involved in agricultural production, thus the natural vegetation has remained only in small areas, e.g. loess and sandy grasslands, riparan forests in floodplains. Nowadays in the northern, Hungarian part of the study area forest plantations are common, while in Vojvodina agricultural land use dominates. There is no common and detailed spatial database for agricultural yields, therefore the analysis since 2000 was performed only for the relatively constant land cover categories: for various forest types, meadows and pastures, and wetlands (Fig4.1/b). The identification of land use categories was based on 1:100.000 Corine Land Cover database from 2018 (Fig 4.1/a). On the low resolution MODIS images the seasonal changes and deviations can be identified based on the homogeneous cells. Due to the sensitivity of remote sensing methods on surface heterogeneity, pixels with a homogeneous land cover had to be selected. Cells with 75% homogenous cover are used by the Hungarian forest monitoring (TEMRE), while Kovács (2018) applied cells with 66% homogenous cover, whereas Kern et al. (2017) used cells that have at least 90% homogenous cover. On the study area we filtered the MODIS cells with at least 50% cover of the given land cover category, therefore 6265 km^2 large area was studied in detail, which is 38% of the entire study area. After the filtering we analysed 37% of the meadows and pastures, 70% of the hilly forests, 40-40% of the lowland and floodplain forests, and 26% of wetlands based on CLC 2018. On the selected plots woody and herbaceous vegetation types were represented equally (50-50%); the majority of the forests belonging to the class of lowland forest (2130 km^2), while the hilly forest can be found in the smallest proportion (200 km^2).

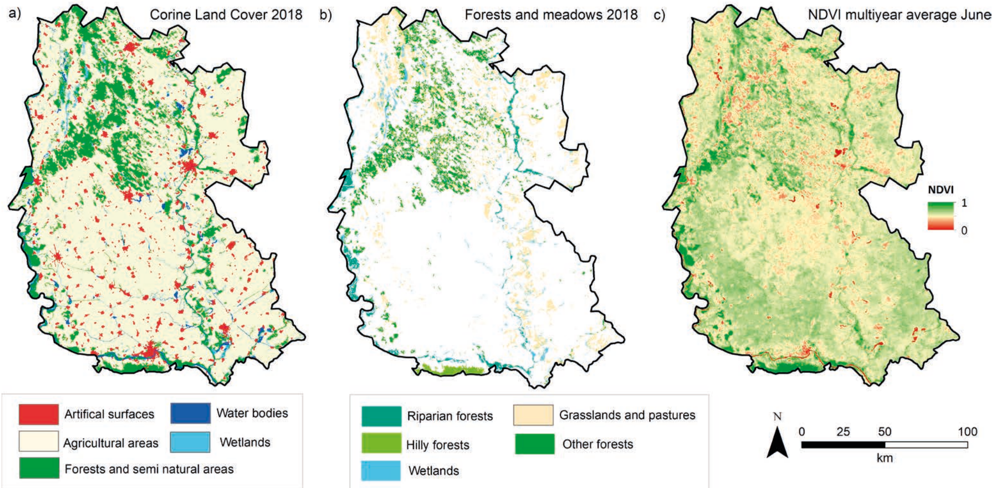


Figure 4.1. *Land cover based on Corine Land Cover (2018) (a); selected forest, meadow-pasture and wetland habitat polygons (b); and the average June (2000-2017) NDVI map of the study area (c)*

Application of spectral indices in drought monitoring

We had tested four generally used spectral indices: Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Water Index (NDWI), Normalized Difference Drought Index (NDDI). The freely accessible 500 m spatial resolution, 8 day MODIS MVC (Maximum Value Composite) couples the cell with the reflectance of the path presenting the highest NDVI; the $NDVI_{max}$ value of the 8-day-period will always be the most accurate geometrically. Indices calculated utilising the MVC processing offer better estimation than the daily data (Huete et al. 2002). The MOD09A1 images and MOD13A1.006 products were processed on the Google Earth Engine platform.

$$NDVI = (NIR - Red) / (NIR + Red)$$

$$EVI = G \cdot ((NIR - Red) / (NIR + C1 \cdot Red + C2 \cdot Blue + L))$$

$$NDWI = (NIR - SWIR) / (NIR + SWIR)$$

$$NDDI = (NDVI - NDWI) / (NDVI + NDWI)$$

where NIR: near infrared, SWIR: shortwave infrared, Red: red, Blue: blue are wavelength ranges; L=1; C1=6; C2=7.5; G=2

According to Kern et al. (2017) and Gulácsi and Kovács (2018), it is justified to use more indices at the same time because there is no perfect index. Their values range between -1 and +1. In the case of NDVI and EVI the higher the index value is, the greater the observed photosynthetic activity. In a biologically complex areas NDVI is suitable for assessing changes, but in areas with a large biomass it converges to saturation and this causes scaling problems. The EVI is more sensitive to high biomass production, it has a better defined peak, besides its narrower range is an advantage in offsetting 'saturation', thus it highlights the leaf loss and reduces the influences of the surface and the atmosphere. The majority of regional observations rely on MODIS EVI solutions (Huete et al. 2002, Solano et al. 2010).

The NDWI describes the humidity content of the foliage, if the moisture content decreases, the reflectance increases in the SWIR range. According to Szabó et al. (2016), the NDWI does not provide considerably extra value for NDVI-based assessment, but Jackson et al. (2004) and Gu et al. (2007) stated that the NDWI is better for estimating moisture content. The statistical relationship between the two indices validates the NDDI drought index that applies them. In case of drought these water indices decline more and faster than the vegetation index, thus the positive deviation of the NDDI indicates drought. The validation studies that were also performed on the study area revealed that the NDVI and the NDWI provide more realistic results considering at-a-site meteorological data, while other remote sensing data refer to the greater reliability of the EVI (Kern et al. 2017, Gulácsi and Kovács 2018, Kovács 2018).

In addition to analysing the multiyear average, it is the standardised anomaly that refers to the extent of exposition to hydrological extremities, which are strengthening based on the forecast of Mezősi et al. (2016). Based on the standardised anomaly the water shortage of the studied period can be identified, which reduces the biomass production or delays its teporal dynamics.

$$NDDI_{standardised} = (NDDI - NDDI_{average}) \,/\, NDDI_{deviation}$$

Usually the indices of plots covered by herbaceous vegetation are consistent with the occurrence of drought, however forests do not necessarily reflect the meteorological anomalies (Kern et al. 2017).

Analysing the vegetation condition on agricultural fields applying the LUCAS database

It is a difficulty in agricultural monitoring that spatial data are not available on various harvest results at a regional scale. To solve this problem, we applied the greatest spatial resolution (250 m) images of the high time resolution MODIS. We utilised the LUCAS database for assessing the biomass curve values that were provided based on the 16-day MVC EVI index for designated corn growing plots. This crop was selected, because corn is the most sensitive agricultural plant to droughts. Land use was recorded on photos taken at designated points on-site, as this database is updated in every 3 years.

We selected the points that indicate corn cultivation in the years 2006, 2009, 2012 and 2015. There was no other type of land use in the proximity of the selected points, therefore the vegetation index realistically reflects the conditions relevant for the corn. In the next phase we characterised spatially and temporally the biomass production curves of the points, according to the individual years and the main landscape types. According to the Pálfai drought index (PAI), from the four studied years the year of 2006 was rainy (PAI_{Szeged}=4.25), while others could be considered as drought years (2009 PAI_{Szeged}=8.26; 2012 PAI_{Szeged}=13.97; 2015 PAI_{Szeged}=10.10). The spatial analysis was performed for four different regions (Bácska, east of the Tisza River, Danube Plain and Danube-Tisza interfluve), thus the spatial diversity of the consequences of droughts could be analysed in differ geographic settings.

Opportunities of very high resolution vegetation monitoring

In the study we performed very high spatial resolution data collection too, as it is necessary in plot-scale vegetation monitoring. SenseFly eBee X fixed-wing drone was applied, which utilises S.O.D.A. sensor that acquires data in the visible spectrum and the Parrot Sequoia+ sensor that captures imagery in the infrared range. The applied 8-cm-resolution made detailed vegetation monitoring possible, in areas up to 20-30 km² large. To study the effects of water shortage on plots with autumn wheat a survey was made in the spring of 2019.

Results

Long-term spatial and temporal analysis of vegetation indices for drought monitoring

The average index values for the 2000-2017 period prove that our habitat selection was correct (for forests, pastures and meadows, and wetlands), as well as the selected four indices were useful (Fig 4.2.). There was a significant difference between the NDVI and EVI too, which apply similar principles. As it was expected, the biomass production is the greatest in the case of hilly forests (Fruska Gora) and during most of a year it is the lowest for herbaceous vegetation. The EVI followed the annual changes in biomass production better, while with the very high NDVI mean values hardly decreased after the summer canopy was fully developed, thus in the remaining part of the vegetation period their applicability is limited. The most intensive change was detected during the rapid spring vegetation growth, when the EVI/NDVI median values grew by up to 0.1 during the 16-day-periods.

Land cover categories could be identified with high precision based on the NDWI. The curves are sensitive to external effects. High NDDI suggest drought, which is important for interpreting lower values, while the riparian forests which were not influenced by water shortage have the lowest mean NDDI.

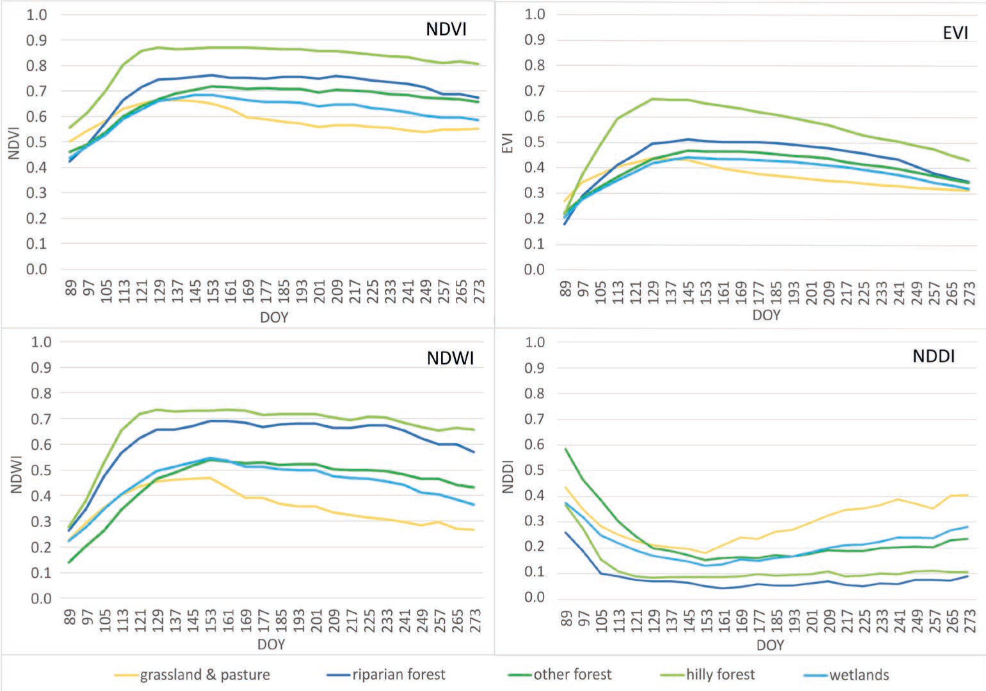


Figure 4.2. *Mean spectral index values calculated for the summer half-year based on the data of 2000-2017 period, applying 8-day composite images (the Y axis indicates the given day of the year - DOY)*

Applying the standardised NDDI anomaly the extremely dry, drought periods for vegetation could be selected. The analysis of the spatiality of the droughts in 2018 and 2019 enabled us to evaluate the geographic consequences of increasingly frequent and severe drought situations (Fig 4.3.).

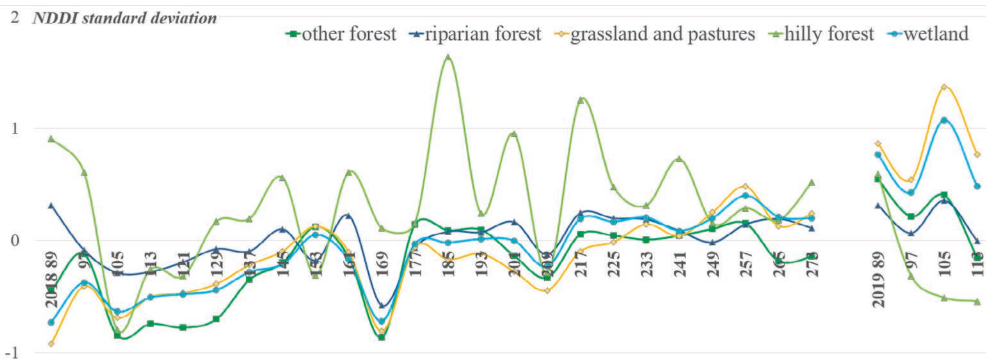
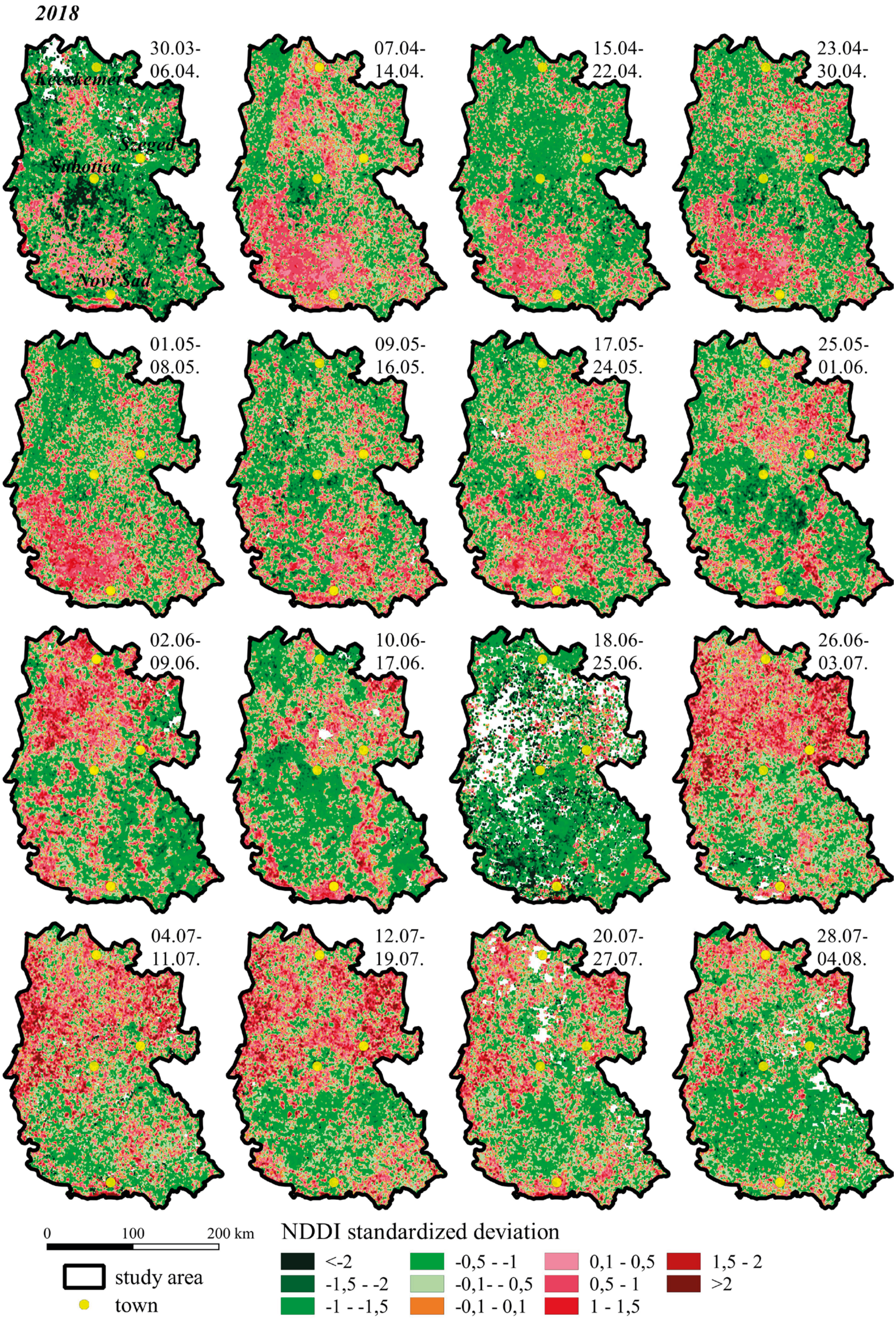


Figure 4.3. *Mean anomalies of the NDDI standardised median values calculated for the periods of 30 March-7 October 2018 and 30 March-30 April 2019*

In the NDDI deviation values above 1.0 indicate drought. If the mean value of an area reaches or exceeds this value, typically drought conditions can be observed. In 2018 it was reached only in the hilly forests, but due to the precipitation and temperature conditions this period was not continuous, so no serious drought developed. In the spring of 2019 the deviation stayed above 0.5 continuously on meadows, pastures and wetlands, which might indicate the development of a summer drought. Unexpected great changes (NDDI deviation >2.0) can occur in the spatial distribution of the value referring to various human impacts (Fig 4.4.).

Among the mean curves of midyear deviations of the studied land cover categories, the deviations of hilly forests are outstanding, as they had either higher values than other surfaces or they run differently than the other curves. It can be explained by the facts, that hilly forests can be found only in the elevated Fruska Gora mountains, and they are located in the southernmost part of the study area, thus they exposed to climate change that is increases towards south. The NDDI deviations are the most typical in the springs, when the climate influences the photosynthesis and water content the most. The curves of wetlands, meadows and pastures rarely differ.

The study area is climatically relatively homogenous, thus the local/regional differences are caused by other geographic effects. At several periods the Danube-Tisza interfluve and the low-lying parts of Bácska are different. In the Hungarian part of the study area since 26 June 2018 mainly areas with positive NDDI deviation are abundant. Drought was characteristic of the entire study area between 6 and 21 September 2018 and in April 2019. Pixel based analysis reflects local characteristics better than the average values, which means that even in the periods with favourable average values there are bad quality, drought lands. In the lowlands forests that are characteristic in the Danube-Tisza interfluve pixels almost continuously positive NDDI deviation values were detected from early June 2018 until late April 2019.


2018
30.03-06.04.
Kecskemét
Szeged
Subotica
Novi Sad
07.04-14.04.
15.04-22.04.
23.04-30.04.
01.05-08.05.
09.05-16.05.
17.05-24.05.
25.05-01.06.
02.06-09.06.
10.06-17.06.
18.06-25.06.
26.06-03.07.
04.07-11.07.
12.07-19.07.
20.07-27.07.
28.07-04.08.
0
100
200 km
study area
town
NDDI standardized deviation
<-2
-1,5 - -2
-1 - -1,5
-0,5 - -1
-0,1 - 0,5
-0,1 - 0,1
0,1 - 0,5
0,5 - 1
1 - 1,5
1,5 - 2
>2

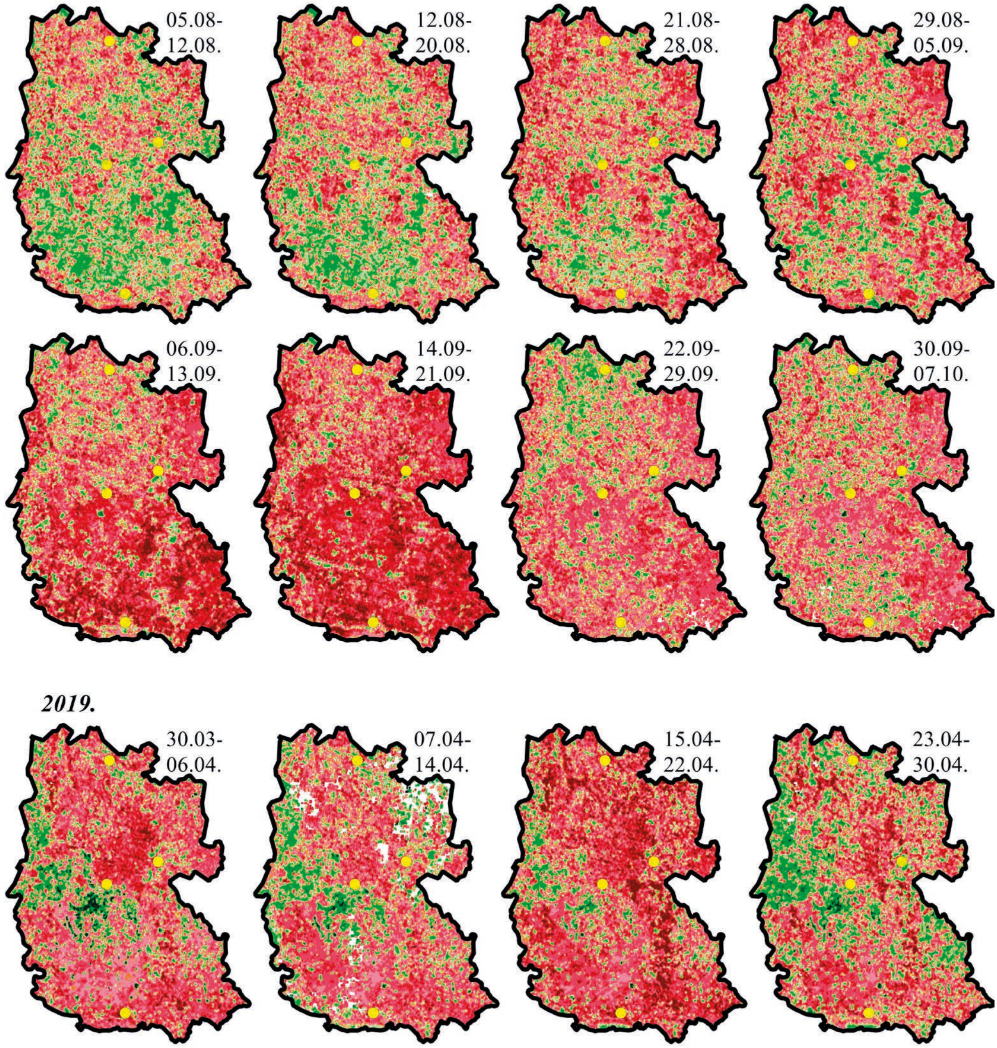
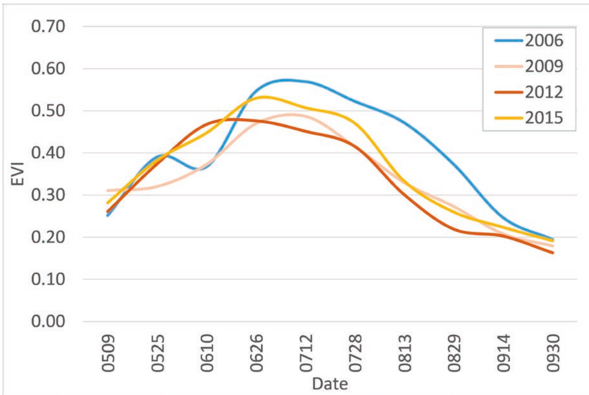


Figure 4.4. *Spatial analysis of standardised NDDI in 2018-2019*

Spatial and temporal changes of agricultural areas

Within the studied period the rainy 2006 had the highest EVI value, but a recession in the average values for early June was caused by a rainy period when the monthly rainfall was above 100 mm in May and June and by the development of inland excess water. In the years of 2009 and 2012 the EVI curves reflect droughts: in May and June 2009 the ascending of the EVI curves started later than in other years, and it reached its rather low peak just by July; while in the case of the year 2012 the initial rapid growth of the curve was followed by the lowest values after early June. These anomalies of the EVI curves are comparable with the average crop yields for the counties (Fig 4.5.). In both counties the crop yield was the highest in 2006, while it was the lowest in 2012.



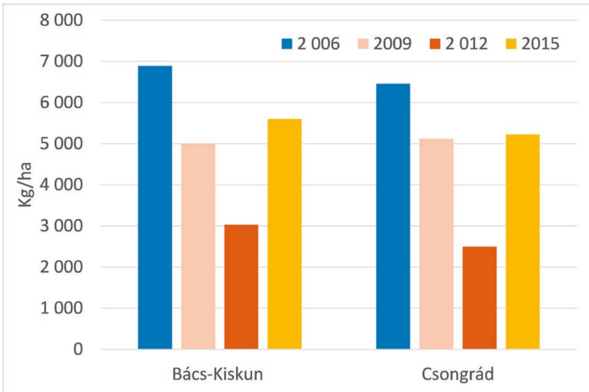


Figure 4.5. *Average EVI values of the corn plots based on 16-day MODIS MVC images in the studied years (a), average corn yield in Csongrád and Bács-Kiskun counties in the same years (b)*

The biomass curves were the most similar in 2006, as the result of favourable precipitation conditions (Fig 4.6.). In this year in July and August the ripening is the most visible, and the highest values developed in the Danube-Tisza Interfluve. In contrary, the differences in EVI values were the greatest in 2009, when the lowest average values were measured east of the Tisza, while in Bácska the curves had steady running. As a result of the drought, the values for the Danube-Tisza Interfluve and for the areas east of the Tisza were halved compared to 2006. In case of drought years, for example in 2015 the maximum EVI values developed only at the end of June or beginning of July, while in 2012 from the beginning of June the EVI value decreased in every study area. The secondary (late) maximum values that can be seen on the curves of the last two years, could also be connected to the full ripening of the corn, which was supported by the dry and hot weather, however in these years rainfall was low in the spring and early summer. In 2012 and 2015 the severity of the drought was similar, but 2012 was preceded by a hot and dry year, while in 2014 there was no drought. This could explain the differences and higher values in Bácska and east of the Tisza. The lowest biomass production was measured in the years with the worst crop yield (2009, 2012) in the plots situated in the Danube-Tisza Interfluve, thus in the future the cultivation of corn should be reconsidered.

The sudden changes in the EVI mean values indicate vegetation that reacts rapidly to changing environmental conditions and human impacts. For example, the development of inland excess water in 2006 that has already been mentioned, or the drop in the EVI in 2012 in the Danube-Tisza Interfluve and in 2015 in the Bácska region was caused by crop harvest, or a sudden increase in the value was caused by favourable meteorological conditions at the end of July 2012 in the Danube-Tisza Interfluve and in 2015 along the Danube.

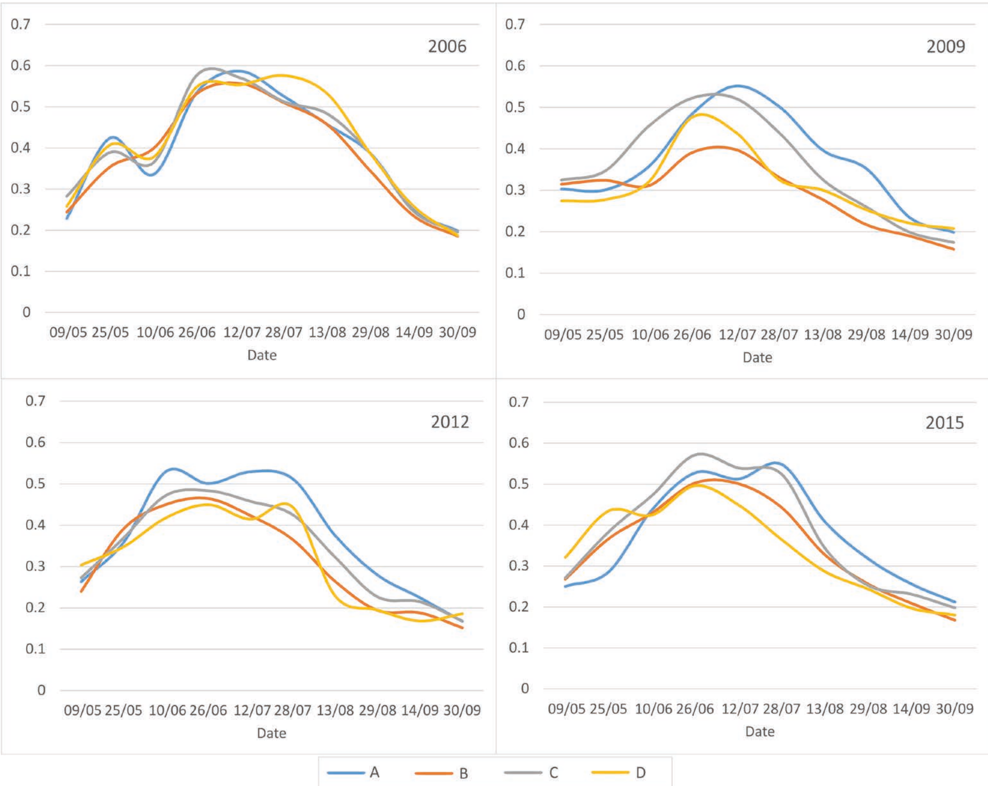


Figure 4.6. *Biomass curves drawn from 16-day composite EVI index images for the studied years for corn fields represented in the LUCAS database in Csongrád and Bács-Kiskun counties A: Bácska, B: Danube Plain, C: Danube-Tisza Interfluve, D: region east of the Tisza River*

The differences in EVI curves applying medium spatial scale were the smallest in Bácska and on Danube Plain (Fig 4.7.). The small differences were related to soil characteristics (high water retention) and favourable water supply conditions. Consequently, the drop caused by the early June rainfall in 2006 was the greatest along the Danube, due to high groundwater and soils types that retain water. Not only droughts, but also too much water could result in negative biomass production anomalies. The Danube-Tisza Interfluve is highly exposed to droughts as the result of sandy soils with small water retention capacity and low groundwater level, thus in 2006 the EVI production was remarkably high. Besides the Danube-Tisza Interfluve the EVI curves of the region east of the Tisza reflect the greatest annual differences.

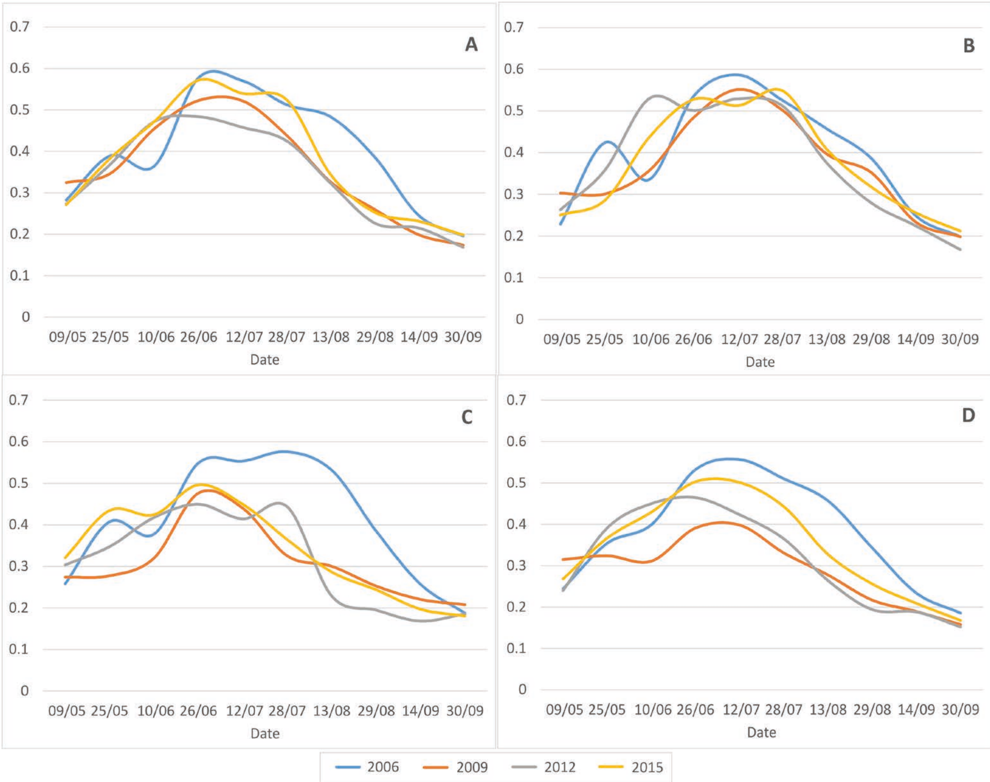


Figure 4.7. *Biomass curves of various regions based on 16-day composite EVI index images for the corn plot points of the LUCAS database corn fields represented in the LUCAS database. A: Bácska, B: Danube Plain, C: Danube-Tisza Interfluve, D: region east of the Tisza River*

Opportunities in high resolution vegetation monitoring by drones

On ortophoto images (made on 16 April 2019) spatial differences within the autumn wheat plots could be detected (Fig 4.8/b, c). The vegetational homogeneity along the edges of the plots is the result of the fact that the same crop is planted on several neighbouring plots, which increases the weed suppressing ability of the crop. One of the reasons of the NDVI spatial anomalies is the difference in soil type that can be observed on satellite images from March (Fig 4.8/a), and the other reason is the heterogeneous spatial distribution of the different weeds. Crop subspecies and weed species could be separated easily on the RGB image. On the real-colour image the light elongated patches indicate different physical soil properties, where different, mostly disadvantageous water-household situation could develop during droughts. According to the Fig 4.8 (c, d), the precipitation in May supported the development of the vegetation, thus the biomass production of the different subspecies varied even more.

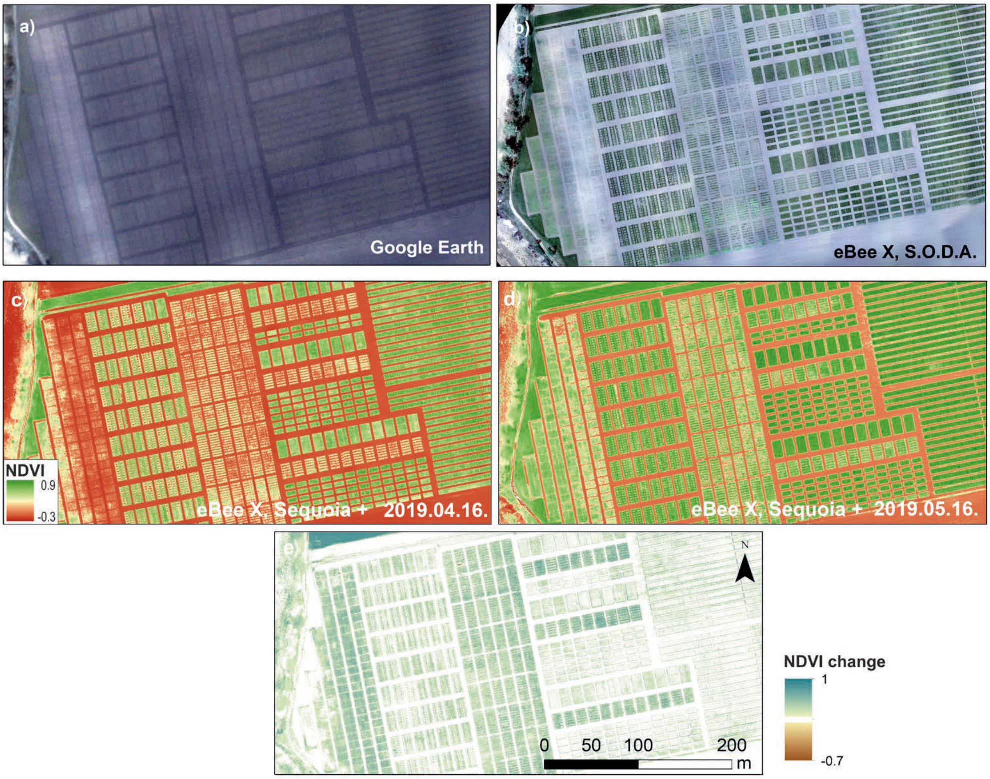


Figure 4.8. *Imagery of autumn wheat plots around Szeged a) GeoEye satellite image (GoogleEarth) made on 14 March 2019; b) eBee X RGB drone image using senseFly S.O.D.A taken on 16 April 2019; c) eBee X NDVI drone image using Parrot Sequoia+ taken on 16 April 2019; d) eBee X NDVI drone image taken on 16 May 2019 e) NDVI changes between 16 April and 16 May 2019*

The extremes in water supply and the weather conditions also limit the survey. Very strong wind at the beginning of the year hindered the survey, and due to low soil moisture the germination started much later. However, later in May the intense rainfalls and frequent cloud cover caused problems in monitoring. The survey was made on experimental plots, where the negative impacts of soil patches on various crop types were reduced by repetitive randomised or fixed crop plantation methods, so the crop type plots are repeated in various parts of the experimental field (Fig 4.9.).

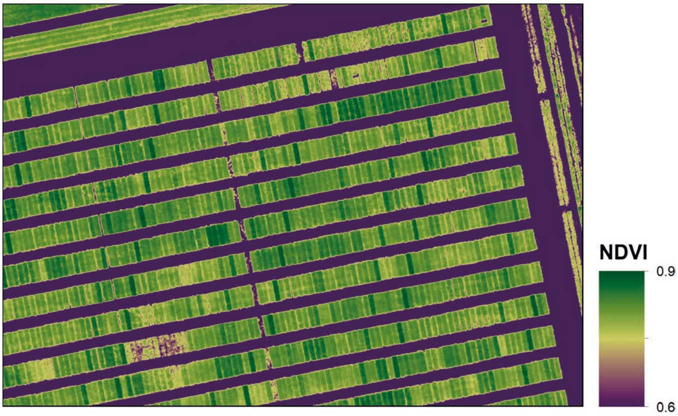


Figure 4.9. *Repetitive crop plantation of various subspecies in the North Eastern part of the experimental field*

Conclusions

The performed environmental monitoring supplied both high and low spatial and temporal resolution data for various land cover categories. The data were carefully pre-processed, thus we were able to make a regional scale analysis applying pixels with homogeneous land cover. The differences in the applied spectral indices applied justify the utilisation of all four index types.

The fundamental differences characterise the biomass production of plots with different vegetation cover, indicating complex processes even within this single landscape forming factor. According to climatological forecasts, in the near future the process of warming will continue, and the extremely dry, drought periods will become more frequent. Consequently, it is very likely that the present decrease in biomass production will become longer. The variability of the indices indicates rapid reactions of the vegetation to the different environmental impacts. The consequences of extremely dry years or periods could be evaluated through careful analysis of deviations in vegetation applying statistics and spatial analysis. In this way the farmers could be supported in taking preventive measures. Our results also proved that there are limitation for corn cultivation in the Danube-Tisza Interfluve.

Due to the complexity of the processes, in aridification research it is advisable to formulate synthesis based practical suggestions. It is a further objective of the monitoring studies to exploit the statistical opportunities in the growing time series. In order to understand the functions of the vegetation better, we should have reveal its relationship with weather and soil parameters, even on a plot level.

The improved remote sensing data provided by several sensors contributed in our new results. With the methodologies applied in the study, the databases can give good results in creating operative, almost real-time and automatic change detection solutions.