University doctoral (PhD) dissertation abstract

Comparison analyses of inland water and drought

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1. BACKGROUND AND OBJECTIVES OF THE THESIS

Understanding the habitat is essential for economic production. As a result of rapidly changing processes, features of habitats may be modified, it may be affected by a wide variety of factors including climate, hydrological and soil conditions and human activities. Climate change and extreme weather conditions may cause serious damage to natural resources and they may be influenced by several risk factors. Risks can be classified in various ways: production risk, financial risk, market or price risk, institutional risk and human (or personal) risk.

Production risk includes risks and uncertainties of growth processes in crop production. Quantitative and qualitative characteristics of products may be determined by different factors including, inter alia, drought, precipitation and diseases (SZÉKELY and PÁLINKÁS, 2008). Preparing for climate change plays a major role in the sustainable use of different resources usable for agriculture (TAMÁS, 2013). Regarding the risk of climate change, risks associated with water constitute one of the main threats for agricultural production. Extremes in water management occur often in the same year and mostly in the same region, however, in other instances they may vary a lot both in time and space. The experience gained over the last decade confirms that in the Carpathian basin despite the more frequent droughts, risks of inland inundations and floods must also be taken into account (LÁNG et al., 2006; BLASKÓ, 2011).
Evaluating drought encounters with difficulties as its definition means problem in both spatial and temporal terms. Drought indicators and indices are widely applied to characterise drought, however, there is no common method to this end. Different indices apply different input data and temporal scale, so my thesis primarily focuses on this, but I also would like to highlight that analysis of drought phenomenon should be considered together with inland water thus I have analysed both phenomena on my sample areas.

For the development of inland waters a combination of several adverse natural factors must be met (PÁLFAI, 2004) and landscape is highly important. Land use change may adversely affect the run-off and accumulation processes and it may increase the risk of inland water occurrence.

Research objectives

The frequency of extreme water management situations (drought, inland waters) affecting agriculture is increasing and it makes problems more acute. Limiting drought and inland water in spatial and temporal terms provides one of the principal uncertainties during investigations. The main objective of my research was the development of methods used for analysing temporal and spatial variability of drought and inland water, which are the major climatic risk factors affecting agriculture, in order to produce more accurate and comparable results.

More detailed research objectives:

- to evaluate a set of key drought indices in two geographical regions with different hydrological features and work out a hybrid drought index and examine it in the reference areas;
- application of biomass investigations for evaluating drought processes using satellite-based time series spectral data;
- a time series analysis of the accumulation and run-off conditions of inland waters applying remote sensing data and different digital elevation models.

2. MATERIALS AND METHODS

During the research the sample areas were: Great Hungarian Plain, Szolnok-Túr-Plain, Nyírség, North-Nyírség. The criterion of choice of sample areas was to evaluate different phenomenas on different scale levels.

Calculation of determinative drought indices in different geographic regions

Calculation of drought indices (Ellenberg's climate quotient, SPI-3, RDI, PaDI)

The relevant temperature and precipitation data required for the calculations of indicators for Szolnok-Túri-Plain was provided by the Research Institute of Karcag belonging to the Institutes for Agricultural Research and Educational Farm (IAREF) of University of Debrecen.

The temperature and precipitation data needed for the calculations for Nyírség for the period of 2002-2012 was supplied by the Research Institute of Nyíregyháza belonging also to the IAREF.

Since the calculation of Pálfai's Aridity index (PaDI) requires a reference period from 1983 and Research Institute of Nyíregyháza have been only able to supply data from 2002, I requested data from Hungarian Meteorological Service (HMS) for the sample area (from Nyíregyháza-Sóstó and Nyíregyháza-Napkor meteorological stations) for the period of 1993-2002.

Ellenberg's climate quotient was calculated on the basis of temperature and precipitation data of the meteorological stations, where the average July temperature values have been divided by the average annual precipitation and then multiplied by 1000. Index values are not scaled, the higher the value, the more extreme the drought is.

Values of SPI-3 (Standardized Precipitation Index) and RDI (Reclamation Drought Index) for the sample areas were calculated using DrinC (Drought Indices Calculator). The calculation is made on a monthly basis for hydrological year (from October to September), for the period of 2002-2012 and for both reference areas.

For PaDI (Pálfai aridity index) after sorting data I have calculated the value of Pálfai aridity index ($PaDI_0$) modified by including correction factors for the period of 2002-2012. The calculation method is detailed in PÁLFAI (1990); BIHARI, (2012); VERMES (2000); KOZÁK et al. (2012).

Methodology of calculating NDVI values

A 10-years (2002-2013) time series analysis of vegetation activity is made for both sample areas. MODIS images used for analyses have been downloaded from website of USGS (United States Geological Survey). I have processed MODIS images for the months of May and August of the period 2002-2013 for arable land classified non-irrigated based on 2012 database of Corine Land Cover and these months cover the period of flowering and crop formation of wheat, winter barley, triticale and maize on both sample areas. This data processing has led to the values of NDVI representing the given periods. Furthermore, from the database of European Drought Centre, I made regression analysis to determine correlation between soil moisture anomalies and NDVI values and this method has also been used for revealing correlations between national and international indexes. I have analysed the relationship between Ellenberg and PaDI, SPI-3 and PaDI as well as RDI and PaDI.

Creation of methodology for a normalised hybrid drought index

A I have carried out a normalised hybrid drought index on the basis of values of drought indexes calculated during my research as these indexes indicated drought in different years and to varying degrees. Therefore, I considered necessary a hybrid drought index to be carried out and I determined the next drought categories: no drought, mild drought, moderate drought, extreme drought and extreme drought. In this way, I have created a uniform classification that can be applied both on national and international level.

Values of the four meteorological indexes selected (Ellenberg, SPI-3, RDI-3 and PaDI) were converted to a scale between 0 and 1. These values have been accumulated and divided by the number of indexes and recalculated to a percentage scale. The weighting factors were as follows PaDI – 0,77; SPI - 3 and RDI – 0,3 while for Ellenberg this value was 0,06 based on calculations on the Szolnok-Túri-Plain. Based on Nyírség data the PaDI was 0,76; Ellenberg – 0,69; SPI- 3- 0,38 and RDI was 0,23. The above values were the deterministic coefficient values obtained between the index values and the NDVI values from August. Based on the categories I have classified each year by the extremeness of drought in the case of both sample areas. Since the input data of indexes are based on point meteorological stations, they fail to reflect well the spatial extent of drought. Thus, the aim of my further research was to make spatial analysis of drought phenomena. In this case I have made calculations for the Alföld (more specifically, for two less extended part of it: Szolnok-Túri-Plain and Nyírség). The weighting was based on the average deterministic coefficient obtained from the NDVI index from August and the

correlation between the index values. The weighting value was for PaDI – 0,76; for SPI-3 and RDI were 0,3 and for Ellenberg 0,37.Then I cumulated these values, divided them by the number of indices, and converted them into a one percentage scale. After a reclassification, I could depict the spatial appearance of drought. From Carpatclim (Climate of the Carpathian Region) database I have downloaded the indexes examined (Ellenberg, PaDI, SPI-3 and RDI- 3) for the period of 2002-2010.

Assessment of drought phenomenon using biomass tests based on time-series satellite data

In IDRISI Taiga software environment, I have created a time series from NDVI images obtained from my calculation. The time series consist of a file pair containing the relevant time series and a documentation file describing the temporal characteristics of the series. The time series of raster images constitute time-space cubes. I have created the time-space cubes for both sample areas for the months of May and August. Subsequently, in the case of NDVI images, I made Principal Component Analysis (PCA) in IDRISI Taiga software environment on the images of May and August of the 2002-2012 period for both sample areas.

The evaluation of the runoff conditions of the inland waters, using time-based remote sensing data, as well as digital elevations models from different sources

Detection of inland water areas using time-series remote sensing radar data

One of my purposes was the assessment of relations between the run-off and accumulation processes of inland water applying time series of remote sensing radar data since one possible approach for monitoring the inland water phenomena and characterising its occurrence risk might be the evaluation of radar images.

I have downloaded Sentinel 1 data about the area of Szolnok-Túr-Plain from the website of European Space Agency (ESA) (https://scihub.copernicus.eu/). During my research work I have processed radar images in ESA Sentinel Application Platform (SNAP) 2.0 software environment. I have processed the amplitude values. As a first step of the pre-processing I have made the radiometric calibration of the images where I have chosen the polarisation intended to be processed and as a result I have got the Sigma0_VV channel and then I have made a filtering on it (single product speckle filtering). It was followed by a geometric correction (range doppler terrain correction). Finally, a binary transformation has been carried out during which

I have selected water from non-water by the histogram of the channel. The histogram shows the reflectance displayed on a logarithmic scale. Low values correspond to water while high values show non-water areas. On the basis of the histogram I have determined a threshold which allowed me to separate them from each other. This threshold was 2.21E-2.
During segmentation I have applied the following relation:

$$255*(Sigma0\_VV<2.21E-2)$$

The expression Sigma0_VV <2.21E-2 is interpreted as logical value. Values less than 2.21E-2 are true (represented with 1) while values higher than that are false (represented with 0). That way I separated the water and non-water areas from January to December 2015 on the area of Szolnok-Túr-Plain.

The basis for choosing the threshold value was a practical description that used the above correlation in flood detection (I1). GULÁCSI (2017), found that its difficult to give a proper inland water threshold value, the spatial resolution of satellite imagery is rough for the extent of the inland water and more transparent the water compared to the slightly deeper lakes and canals. Using the Corine Land Cover 2012 database, I have quantified the size of inland water areas (expressed in ha) for non-irrigated arable land, grasslands and pastures. As a next step, using the Corine Land Cover 2012 data, I defined the inland water bodies in non-irrigated arable fields. When investigating the relationship between the soil properties and the formation of the inland water areas, I sorted the soil types on the sample area using the AGROTOPO database, physical clarity and water management categories in the Global Mapper 15 software environment.

Detection of inland water areas using digital elevation models from different sources

Regarding my research, the evaluation of relations between the run-off and accumulation processes of inland water applying different digital elevation models was an objective to be achieved. In the case of the sample area in the Nyírség, I have chosen two smaller sample areas (typical for that landscape) located close to Nyírbátor. The two reference areas were a grassland of 15.6 hectares and an arable land of 85.55 hectares with its immediate vicinity

Detection of inland water areas using traditional elevation model

In the case of DEM generated from analogue basic data the processing steps were the followings: scanning the conventional topographical paper map at a resolution of 600 dpi and

transforming it into EOV projection. Subsequently, vector layer has been created and on the basis of topographical map contour lines have been digitalised. Then database has been compiled with height data. A total of 25,372 vertex points representing height data have been input and I have generated 3D contour surface using kriging method. On the basis of the elevation model I have marked the areas susceptible to inland water.

Detection of inland water areas from digital elevation model of LiDAR data

The aerial LiDAR survey arising from cooperation between Institute of Water and Environmental Management and Eurosense Kft. The two locations of the survey were a grassland of 15,6 hectares and an arable land of 85,55 hectares with its immediate vicinity. Laser scan survey was carried out by Eurosense Kft. using IGI LiteMapper system.

They surveyed arable land between harvesting the former crop and sowing the next one and grassland with the lowest vegetation. The combination of the resulted appropriate factors provided a good opportunity to understand topography of areas and evaluate differences in micro-relief. The area was made up of in a total of 129,072,937 points. The resolution of LiDAR data points is 14,58 point/square kilometres thus it can be used to build high resolution models.

The laser point cloud processed by photogrammetry was pre-processed with GlobalMapper software. I also carried out a preliminary elevation profile analysis in the software for the arable and grassland sites.

On the basis of LiDAR images I have made the elevation model of the sample area including both the arable and grassland then, as in previous investigations, I have prepared the maps of slope categories and finally I have marked the inland marshes located in the sample areas. Elevation model based on high-resolution LiDAR data was analysed using similar steps as for processing DEM based on analogue (so-called conventional) data. During processing I have made different optimisation methods for pixel aggregation. Then, I have sorted the roads, canals and reservoirs. During the next phase I have investigated the run-off and accumulation relations on the basis of slope conditions. After this, I have examined the intensity values of the laser survey to map the inland water. In the next step I have compared the applicability of digital elevation models based on two different types of mapping, conventional and LiDAR images, for mapping inland water.

3. RESULTS

Results of determinative drought indices in different geographic regions

I have got the next results for Szolnok-Túr Plain on the basis of index values. According to the values of Ellenberg Index, 2002-2003, 2003-2004, 2007-2008, 2009-2010 and 2011-2012 years were affected by drought. SPI-3 showed that there was a moderate drought in the year 2006-2007. RDI values showed that years 2006-2007 and 2011-2012 were dry. On the basis of PaDI 2002-2003 and 2011-2012 were years affected by extreme drought and years of 2006-2007, 2008-2009 and also 2010-2011 were affected by moderate drought.

For the area of Nyírség the periods of 2002-2003, 2006-2007, 2010-2011 and 2011-2012 found to be affected by drought based on the values of Ellenberg Index. SPI-3 showed the years 2002-2003, 2005-2006 and 2011-2012 were affected by moderate drought. 2002-2003 and 2006-2007 were very dry years due to RDI. The years 2002-2003, 2006-2007, 2011-2012 were characterised by moderate drought and the year 2008-2009 by mild drought on the basis of PaDI values.

During the research my aim was to compare the meteorological indices, and examined their applicability on national level. Compared the index values I found national and international indexes indicate drought for different regions to varying degrees and in different years, thus, I have run a regression analysis in order to reveal correlation. Linear correlation analysis carried out between indexes calculated for Szolnok-Túr Plain showed a significant correlation between Ellenberg-Index and PaDi, presumably because both index contains temperature and precipitation data as input parameters. There are a moderate correlation between SPI-3 and PaDI and also between RDI and PaDi. Linear correlation analyses calculated for Nyírség showed significant correlation between Ellenberg and PaDi, SPI-3 and PaDi and also between RDI and PaDi, which means there is a strong dependent relationship between them.

Evaluation of NDVI values for both sample areas

Besides the meteorological indices I have also calculated one of the satellite-based indices, the Normalised Difference Vegetation Index. From the values of the period considered I selected the images for May and August (these months cover the period of flowering and crop formation of wheat, winter barley, triticale and maize grown in the area) and based on Corine Land Cover we cut the non-irrigated arable land (category 211).

Based on the analysis of May, I determined for the Szolnok-Túri-Plain that years of 2003, 2007, 2009 and 2012 were affected by drought, which is reflected in the lower values of NDVI, while higher NDVI values can be seen for the years 2004, 2005 and 2008. Regarding the analysis of August, 2003, 2007, 2009 and 2012 were years affected by drought, which is reflected in the lower values of NDVI, while higher NDVI values can be observed for years 2004, 2005, 2008 and 2010.

The evaluation of the images for the Nyírség in respect of May revealed that 2003, 2004, 2005, 2009 and 2012 were years affected by drought, which is reflected in the lower values of NDVI, while higher NDVI values can be seen for the years 2006, 2007 and 2010. On the basis of images for the period of August, 2003, 2007 and 2012 had drought, while the years 2004, 2005, 2006, 2009 and 2010 experienced higher NDVI values.

Finally, I compared the May and August NDVI values with the meteorological index values. There was a close relationship between the August NDVI values and the meteorological index values. Based on it, I determined the relative reliability of the indices (PaDI, Ellenberg, SPI-3, RDI) and I used the deterministic coefficient values as well as the weighted values for calculation of normalised hybrid index.

Results of normalised hybrid drought index calculated for both sample areas

I have carried out a normalised hybrid drought index based on the values of drought indices I calculated. As these indices indicate drought in different years and to varying degrees, I considered necessary to carry out a hybrid index with the following drought classification: no drought, mild drought, moderate drought, drought and extreme drought.

I found for Szolnok-Túr-Plain that in the period between 2002 and 2012 there were three year without drought (2007-2008, 2009-2010, 2010-2011), and there were extreme drought in the years of 2002-2003, 2006-2007 and 2011-2012. 2003-2004 and 2008-2009 were affected by moderate drought. Year of 2004-2005 was affected by mild drought.

In the case of Nyírség I found, throughout the period considered, there was not a year without drought or mild drought. 2010-2011 was the year with moderate drought. Years of 2003-2004, 2007-2008, 2009-2010 and 2011-2012 were affected by drought. Years of 2004-2005, 2005-2006, 2006-2007, 2008-2009 were classified in category of extreme drought based on the normalised hybrid drought index.

Spatial representation of hybrid drought index on the Great Hungarian Plain

I represented hybrid index carried out using the four indices overviewed (PaDi, Ellenberg, SPI-3 and RDI-3) for the Great Plain between 2002 and 2010. At pixel level I have converted index values to percentages and then they were categorised (Figure 1.).

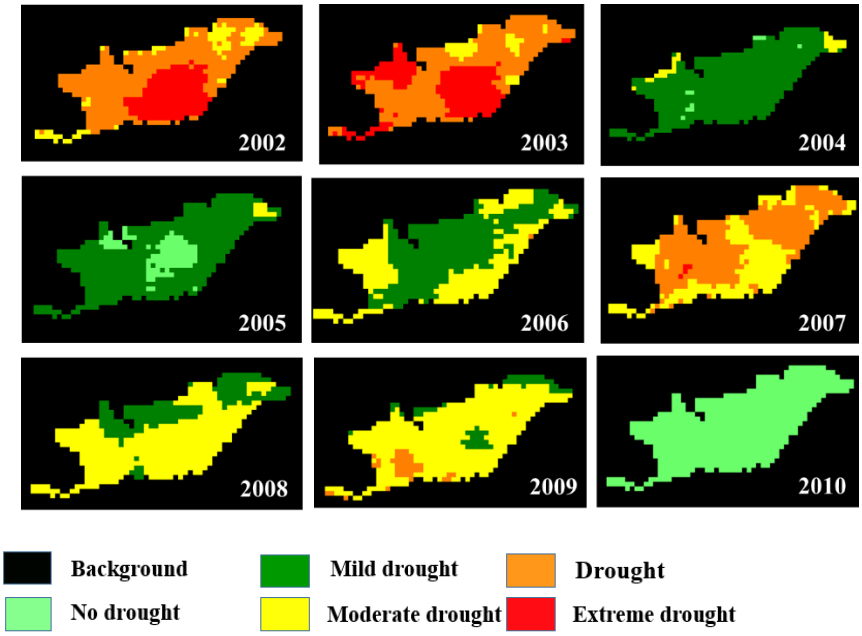

Figure 1: Drought trend for the Great Hungarian Plain based on values of hybrid index

As shown on Figure 1., I concluded on the basis of the values of normalised hybrid index that there was extreme drought in certain areas of the Great Hungarian Plain in 2003 and the drought category was the highest in 2007, but the majority of the area belonged to the category of moderate drought. The region, however, experienced a rather moderate drought in 2009. The weather was extremely rainy in 2010 and hybrid index also confirms it as the whole Great Hungarian Plain region fell into the 'no drought' category.

During my investigation I have also calculated the exact geographic scope in percentage of the different drought phenomena for the Great Hungarian Plain.

In 2003, an area of more than 35% of the Great Hungarian Plain was affected by extreme drought, 58,8 % were affected by drought and 7 % by moderate drought. I have determined moderate drought (39%) and extreme drought (1%) in the area for 2007. In 2009, was a mild drought on 10 %, moderate drought on 83 % and drought on 7% in the sample area.

In addition, in years affected by drought we investigated the drought characteristics in our two sample areas. First, I present the results of the research on Szolnok-Túr-Plain. The results of the normalised hybrid drought index for 2003 suggest that the highest proportion of the area

of Szolnok-Túr-Plain (26 213 ha) fall into the extreme drought category, moderate drought affected the area to a lesser extent (15 786 ha). In 2007, 26 213 ha were drought and 15 786 ha were in moderate drought cathegories. Based on the results I found that the drought phenomenon affects the same areas but different way, but the effects of drought are also located to other areas. Based on the normalized hybrid index, 6002 ha were affected by mild drought and 35 997 ha were affected by moderate drought in 2009.

Based on the normalised hybrid drought index I determined for Nyírség that the highest proportion of the area in 2003 was affected by drought (373 612 ha) and moderate drought (76 486 ha) were scattered in the area. In the Nyírség, the larger proportion of the area (370 564 ha) was affected by drought in 2007, while a smaller area saw moderate drought (79 534 ha).

Due to the normalised hybrid drought index calculated for 2009, the highest proportion of the area of the Nyírség fell into the category of moderate drought (420 954 ha), a smaller area fell into the category of mild drought (20 827 ha), while there was extreme drought in an area of 8317 ha.

Evalutaion of drought phenomenon using biomass test with time-series satellite data in case of Szolnok-Túr-Plain and Nyírség

The results of principal component analysis for both sample areas

For the assessment of drought, I performed biomass analyses based on satellite spectral time series data (MODIS NDVI) for non-irrigated arable lands of both sample areas. I performed analysis using these NDVI images for the periods of May and August and for both sample areas (between 2002 and 2012) to understand the correlation between drought periods and biomass.

In the case of Szolnok-Túr-Plain for the period of May, the image of May 2003 was the first component and it explained 96,99% of the total variance, while for the period of August, 96,67% of the total variance was explained by the image of August 2008, as the first component. In the case of Nyírség for the period of May the first component was the image of 2008 and it explained 97,79% of the total variance. Regarding the images of the period of August, the image of August 2013 was the first component and it explained 98,66% of the total variance.

There may be several reasons for the variability of NDVI values. The largest proportion of areas in the area are arable land and grassland categories, so the reason for the above results may be that the sowing structure has a modifying effect on the NDVI values. Therefore, it is important

to examine in which areas of the crops what kind of sowing structure and what phenological phase they are at test times.

Results of the evaluation of the runoff conditions of the inland waters, using time-based remote sensing data, as well as digital elevations models from different sources

Results of the detection of inland waters in the Szolnok-Túr Plain based on radar data

I have marked the areas affected by inland water for 2015 and I made a comparison between these areas and the section border used in Kvassay-plan to compare and evaluate their spatial correlations. I have marked the land use categories in our sample area based on Corine Land Cover database for 2012. Following this, I quantified the area of inland marshes in non-irrigated arable land, grassland and pasture land in IDRISI Taiga software environment. During the processing I made selection for the categories above based on Corine Land Cover. The results are summarized in Table 1.

Table 1. The area of non-irrigated arable lands and grasslands affected by inland water in hectares in the case of Szolnok-Túr-Plain in 2015

Month	Inland water areas in non-irrigated arable lands (ha)	Inland water areas in grasslands (ha)
January	14,06	15,87
February	40,61	13,92
March	507,52	3,28
April	161,23	3,49
May	17,37	3,28
June	29,87	337,14
July	105,95	1113,67
August	42,08	10,25
September	50,53	16,35
October	34,85	23,20
November	29,07	8,05
December	17,15	10,60

Based on values in Table 1, I consider that the most extensive flooding was in March in the case of non-irrigated arable land category (507,52 ha), followed by April (161,23 ha). July also represent a high value, 105,95 hectares had inland water on the area based on the results of

sorting radar data. In the case of grasslands all months of the year examined had inland water, but two of these months, July (1113,67 ha) and June (337,14 ha), were outstanding.

My results are consistent with GULÁCSI (2017) research, which found that Sentinel-1 radar recordings can be used to detect inland water with large temporal and spatial resolution. During the examination of the soil properties, such as soil type, physical density and water management cathegories, I have determined that the contradictions between the soil's water management properties and inland water formation need further investigation to indentify the role of the microrelief.

Analysis of the results of elevation model digitised analogue basic data in the case of Nyírség

Based on DEM height difference of 7 metres for arable land and 20 metres for grassland have been identified. Following this, I have carried out the slope category map for the sample areas based on digital elevation model. Based on the slope category map for arable land I found that 90.8% of the studied area is flat with slope of 5%. Due to the slope category map of grassland I determined that, similarly to arable land, the highest proportion of the area can be considered flat. Subsequently, I marked the areas susceptible to inland water using the elevation model.

The results calculated based on the 1:10000 scale topographical map show that solely based on elevation both grassland and arable land lack risk of inland water. It is, however, contradicted by the inland marshes seen on arable land during on-site visits and which can be marked on the aerial laser images. This can be explained in part by soil and hydrological characteristics and the 10 meters resolution of the elevation model by which the micro relief changes can be monitored to a limited extent.

Results of detection of inland water based on DEM obtained by aerial LiDAR in the case of Nyírség

As in the previous investigations, I analysed the same two sample areas (grassland of 15,65 hectares and arable land of 85,5 hectares) in the Nyírség by DEM obtained by airborne LiDAR.

Based on airborne LiDAR images I created the digital elevation model in ENVI LiDAR software environment for the grassland and the arable land with 50 cm resolution.

After the slope category map has been drawn up (0-5, 5-12, 12-17, 17-25, 25<) I determined that the fragmentation of slope category caused by the resolution is high. 68,30% of the area can be considered flat (0-5%) and 28,23% of the area belongs to the slope category of 5-12%,

however, based on the data previously presented I identified a total of 7 metres height difference on the area of more than 80 hectares.

Due to the high resolution the traces of cultivation (wheel track, furrow slice etc.) have significant impact on the final result of slope category map. In order to remedy these failures I chose a smaller (10x10m) resolution. After “artificially degrading” the resolution I still found slope categories of 12-17%, 17-25% and >25% on the area, however, these areas are smaller in scale (0,37; 0,27 and 0,06 ha). Then, I sorted the roads, canals and reservoirs.

Based on the filtered map without disturbing objects, 93,90% of the area can be classified into the slope category of 0-5% (and can be considered flat), while 5,28% of the area can be classified into the slope category of 5-12%. DEM derived from laser data compared with the conventional elevation model (obtained by digitising analogue data) I concluded that the lands situated in the northern and north-west part of the area which can be classified into the slope category of 5-12% overlap, however, this overlap is not absolute due to the different data sources and resolution.

Similarly to the simulations run for arable land I made modelling also for grassland. The grassland is an area of 15,65 hectares and heterogeneity of the relief is high.

The area is crossed lengthwise by a hill almost in half significantly determining the run-off and accumulation of precipitation on the surface. The hill rises from the lowest spot of the area to a height of 5 meters and this elevation of the relief serves as a catchment border. The runoff vectors show the direction of runoff water. We marked the accumulation points in the area using these vectors. Accumulation lines representing surface runoff also helped.

On the basis of the runoff lines I determined that deeper accumulation cauldrons could pool water as a result of high-intensity precipitation or snowmelt, hence, I analysed the intensity values of the laser survey. Since airborne LiDAR system used infrared wavelength range for measurements, it can be suitable for mapping the potentially harmful excess surface water. During the selection of intensity values I identified 45 pieces of harmful inland water on the area, representing almost 0.2 ha (Figure 2/A and B).

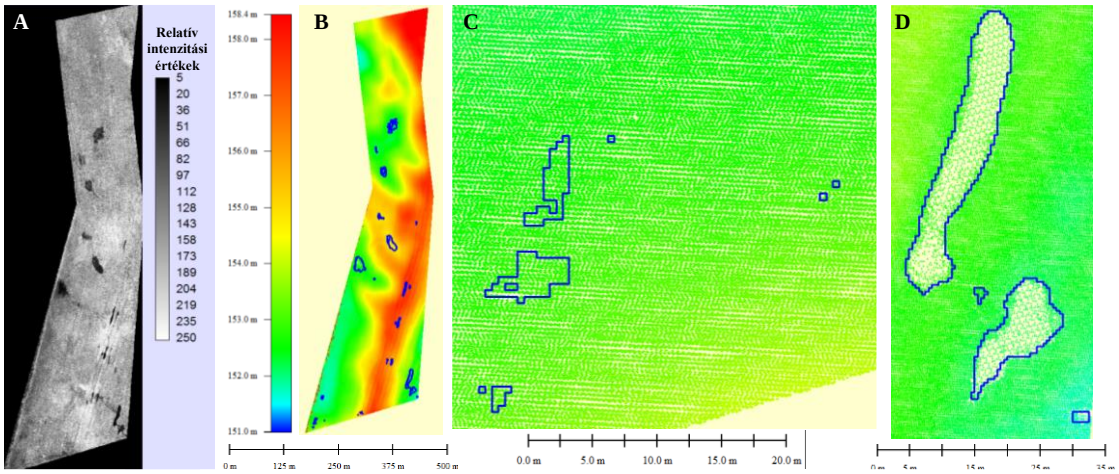

Figure 2: The map generated based on the reflected laser intensity (A), the inland water map made as a result of the sorting procedure (B) and the inland marshes sorted with errors (C) and appropriately (D)

Among the areas some have been wrongly classified in a given category during the sorting procedure (it concerns mainly the southern areas with a size of less than 15 m^2) (Figure 2/C and D) because the point density was higher. Sorted these areas, only 13 pieces of larger and coherent area affected by inland water could be found of which more than half were less than 100 m^2, while the size of the largest inland marsh was 512,5m^2.

The validation of inland water areas was carried out using Sentinel 1 data and CIR and RGB recordings. As a result of the correlation between the relief and the inland water areas, I could separate the natural and anthropogenic water bodies. PÁSZTOR et al. in their 2006 article, they also confirm that the role of the surface should be approximated through the relative relief for the inland waters. One of the most important factor is the relief in the formation of inland water by BAUKÓ et al. (1981); RAKONCZAI et al. (2003). The results of my examinations coincide with the authors emphasizing about the dominant role of the relief.

Comparative analysis of elevation models

I made comparative analysis between the conventional elevation model obtained by digitising analogue data and DEM derived from airborne LiDAR for both arable land and grassland.

In the case of arable land I compared the two types of DEMs, one is the 10x10 meters resolution DEM derived from conventional DEM (obtained by digitising analogue data), the other is the 10x10 meters resolution DEM derived from artificially degraded LiDAR mapping. I also compared the slope category maps derived from the two different DEM types. Both

databases showed that most of the area can be considered flat (an average of 95.2%), however, based on LiDAR data 4,15% of the area belongs to the 5-12% slope category while this value in the case of DEM obtained by digitising analogue data is 5,13%. Other categories can be neglected.

Elevation models for grassland using the same resolution also show significant differences. The height difference of the area is 7,94 m due to laser data while conventional DEM (obtained by digitising analogue basic data) showed 19,11 m. I found that significant change of the relief can be seen in the northeastern part of the area, however, there are also similarities in terms of the location of the deepest points. The major difference is the lack of pattern of the higher part running lengthwise along the area and the erosion running in the direction of the slope on conventional DEM (obtained by digitising analogue basic data). Significant differences in meso-relief are reflected on the slope category map as well, under the same resolution. LiDAR based DEM shows that there are only three slope categories (0-5%, 5-12%, 12-17%) on the area, however, category of 12-17% represents only 0,15% of the total area, category of 0-5% has the highest proportion of the area (55,75%) and 44,10% of the area was in the category of 5-12%. Despite this, on the slope category map based on conventional DEM (obtained by digitising analogue basic data) the slope category of 17-25% appeared in the northeastern part of the area (with a proportion of 5,3%). As topography failed to show the differences, slope categories also showed homogeneity in the central parts of the area.

4. NEW SCIENTIFIC RESULTS OF THE DISSERTATION

1. I have evaluated drought indexes which are major at both national and international level (Ellenberg Index, SPI-3, RDI, PaDi) in two Hungarian geographical regions with different hydrological characteristics. Based on my results I found the relative confidence of drought indexes: PaDi>> Ellenberg>>SPI-3>>RDI.
2. I have carried out new methodology for comparative evaluation of drought index values with different scale. It was a basis for calculating a unified hybrid index.
3. Analysis of time and space series resource monitor satellite data (VIS-NIR) is suitable for monitoring drought phenomenon in small regions.
4. I have carried out a methodology to spatial delimitation of areas affected by inland water based on new-type, active radar remote-sensing data.
5. I have evaluated the run-off and accumulation processes of inland water in the Nyírség based on precision photogrammetry aerial LiDAR data processing. I have marked more precisely than to date 13 larger coherent areas affected by inland water.

5. APPLICABILITY OF RESULTS IN PRACTICE

1. The normalised hybrid drought index I carried out provides opportunity to a more unified assessment of drought phenomenon at the level of geographical regions.
2. Vegetation index contributes to better predict the consequences of drought in crop production.
3. Areas affected by inland water can be marked more precisely during inland water management, even in bad weather conditions, using the new active radar remote sensing data presented in this study.
4. The elevation and surface model compiled using high-resolution airborne LiDAR data allows us to evaluate and optimise the run-off and accumulation processes of inland water, thus damages caused by inland water may be reduced, land use and land structure can be optimised.

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A PhD értekezés alapjául szolgáló közlemények

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