GIS ANALYSIS OF SHORT AND LONG TERM HYDROGEOGRAPHICAL CHANGES ON A NATURE CONSERVATION AREA AFFECTED BY ARIDIFICATION

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Abstract. The shrinking of wetlands in Hungary is a striking consequence of recent climatic processes and anthropogenic influence. The investigation of endangered wetland areas is of crucial importance, since the complex phenomenon of climate change superimposed by inadequate management strategies seriously threatens these exceptionally rich and diverse areas. Statistical and spatial assessment is a difficult task as tendencies need to be realised and quantified in a highly variable environment. The quantity of water in the landscape is a key factor from this aspect. The database of the study was made up of medium scale and freely accessible LANDSAT satellite images at the greatest possible temporal resolution. The main object of the investigation was the mapping of aridification on a longer 130 year and a shorter 4 year timescale at the protected Upper Kiskunság Lakes, being severely hit by droughts in the past decades. When analysing maps and images certain areas were difficult to classify and results did hardly yield a general and uniform long term tendency. Degradation processes were evaluated by applying both an optimistic and pessimistic scenario. In case of the optimistic evaluation, ambiguous patches were always considered to represent the favourable state in the future (the pessimistic approach worked the opposite way). Concerning the optimistic and pessimistic scenarios 5.6 and 33.5% of the study area will be affected negatively by water management strategies and precipitation decrease, respectively. As a consequence a remote sensing based monitoring activity is suggested by using sensors of great resolution in order to support planning, decision making and nature conservation in the future.

Keywords: climate change; water management; LANDSAT; landscape dynamics; monitoring; remote sensing; wetlands.

1. INTRODUCTION

One of the greatest human impacts ever on the land of Hungary was river regulation and related drainage system construction during the 19-20th centuries. No wonder that probably the most striking consequence of these activities in Hungary has been the regression and transformation of the extremely valuable and productive wetland ecosystems. A long time ago in the 18th century travellers had found here a land of "thousand islands" inundated regularly by the flooding water of rivers. Several studies emphasize that in the second half of the 18th century 75% of the Great Hungarian Plain was in a close to natural state; however, by the 1960s due to extensive regulation and drainage activities wetlands almost disappeared (Somogyi, 2000; Mezősi, 2011). Nowadays the proportion of permanent or at least temporary wetlands on the Great Plain is

hardly exceeding 2-3%, while it was 30-35% before the regulations in general and 50% in the surroundings of our study area (Tóth, 2000). Concerning the Danube-Tisza Interfluve (DTI) 16,000 ha of marshy and swampy, and 38,000 ha of saline grasslands and lakes were affected (Láng et al., 2007). By now the fast regression of wetlands is a general problem. According to certain estimates, half of European wetlands have disappeared in the last century due to climate change, elongating arid periods and intensifying urbanisation (Dawson et al., 2003; Castañeda et al., 2005; Bortels et al., 2011). By the end of the 19th century as a consequence of river regulations time to time flooding of riparian lowlands ceased. Then by the second half of the 20th century canalization works made the drainage of "excess" waters even faster. Saline areas remained more and more frequently uncovered by water. In the mean time secondary, human induced salinization pro-

cesses appeared, affecting increasing areas, since climatically induced warming and evaporation also fuel alkaline and steppe type soil processes (Kovács et al., 2006; Csorba, 2011).

During the 1980s intensifying aridification worsened the state of territories depending on precipitation supply (Kertész & Mika 1999; Rakonczai, 2011). By the end of the 20th century 80 % of saline lakes, protected by law, desiccated on the DTI. Lake beds were occupied by thick vegetation, and original zonation has disappeared (Boross & Biró, 1999; Hoyk & Sipos, 2010). The natural value of the still surviving wetlands is exceptional; however, they have become very sensitive in terms of environmental changes. Therefore, spatial and temporal investigations, rather incomplete today, should provide an indispensable input for decision making, planning and biomonitoring (Kovács-Láng, 2006). Since the Ramsar Convention (1975), the development of an effective international wetland inventory is aimed, providing authentic, reliable and standardized data on global, regional and local scales (Rebelo et al., 2009). Remote sensing (RS) and Geographical Information Systems (GIS) are highly suitable to maintain these datasets (National Wetland Inventry, Nature Conservation Information System-Hungary).

The already outlined changes in water supply justify the need for the evaluation of landscape transformation (Ladányi et al., 2011). This requires a continuous and objective observation focusing primarily on the spatial distribution and intensity of change. From geographical perspective water cover can have a significant role in determining landscape transformations, and as such it is a good indicator of potential changes. Its dynamic regression has a key role in accelerating landscape degradation processes on the DTI (Fig. 1). Recently suggested solutions, like water retention (implemented at certain lakes from the 1990s for example by removing culverts) and water recharging are not solely enough to solve the problem entirely; adaptation thus to the new circumstances is unavoidable.

2. STUDY AREA

The shrinkage of temporary and permanent water bodies was studied on the strictly protected Upper Kiskunság Lakes (UKL), where 40 % of the area is endangered by aridification (Kovács, 2008) (Fig. 2). 85 % of the 13,000 ha study site is part of the National Ecological Network (Natura 2000), two third of it is considered to be a core area; half of it belongs to the Kiskunság National Park. Human influence is manifested in the fact that one third of the 50 m buffer zone of wet patches is not natural according to the 1:50,000 Corine Land Cover data.

Corn, sunflower and lucerne fields reach down to lake shores, thus beside water management the consequences of intensifying landuse have to be also considered. More than half of the investigated territory is artificial or agricultural (primarily arable land), while the remaining lands (44%) are occupied by saline lakes (4%), marshlands (10%), grasslands (23%) and alkaline surfaces (7%). Compared to the 1882 state, most of the originally wet areas are still occupied by lakes, grasslands or swamps, and only 14% has become an arable land or pasture.
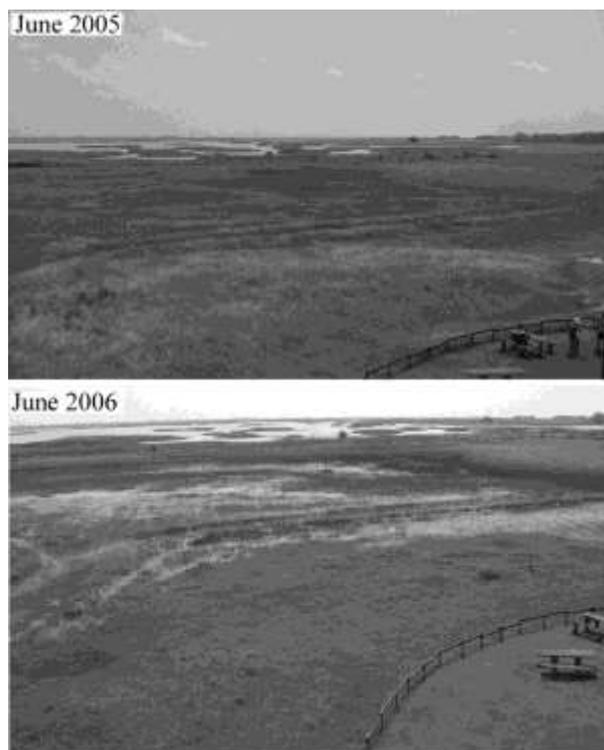

Figure 1. Changing water cover: Kelemen-szék Lake

2.1. Processes endangering wetlands on the study area

The effect of climate change on the water household of wetlands can be determined by calculating the difference between precipitation and potential evapotranspiration (Dawson et al., 2003). In Hungary, the several-year mean of climatic water shortage is the highest on the DTI (higher than 300-350 mm). As a matter of fact, during the 1991-2007 period, eight years were warmer and drier than the average, and it is widely known that the 2000-2009 period was the warmest decade ever on record (Szalai, 2011). Half of the extreme drought events of the past 80 years occurred in the last 20 years (9 events).

The study site is located on the edge of the driest zone of the country. According to Pálfai (2011), drought susceptibility has increased on the DTI compared to the 1931–2000 period.
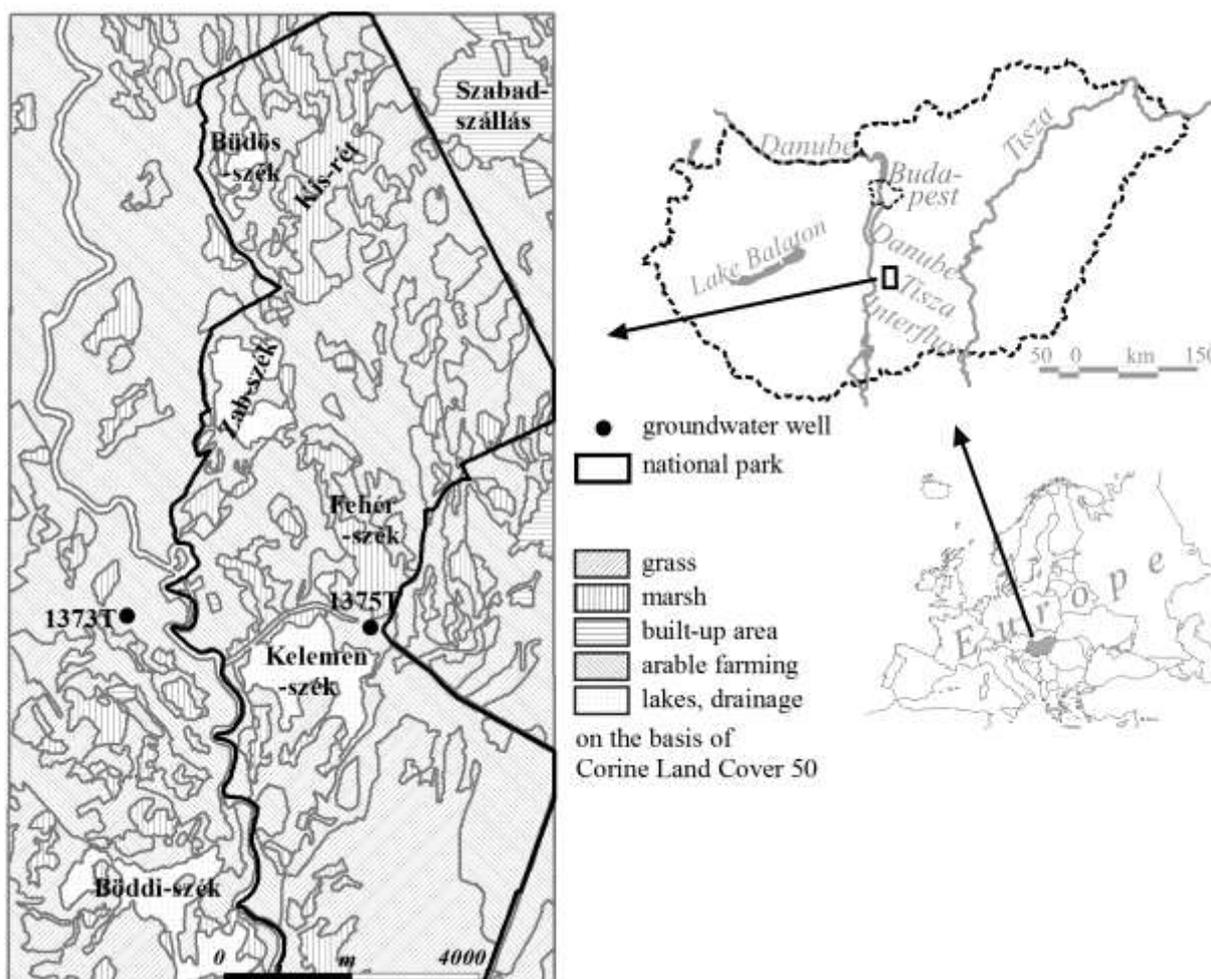
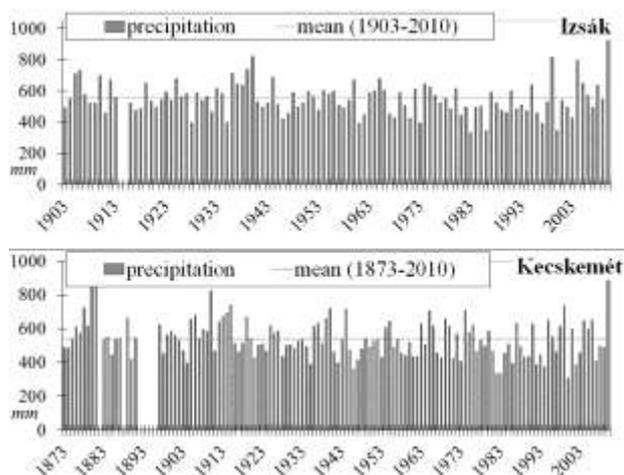Figure 2. The protected Upper Kiskunság Lakes (UKL) and their environs.

Figure 3. Long term variation of annual precipitation in the environs of the study site (OMSZ: Kecskemét and Soltvadkert, VITUKI: Soltvadkert) (the missing 2010 value of Izsák is substituted by data from the Soltvadkert station).

Precipitation is a key source of water, and as such it is important to study both long and short term trends in its change. Based on precipitation data, measured at some locations near the study site either by the hydrological or the meteorological service since the 1870s, a decreasing trend can be realised in the annual, wintertime and also summertime precipitation (Fig. 3).

The average precipitation in the 1961–1990 climatic reference period is already 15-40 mm lower than the long term 110-130 year mean values. This amount equals to the precipitation of an entire month in certain periods. The more recent 30 year average (1981–2010) is also far below the long term 540–590 mm means. Even if the extremely wet year of 2010 is included, January, April, August, September, October, November and December precipitation is still considerably less than long term monthly averages. According to country-wide analyses, precipitation decrease is the most significant in the spring period. Concerning the winter half-year, responsible for most of the annual water supply, in four out of six months a significant, 13-20% decrease was observed. The only month is June when a very little but noteworthy increase can be detected.

On the DTI during the past 15 years following the "rainless" two decades from the second half of the 1970s (the minimum values of the entire dataset occurred in 1983, 1986, 2000) only in 3-4 occasions did

annual precipitation stayed below the reference value by more than 10%. On our study site in the 1977-2004 period annual precipitation exceeded the average value by 10% in three years, while in quarter of the investigated period precipitation was 20% less than the several-year mean, respectively. The reason why there is not an overall decreasing trend in annual precipitation is the outstandingly wet years of 1999, 2004-2006 and 2010. The extreme and concentrated precipitation of 1999 and 2010 might even out long term statistics, but concerning geographical processes one or two outlying years do not make much difference. The problem is even clearer if we consider that both before and after 1999 there were 3-4 quite dry years, and in the first four month of 2011 only 1/3 of the usual precipitation was observed (Fig. 4).
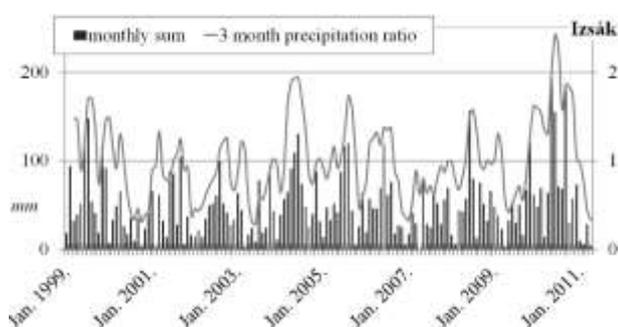

Figure 4. Monthly precipitation values and ratios from January 1999 till April 2011 (source: VITUKI) (missing 2010 and 2011 values were substituted by data from the Soltvadkert station).

The following, more detailed analysis of precipitation in relation with the past 11 years will help the interpretation of high temporal resolution satellite imagery. The 3 month precipitation ratio was calculated by adding up the precipitation of the investigated month and the two preceding ones, and dividing it with the sum of long term (1903–2010) averages for the same three months. It clarifies for example that the reason for extensive water cover in the otherwise arid year of 2000 is the high amount of precipitation in the period preceding the date of satellite image acquisition. Concerning the 3 month precipitation ratio the worst periods occurred from October 2001 to February 2004 and from September 2006 to May 2008. From March 2004 to September 2006 and from November 2009 to January 2011 water supply was much higher.

Thus, from the turn of the millennium, there have been some advantageous water rich periods contributing a lot to the survival of lake systems in the area. Note, that satellite images from 1999 and January 2011 show the greatest water cover ever since inland excess water cover has been assessed in the country. A few positive events, however, cannot override general

unfavourable trends. The real geographical hazard of climate change is not the predicted 3-4°C regional warming, but the continuation and acceleration of the process in the following centuries due to positive feedbacks; in Hungary warming has rather an exponential than linear character (Szalai, 2011).

According to different models, the share of climate change in groundwater table sinking is 15% to 50%, while the share of direct human impacts decreased by now from the previously suggested 50% to 33%. However, severe water shortage developing in the past 25-30 years can primarily be related to the consequences of climate change (Pálfai, 2010). Studies focusing on the changes of groundwater, having a crucial role in water supply, claim that water table sinking hits primarily the sandy, usually elevated territories of the DTI (Rakonczai, 2011). Here, on the Danube Lowlands natural variations due to precipitation change can be observed but there is not a well definable negative trend, nevertheless the amount of groundwater arriving from the elevated sandy territories is continuously decreasing (Fig. 5).
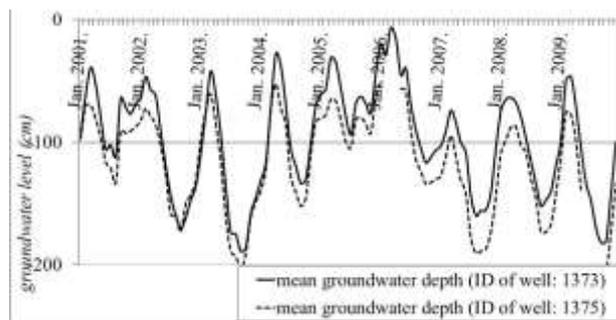

Figure 5. Variation of groundwater on the study site between 2001 and 2009 (source: VITUKI).

Groundwater-fed lakes on the study site (such as the Kelemen-szék Lake) are in direct relationship with subsurface waters down to a depth of 10 m. These lakes are filled with water only in case groundwater level rises above the lake bottom. The amount of groundwater and precipitation input is at the same order of magnitude, but since there is groundwater outflow as well, the net role of subsurface waters is secondary (Simon et al., 2008). Nevertheless, a peculiar east-west seepage system, starting from the Ágasegyháza Lake, flowing towards the Kolon Lake and draining into the Kelemen-szék Lake, might also have a significant contribution to groundwater dynamics (Mádl-Szőnyi & Tóth, 2009).

3. METHODS

The changes in the extent of water cover, the main landscape forming factor on the study site, were determined by using a large set of topograph-

ical maps and satellite images, integrated into a coherent spatial database (Table 1). The differences between successive snapshots determine the direction and sometimes the rate of change. For a long term analysis the close to natural, semi-natural reference state of the DTI can be reconstructed best from the maps of the First Military Survey of the Austro-Hungarian Monarchy from the 18th century. Nevertheless, maps with adequate precision are only available from the 1880s, and as such the preceding 100 years can be evaluated just qualitatively.

In case of historical maps, an average picture is received, as for example prior to the 1859 survey only the 1856-1857 period was considerably arid, and until the 1882 survey only one other extreme drought was recorded, in 1863 (Réthly, 1998) (Table 1). On the other hand, according to the meteorological data series, above average precipitation can be assumed during the 1882 survey (see Fig. 3). It was compiled 8-10 years after the start of flood regulation works but by knowing its similarity to the Second Military Survey, made 23 years earlier, and the imprecision of the First military Survey, it can truly be considered as a referential map in terms of the close to natural state. In 1959-1960 annual and winter precipitation were well below the several-year average, while 1981-1982 was part of a long lasting dry period. Droughts are natural phenomena on the investigated territory, the problem of desiccation is, however, the most severe if there is water shortage already during early summer. In this case the situation of wetlands can be critical. By utilising the advantages of high temporal resolution satellite images the most favourable, wettest periods, could be selected for the analysis. These were mostly represented by June images.

From the database of the US Geological Survey (GLOVIS) and the Department of Physical Geography and Geoinformatics, University of Szeged 10 LANDSAT TM and ETM+ multispectral images could be selected for the longer term, 1986-2011 analysis owing to good weather conditions during June acquisition. Based on the entire dataset, consisting of 13-15 overlays, the changes of more than 220 years could be outlined, and the last 30 years, being more important in terms of recent aridification, can be analysed in more detail.

The amplitude of a phenomenon with some years of periodicity can be naturally higher than the trend of climate change. The decision between trend or variation was made on the basis of the degree and rate of changes, thus it was very important to investigate surface elements at a high temporal resolution. Low lying lakes and swamps exhibit a remarkable seasonal variation, making the realisation of true trends quite difficult (see Fig. 1). An adequate trend analysis can only be made by determining the degree of variability; preferably by using high spatial and temporal resolution datasets. To determine the domain of possible values the analysis of extremes may provide a point of reference. From the local consequences of climate change the increasing frequency of droughts and short but intensive precipitation events must be emphasized. Thus, lake basins can get filled up or dry out in a relatively short time. Taking into consideration the above, the high resolution analysis of a period with both types of extremes may provide useful reference values for the near future. Processes observed around the outstandingly variable year of 2000 can return later as well; consequently, short term variation was analysed in the July 1999 – October 2003 period by applying 22 satellite images (Table 1). This analysis also allowed the assessment of the effects of a short, relatively humid period on a long term unfavourable aridification process.

Multispectral 30 m geometric resolution LANDSAT images enabled mapping at a maximum scale of 1:50,000. The temporal resolution is 16 days. To verify and supplement our results LANDSAT MSS image from 1979, 1m resolution aerial photographs from February 2000 and a 5 m resolution RapidEye satellite image from 2011 were applied. Georeferencing was made either on whole images by using topographic maps and receiving a maximum RMS error of 0.4-0.8, or by the transformation of UTM projected ortho-corrected image crops (Reproject function) receiving an RMS error <0.1. Factors making monitoring-type analyses more difficult (atmospheric conditions, phenological phases, sun altitude) were reduced by using numerous very high quality images acquired by the same sensor, in the same period of the investigated years. The maximum imprecision of the best historical map (Third Military Survey, 1882) was 30-50 m.

Changes can be detected using different RS methods: subtracting one image from the other, calculating the ratio of bands from images of different dates, comparing vectorised data or classified images or applying image transformation (Ozesmi & Bauer, 2002; Kleinod et al., 2005).

In both the evaluation of water content and the detection of vegetation change, the simultaneous use of these techniques on medium scale imagery can yield such methodological advantages which cannot be overtaken even by higher resolution field mapping (Rakonczai et al., 2003; Kleinod et al., 2005). Using map series for analysing landscape change on the DTI is more general (for example Dóka & Alexa, 2011) but less productive; however, these map based analyses can also detect dramatic changes in the extension of wetlands (Gottgens et al., 1998).

Table 1. Maps and images used for long term and high temporal resolution analyses.

Long term analysis		High temporal resolution analysis
maps (scale)	satellite images (sensor)	satellite images (sensor)
1783 (1:28.800)		
1859 (1:28.800)		
1882 (1:25.000)		
1960 (1:10.000)		
1982 (1:10.000)		
	June 1986 (LANDSAT TM)	
	June 1994 (LANDSAT TM)	
	July 1999 (LANDSAT ETM+)	17. Jul. 1999. (LANDSAT ETM+)
		09. Aug. 1999. (LANDSAT ETM+)
		28. Oct. 1999. (LANDSAT ETM+)
	June 2000 (LANDSAT TM)	14. Apr. 2000. (LANDSAT TM)
		08. Jun. 2000. (LANDSAT ETM+)
		10. Jul. 2000. (LANDSAT ETM+)
		11. Aug. 2000. (LANDSAT ETM+)
		20. Aug. 2000. (LANDSAT ETM+)
		14. Oct. 2000. (LANDSAT ETM+)
	June 2001 (LANDSAT ETM+)	07. Mar. 2001. (LANDSAT ETM+)
		03. May 2001. (LANDSAT ETM+)
		27. Jun. 2001. (LANDSAT ETM+)
		30. Aug. 2001. (LANDSAT ETM+)
	June 2002 (LANDSAT ETM+)	22. Feb. 2002. (LANDSAT ETM+)
		23. Jun. 2002. (LANDSAT ETM+)
		26. Aug. 2002. (LANDSAT ETM+)
		22. Mar. 2003. (LANDSAT ETM+)
		14. Apr. 2003. (LANDSAT ETM+)
		16. May 2003. (LANDSAT ETM+)
		20. Jul. 2003. (LANDSAT TM)
		06. Sep. 2003. (LANDSAT TM)
		15. Oct. 2003. (LANDSAT TM)
	June 2006 (LANDSAT TM)	
	June 2007 (LANDSAT TM)	
	June 2010 (LANDSAT TM)	
	July 2011 (LANDSAT TM)	

The classification of water content in the multispectral data space can either be done by controlled or automated methods. Bortels et al., (2011) made ISODATA analysis on LANDSAT and ASTER images when studying a 25,000 ha study site, where the area of swamps and water bodies decreased by 32% within 15 years. In case of a rapidly degrading large area with wetland habitats, Castañeda et al., (2005) reclassified a large set of satellite images following radiometric correction and automatic classification by applying visual evaluation and principal component analysis. Using similar satellite imagery in the international wetland inventory programme Rebelo et al., (2009) mapped several study sites by using the Maximum Likelihood method.

Based on our previous experiences, an automatic (ISODATA) classification was applied in this study on each of the 29 images. This way 30 classes were generated (tolerance threshold: 0.95), which were then reclassified visually on the basis of reference-

ential data. Images were processed with ERDAS Imagine 9.1. For the secondary refining of classes spectral indices were applied.

Conditions of wetness were determined primarily by the Tasseled Cap Wetness Index (WI) (1):

$$\text{WI}_{\text{ETM+}} = 0.263_{\text{ETM1}} + 0.214_{\text{ETM2}} + 0.093_{\text{ETM3}} + 0.066_{\text{ETM4}} - 0.763_{\text{ETM5}} - 0.539_{\text{ETM7}} \quad (1)$$

where ETM1…ETM7 are different wavelength ranges.

Vegetation cover was determined by the normalised vegetation index (NDVI) (2):

$$\text{NDVI} = (\text{TM4-TM3} / \text{TM4+TM3}) \quad (2)$$

Maps showing the final categories such as "open water or high water content area", "waterlogged area", "dry surface" were primarily made by automatic classification, or secondarily by considering the WI index values. The above mentioned categories were also identified on the digitized 19-20th

century topographic maps based on their legend.

4. RESULTS

4.1. Long term changes in the area of the ukl

The first geometrically precise map of the area was made during the Third Military Survey. At this date one third of the study site was waterlogged (Fig. 6).
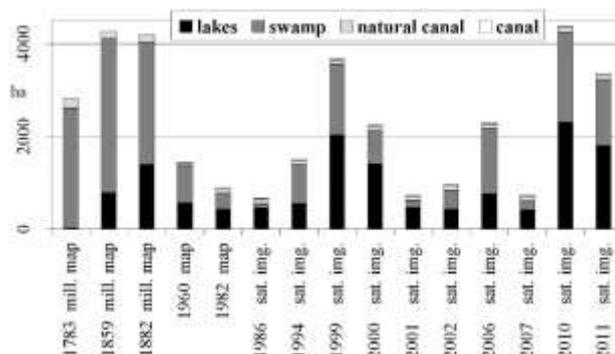

Figure 6. Hydrogeographical change of wetlands from the 18th century till nowadays.

By looking at the data series, it turns obvious how variability can make the realisation of trends difficult. Differences between separate years can be observed, but a short favourable period is enough for the return of the original state.

As a matter of water management measures from the 19th century, and precipitation decrease from the 1970s (see Fig. 3) the most striking change of wetlands has occurred in the century subsequent to the 1880s. During this period 84 % of water-rich areas disappeared and only 5 % of the total area remained waterlogged. In the meantime, the extension of swamps decreased by 96 %, and by 1960 the area of open water surfaces dropped by 60%. Variations in precipitation do not explain such a decrease. Therefore, the above changes were mostly the result of 20th century drainage works subsequent to flood protection in the late the 19th century. Interestingly, in 1994 due to an above average precipitation in one hydrologic half-year the area of waterlogged territories increased considerably and reached once again values characteristic 30 years before.

The effect of rainy years following the second half of the 1990s is very significant and clearly detectable on 1999-2000, 2006 and 2010-2011 images. The extension of the total waterlogged area was tremendous in 2010 and 2011, higher than ever measured. What is more important the proportion of open water surfaces within waterlogged areas increased significantly and exceeded 50 %. Lake surface area was one and a half times greater than during the ref-

erential Third Military Survey. Therefore, in a hydro-geographical sense in 2010 the close to natural state of the study area practically revived (Fig. 7). Water exchange between lakes, ceasing from the 1980s, restarted and in case of several lakes (Kelemen-szék Lake, Zab-szék Lake, Büdös-szék Lake, Böddi-szék Lake) open water surface has never been so extensive. It is noteworthy, however, that the Kis-rét Lake once having the largest open water surface is rather swampy nowadays. Based on spatial comparisons from the Third Military Survey up till now half of the investigated territory can potentially be waterlogged.

Conversely, after the extensive inundations of the 1999-2000 period and 2006 low water cover values, characteristic of the 1980s, returned shortly. By 2001 3/4 of the water cover disappeared permanently in the lack of adequate water supply. The difference between 2006 and 2007 is especially striking, as due to unfavourable conditions (lack of precipitation) 50 % of open water surfaces and 85 % of swampy areas disappeared in only one year. It is clear therefore that one or two wet years are not enough to bring an end to unfavourable processes being present from the 1970s. A similar conclusion was made by Hoyk (2010) in the area of the nearby Szappan-szék Lake.

High water cover values of 2011 are also related to the record precipitation of the previous year, though 1/5 of open water surfaces and 1/4 of swampy areas dried up during the rainless first half of the year (however, values are still close to the 1999 record). Seemingly, years with extreme precipitation are the last chance for the survival of the territory's ecological potential. Nevertheless, these rainy periods are not general at all, and in the lack of them landscape degradation can accelerate.

As a consequence of the diversity of images it is hard to determine the presence and the general degree of aridification (Fig. 8). In the light of the referential status, based on 1882 and 1962 values, several phenomena observed do not unambiguously comply with suspected long term processes (for example a surface is covered sometimes by open surface water, other times it is just waterlogged or even dry and vice versa).

Regarding figure 8, the category of "permanently waterlogged" stands for areas being swampy and covered by water for the entire 130 year study period. Wetland patches delineated in years of close to average precipitation are classified as "usually waterlogged", while areas inundated during high waters are named "occasionally waterlogged". The category of "moderately drying" stands for areas which underwent a lake to swamp or swamp to dryland transition and also for territories which were covered by water only during the greatest inundation periods.
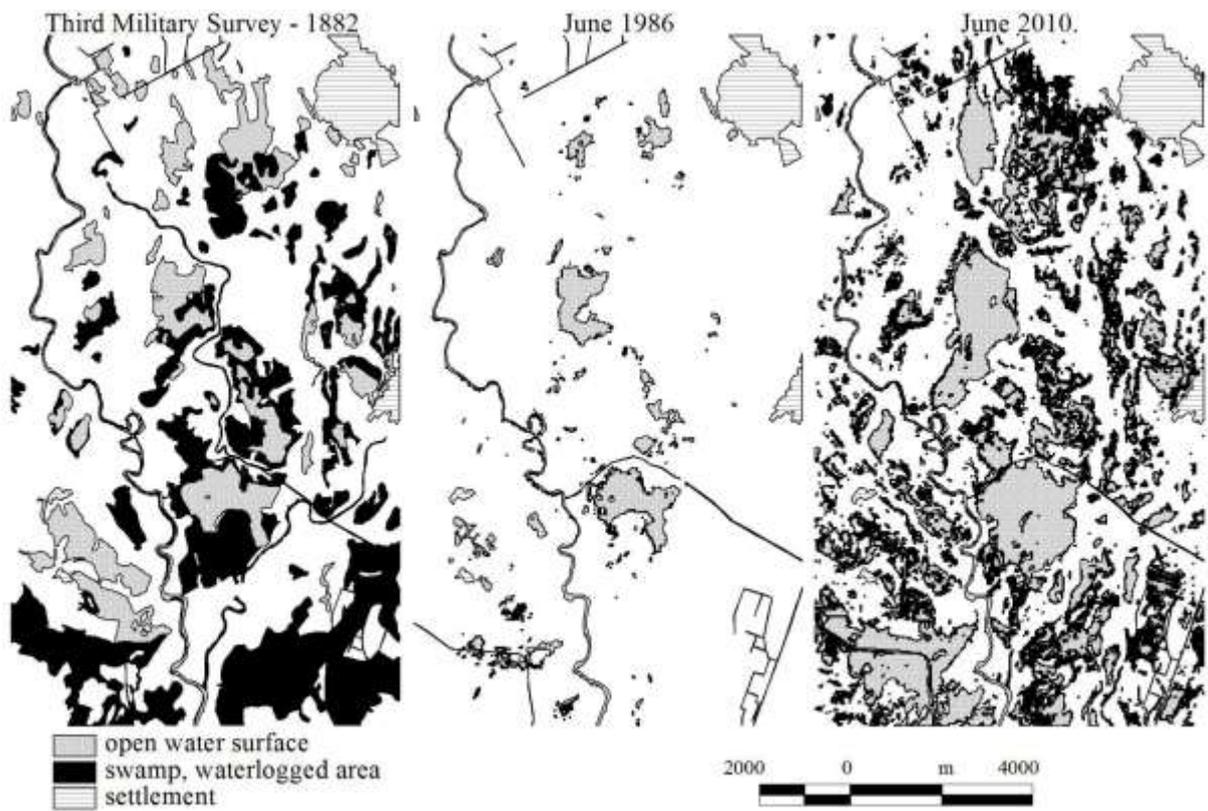
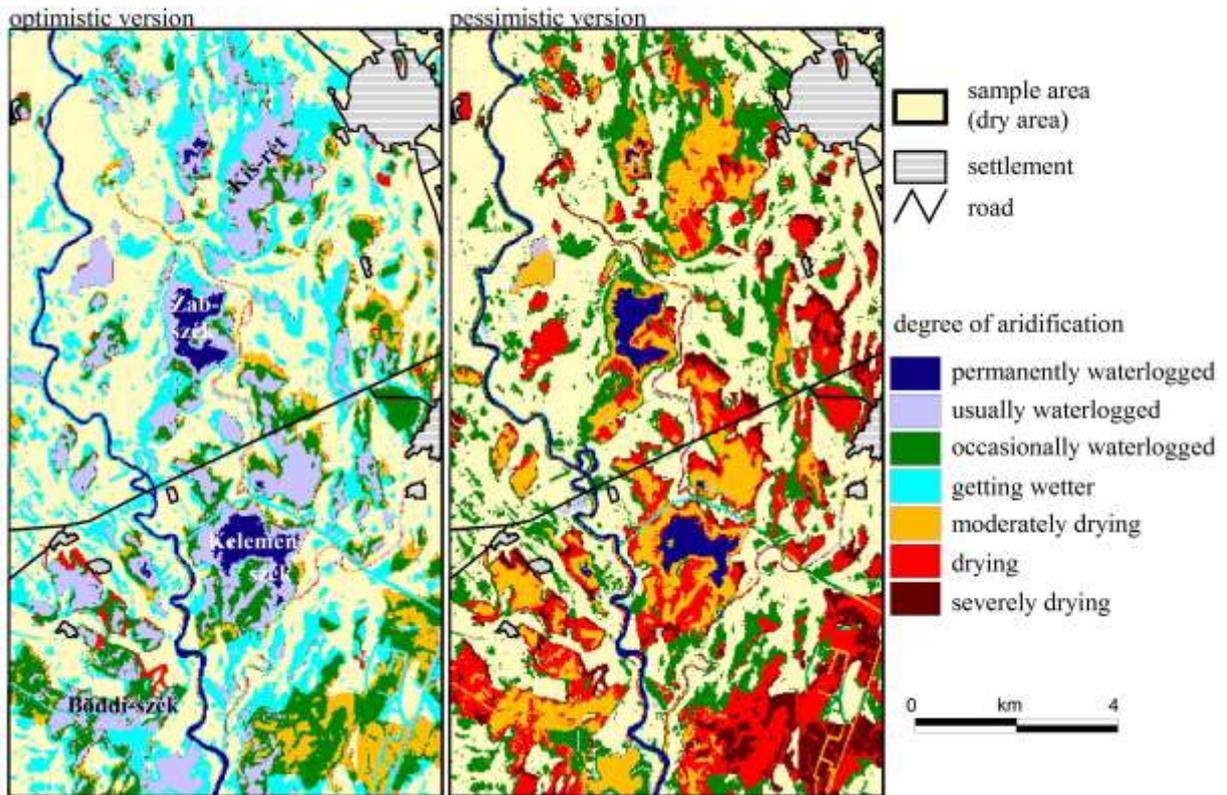Figure 7. Spatial distribution of waters and waterlogged areas at different, characteristic dates.

Figure 8. The spatiality of aridification from the optimistic and pessimistic aspects.

The class of "drying" collects those originally waterlogged territories which were usually dry in the past few decades. If the dry phase was continuous and permanent since the 1980s the patch was considered to be "severely drying". The category of "getting wetter" signs an opposite process and marks

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surfaces which were originally dry but become waterlogged. When determining the degree of degradation, especially because there were questionable areas, two scenarios, an optimistic and a pessimistic were outlined. In case of the optimistic version always the more favourable, i.e, higher water content category was attributed for ambiguous patches (for example in case of overlapping between categorises such as "occasionally waterlogged" and "moderately drying"), while in case of the pessimistic version evaluation was made the other way around.

According to the pessimistic and optimistic versions of evaluation, 33.5 % and 6.5 % of the study area has been affected by drying on the basis of the 130 year long data series. In case of the positive scenario no severely drying surfaces can be identified; conversely, by using the opposite approach 6.3 % of the territory falls into this category, and further 15.5% can be qualified as drying. Nevertheless, the pessimistic results are still better than those yielded by earlier analyses, when the 1882-2002 period was studied and 40 % of the study area was found to be endangered by aridification (Kovács, 2008).

The spatial delineation of aridification hazard is especially important in case of once larger water bodies and saline or swampy areas connecting these, because the ecological network would be severely hit by their desiccation. Due to the drying up of waterlogged connections ecological corridors may disappear in the once upon a time very mosaic landscape. With the exception of four larger waterlogged patches each of the former lakes has ceased to exist as an open water body.

4.2. Variability – high temporal resolution analysis

Figure 9 clearly highlights that precipitation provides the main water supply. The values of the retrospective 3 month precipitation ratio index explain well both the decreasing water cover within one year (for example 2000) and the expansion of lakes and waterlogged surfaces in others (for example 2001, 2002, 2003). With the exception of 2002 the study area is characterised by an extreme variability. Even in case of the definitely dry 2003 spring values are three times higher than autumn ones. In this year one rainy autumn month was enough for the formation of an additional 200 ha open water surface. Based on the minimum and maximum extension of water cover in the 1999–2003 period, on average 2225 ha, i.e. 1/6 of the total territory is affected by the annual water cycle.
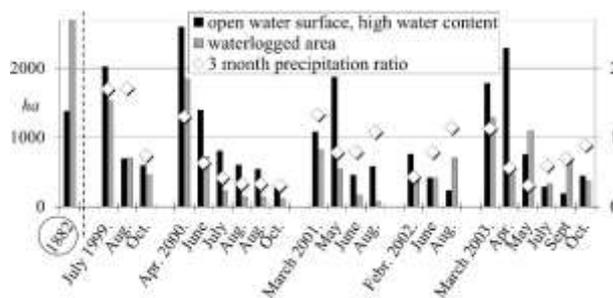

Figure 9. Relationship between precipitation and the extension of waterlogged areas (1882 data are informative reference values).

A very characteristic water cycle can be accounted for the referential year of 2000, affected considerably by both excess water and drought. During the period of maximum water content 1/3 of the study area was under water cover. As a matter of meteorological factors (in this year 3/4 of monthly mean temperatures were above the average) values decreased rapidly in April. By June the extension decreased by 50%, then by July this value was halved again and finally in October only 10% of the original water cover remained. Approximately 4000ha of waterlogged area disappeared between April and October at an average rate of 22 ha/day. If calculating with a shallow, in average 30 cm water depth this amount equals to the evaporation and infiltration of 120,000m^3 water. This is much more than the largest annual water shortage or surplus detected on the territory so far. The mosaic character of the landscape raises the hope that aridification is not irreversible.

Contrary to the above, several other parameters do support the generally decreasing water content experienced also in the trend analyses. Although in May 2001 and April 2003 relatively large quantities of water were detected on the study area, as a consequence of the precipitation poor second half of 2000, and the dry periods of October 2001 and February 2004, by early summer, in around one and a half months, water cover decreased to 1/3-1/4 of the original value in both years. On the June 2001 image, in spite of the relatively high precipitation in the first half of the year, only a fourth of the 2000 record inundation can be detected and by the same period of 2002 only the size of temporary swamps was higher than average. Concerning the late summer and autumn period, the only year was 1999 when water content was higher than usual, but this affected only the area of temporary waterlogged territories; values concerning open water surfaces were only slightly higher than in the subsequent years of 2000 and 2001. In 2002 and 2003 open surface decreased further though the area of temporary inundations increased.
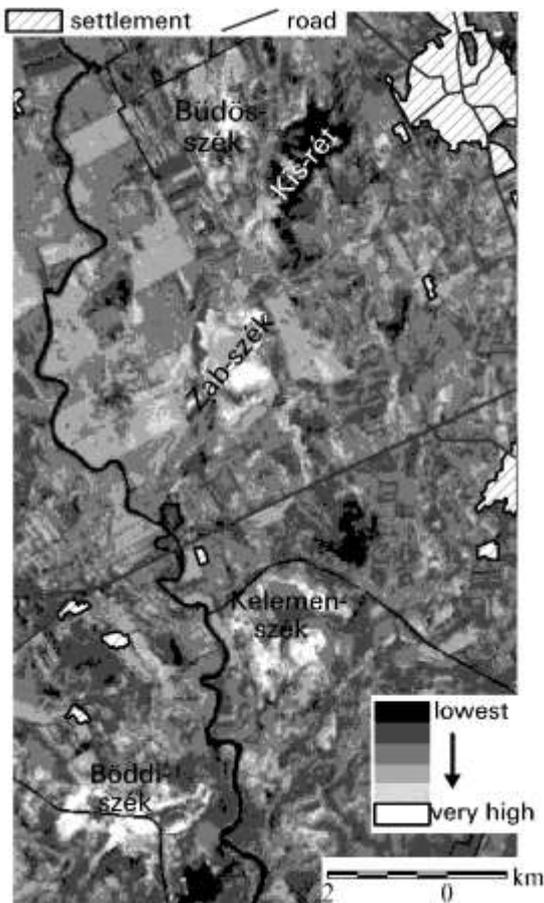
Figure 10. Variability of water content based on the 1999–2003 period.

Based on the spatial analysis of the 1999–2003 period, 22 % of the study site had a variable water content, though the degree of variation was moderate (Fig. 10). On surfaces of intensive variation the determination of longer term trends is more uncertain, on the other hand degradation can be more harmful if it affects processes on less variable territories. The optimistic and pessimistic versions of the long term analysis were refined with the spatial results of temporal variability, meaning that those patches were analysed further where variations were low (Fig. 11).

Based on the refined map, the aridification value of the pessimistic version decreased from 33.5% to 24.7%. This way 20% of the study site would remain a wetland. The 6.5 % value on the optimistic map decreased to 5.6%. Nevertheless, several endangered territories are located next to open waters for example: Kis-rét Lake, southern part of Zab-szék Lake, northern and southern vicinity of Kelemen-szék Lake and northern part of Böddi-szék Lake.

By looking at figure 11 one might ask, which scenario is closer to reality after all? By considering decreasing water cover values based on long term observations and rapid drying up after high water events, it seems as if lakes are more endangered than it could be suggested on the basis of the optimistic version.
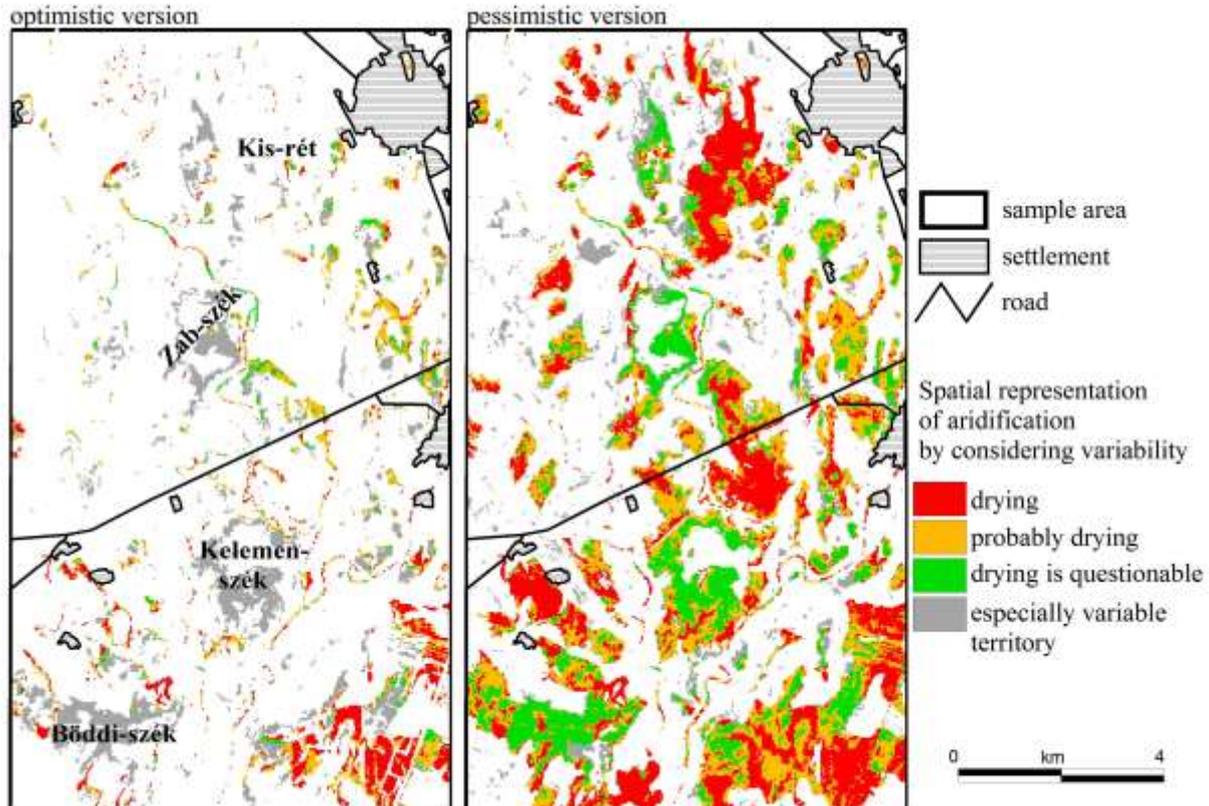

Figure 11. Spatial representation of aridification by considering variability.

On the southwestern, southeastern, eastern and central part of the study site even the most optimistic approach does reveal problems. The pessimistic version, however, hides the favourable changes of the past few years, i.e. considerable amount of precipitation in certain years.

5. CONCLUSION

Concerning the "threats" of climate change on earth surface processes gloomy predictions are usually more effective means in the hand of the media and decision making. Changes in surface waters, a key indicator addressed in the present study, unfortunately supports rather the pessimistic views. In our opinion, however, it would be a mistake to take only one stand when objectively investigating such a highly variable territory as the UKL. Therefore, instead of unambiguous results rather a framework is provided in the present study to describe the degree of landscape change. The probability of the outlined optimistic and pessimistic scenarios can be determined more precisely with regular field measurements and RS monitoring.

These measures can be effectively carried out by using the methodology and database built up in the present study. Nevertheless, by realising the strong relationship between precipitation and hydrogeography, considering climatic trends outlined earlier, and knowing geographical processes in the region, the results of our pessimistic approach seem to be more reliable in the long run.

High resolution monitoring could also be a used by nature conservation planning to delineate problematic territories. The trends determined by the statistical analysis of recent changes might not be valid for the future; however, by time to time analysis of variability the possible long term shifts in the domain of water content values can be resolved.

Subsequent to the dry 1980s the effect of the more humid years from the end of the 1990s is definitely favourable, though positive effects are not general.

Most of the originally waterlogged territories are only partially revived and for short periods. Present results comply with our earlier conclusions, namely in terms of the once permanently waterlogged areas a continuous drying trend can be suspected with periods of more precipitation when wetlands are temporarily reactivated.

ACKNOWLEDGEMENT

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