Journal of Env. Geogr. Vol. I. No. 3-4. pp. 7-14

EVALUATION OF CHANGES AND INSTABILTY OF WATER CONTENT USING REMOTE SENSING METHODS IN A NATURE CONSERVATION AREA

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Abstract

The most significant landscape forming factors in the Great Hungarian Plain are humans and water. Before the regulation of the waterways one quarter of the present-day territory of Hungary belonged to the complex network of periodically or permanently inundated flood plains, marshes and swamps. Owing to human activities and the climatic changes observed in the last decades, processes that indicate landscape change have occurred in the Great Hungarian Plain (Rakonczai J. 2007). Loss of wetlands is a major process of landscape change.

Evaluation of geographical changes caused primarily by water shortage is a difficult task as on the one hand only a limited data set is available and, on the other hand all the processes taking place in the area have to be known and understood in order to recognize the exact change. Habitats are extremely changeable and after the early summer floods, sometimes they entirely dry up to the end of the season. For detection and accurate evaluation of the long term changes lasting from the 19th century to present days the spatial and temporal development of instability has to be revealed. This has been determined on the basis of a series of high time resolution satellite images by digital image processing methods for the geographically very interesting period 1999-2003.

Keywords: wetlands, excess water, change, instability, landscape dynamics, LANDSAT, spectral index

RATIONALE

A new phase of landscape evaluation is indicated by the assumption that in a rather short period of time change is expected in the climatic conditions. As a result of the likely climate change and the human activities increasing aridification can be observed in the Great Hungarian Plain. All the natural processes included in aridification are long-period ones and affect every other factor and process. Water shortage induces changes in the landscape (Barna Gy. 2008, Rakonczai J. – Kovács F. 2008), which are aggravated by the forecast that the acceleration of degradation can be expected in the near future. The water shortage has an adverse effect in the summer period, and in the wetland ecosystems the persistently low water level may lead to landscape transformation.

Examination of the dynamics of those landscape factors that are dominant due to the local characteristics (e.g. water coverage, vegetation) is of key importance in the accelerating degradation processes (Kovács F. 2007, Ladányi Zs. et al. 2009).

The amplitude of multi-years period of fluctuations of a phenomenon can be naturally higher than the short-term effects of climate change, which makes the geographic evaluation of the effects observable on the surface more difficult. The rate and speed of change settles whether it is change or fluctuation, this is why the long-term studies are of considerable importance. The main point in the study of change is not the values the studied variable took on in a time series, but rather the values it could have taken on at a given time, and whether there is a change in these values or not. Consequently the change of process is interpreted as the change of the probability distribution of the possible values (Nováky B. 2003). The analysis of extreme situations could present a basis for the determination of the possible range of values characteristic of a geographic phenomenon.

The necessity of such studies is proven by the prognosis for the near future, in which extreme weather events are given high priority. The increase in excessive rainfall events (i.e. short but intense precipitation) and in drought frequency also affects the appearance of surface water. Analyses at high spatial and temporal resolution make the evaluation of instability possible, which is essential for a detailed evaluation of change.

The study area

Saline areas located in the Danube valley, having one of the most extreme characteristics in Hungary, have been put under protection. "… and in the absence of levees the river flooded the low-lying areas of the Upper-Kiskunság… The former traveler found himself in the world of thousand island…" (Illyés B. 1992). The nearby early Holocene main river bed and the Kígyós brook were navigable (Erdélyi M. 1960). Approximately 75% of the Danube plain was in near-natural state in the second half of the 18th century, however, at the end of the 1960s the proportion of standing water was only 0.3% (Pécsi M. 1967, Bíró M. – Molnár Zs. 1998).

The remaining wetlands are highly important from the point of view of nature conservation and tourism, but it is more and more difficult to maintain their present condition as they are very sensitive to environmental changes. The strictly protected Upper Kiskunság Lakes, classified as natural habitat complex in the National Ecological Network, belong to the category of shallow water (*Fig. 1*). Half of the 13,000 ha study area is national park, and 85% of the area is part of the ecological network. 44% of the study area is covered by alkaline lakes, swamps and grasslands. One third of the 50 m area surrounding the wet patches is not near-natural in character. Comparing the maps of the Third Military Survey in 1882 with the present landscape it can be concluded that in most cases lakes and swamps can be found in the same place where there were wetlands earlier, only 14% of these areas have become arable or pasture. In case of the groundwater under pressure, a 2.5-3.5 m difference in water level can be observed within a distance of 1.5 km (Molnár B. – Kuti L. 1978). The salt content of the lake water is 700-1200 mg/l (3000 mg/l in Kelemenszék) (Schmidt A. 2003).

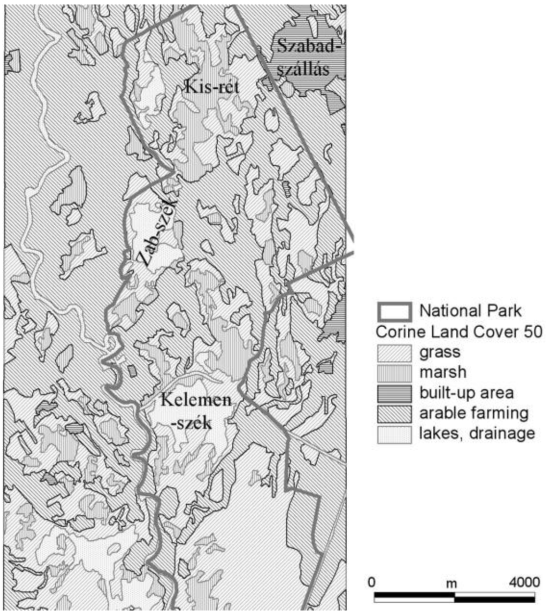

Fig. 1 Land cover of the Upper Kiskunság Lakes

Recent geographical processes endangering wetlands

In the course of flood regulation and inland drainage one million ha wetland habitats were destroyed (Istánovics V. – Somlyódi L. 2002). In the Danube-Tisza Interfluve 16,000 ha swampy, marshy areas and 38,000 ha saline grasslands were damaged (Láng I. et al. 2007). It is only the precipitation and the groundwater that can recharge water.

Based on the data set of 135 years it can be stated that there is a decrease in precipitation concerning the yearly, seasonal and monthly means (Láng I. et al. 2007). The decrease in the period of 1956-2005 was more than 6%; there is a decrease in precipitation in spring, summer and winter as well (Bihari Z. et al. 2006), consequently the time periods important in the recharge of lakes are also affected. Despite there are favorable periods in aridification, a significantly decreasing trend in precipitation can be observed (Konecsny K. 2006, Pálfai I. 2007).

In the Danube-Tisza Interfluve there was a more than 4.8 km^3 deficit in groundwater in 2003 compared to the 1970s (Rakonczai J. 2007), therefore less and less groundwater flows from the higher grounds to the lakes.

The winter water recharge, necessary for the lifecycle of alkaline lakes, does not take place for some time. In the Danube-Tisza Interfluve all lakes have been in extreme danger since 1980, as they are dry even in spring (Iványosi Sz. A. 1994). Spatial and temporal analyses could reinforce the main objective of conservation planning i.e. the rehabilitation of degraded habitats.

PRINCIPLES OF THE ANALYSIS AND THE APPLIED REMOTE SENSING METHODS

The extreme seasonal instability of lakes and swamps is an important aspect in the accurate evaluation of wetlands sensitive to external factors, and thus it is suitable for the spatial and temporal evaluation of the process of change. Two types of evaluation could be applied to assess the degree of changes: one covering a long time period, based on maps, photos and images; and another one covering a shorter time period, based on photos and images, but having high time resolution. Making use of the accurate maps made since the 19th century, the aerial photographs taken since the 1950s, and the satellite images created since the 1980s, the last 130 years can be analysed. For a dynamic landscape evaluation based on remote sensing methods the time resolution should be increased in case of extremely sensitive areas (e.g. saline areas) as the dynamics of moisture conditions can be given only in this way. For the analysis of fluctuation a short period would be ideal when many different states of the wetlands are observable. The evaluation of a very dry and a very wet period is needed for the determination of the possible range of values, therefore the years 1999 and 2000, when there were extreme moisture conditions in the study area, could be appropriate reference periods (*Fig. 2*). The increase in the frequency of short but intense precipitation events and droughts is one of the local effects of climate change. There is a possibility that the lake beds recharge quickly but it is also possible that they dry up quickly and permanently. The processes taking place in the extreme year of 2000 could be characteristic of the near future. The spatial-statistical analysis of extreme weather events can contribute to the examination of the hydrological budget of wetland habitats as the objective spatial delimitation based on time series cannot be accomplished by the classical mapping methods.

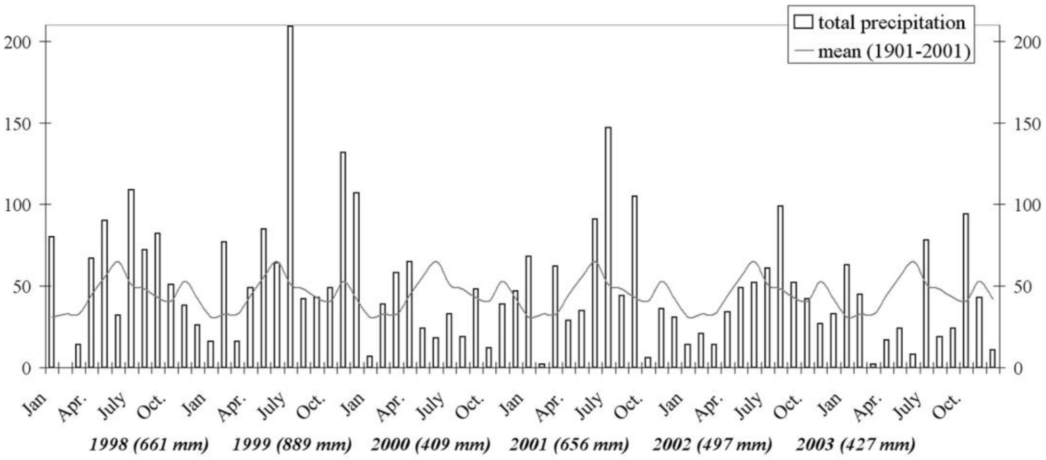

Fig. 2 Precipitation in Izsák in the period 1998-2003 (source: Hydrological Almanach)

Although drought and aridity are characteristic of the climate of the study area, the problem of aridification is the most serious if there is no water in the area even in the early summer period. Taking advantage of the remote sensing data acquisition the differences between the years have been analysed according to the most favorable i.e. the wettest conditions, therefore the images for June have been added to the data set for each year under scrutiny. If even this optimal state is unfavourable, wetlands are in a critical condition.

Thanks to the database of the US Geological Survey and the Department of Physical Geography and Geoinformatics at the University of Szeged, 22 LANDSAT TM and ETM+ multispectral images are available for the short time period between July 1999 and October 2003 (*Table 1*). The study makes it possible to analyse the effects of a short and wet period within a period becoming more and more arid in the long run. Aerial photographs taken in 2000 were used for reference analysis.

Making use of the data content of multispectral images three different spectral indices were applied (ERDAS support, Mucsi L. 2004, Szatmári J. 2005). Moisture conditions were determined by the wetness index of the Tasseled Cap, which has two versions because of the

Table 1. Remote sensing and cartographic database

Year of mapping (scale) Change analysis	*Satellite images (name of sensor) Change analysis*	*Satellite images (name of sensor) Instability analysis*
1783 (1:28.800)	June 1986 (LANDSAT TM)	17. July 1999. (LANDSAT ETM)
1859 (1:28.800)	June 1994 (LANDSAT TM)	09. Aug. 1999. (LANDSAT ETM)
1882 (1:25.000)	June 2000 (LANDSAT TM)	28. Oct. 1999. (LANDSAT ETM)
1960 (1:10.000)	June 2002 (LANDSAT ETM)	14. Apr. 2000. (LANDSAT TM)
1982 (1:10.000)	June 2006 (LANDSAT TM)	08. June 2000. (LANDSAT ETM)
	June 2007 (LANDSAT TM)	10. July 2000. (LANDSAT ETM)
		11. Aug. 2000. (LANDSAT ETM)
		20. Aug. 2000. (LANDSAT ETM)
		14. Oct. 2000. (LANDSAT ETM)
		07. Mar. 2001. (LANDSAT ETM)
		03. May 2001. (LANDSAT ETM)
		27. June 2001. (LANDSAT ETM)
		30. Aug. 2001. (LANDSAT ETM)
		22. Feb. 2002. (LANDSAT ETM)
		23. June 2002. (LANDSAT ETM)
		26. Aug. 2002. (LANDSAT ETM)
		22. Mar. 2003. (LANDSAT ETM)
		14. Apr. 2003. (LANDSAT ETM)
		16. May 2003. (LANDSAT ETM)
		20. July 2003. (LANDSAT TM)
		06. Sept. 2003. (LANDSAT TM)
		15. Oct. 2003. (LANDSAT TM)

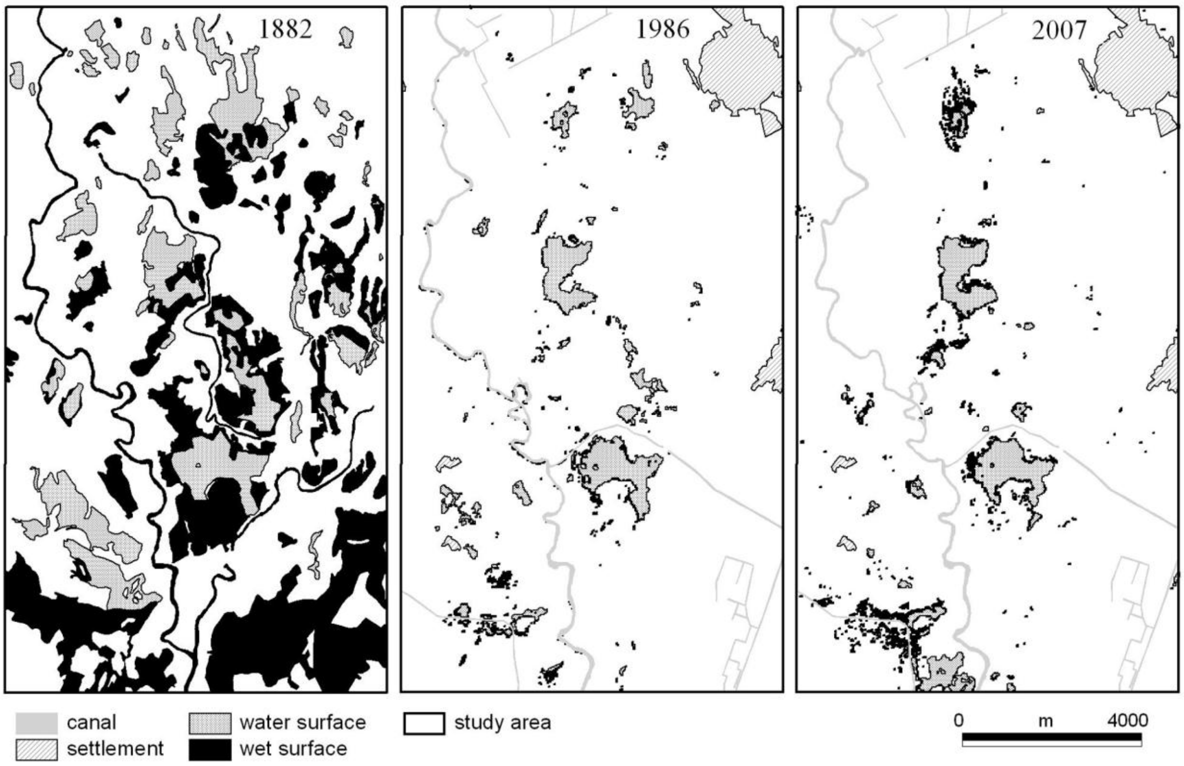

Fig. 3 Decrease in wetlands and transformation of the ecological network

different sensors:

$WI_{TM} = 0.1446_{TM1} + 0.1761_{TM2} + 0.3322_{TM3} + 0.3396_{TM4} – 0.6210_{TM5} – 0.4186_{TM7}$

$WI_{ETM+} = 0.262_{ETM1} + 0.214_{ETM2} + 0.092_{ETM3} + 0.065_{ETM4} – 0.762_{ETM5} – 0.538_{ETM7}$

where: TM1, TM2. …, TM7, and ETM1, ETM2, …, ETM7 are different wavelength ranges.

Water Mask index shows the amount of water in wetlands: WM=TM5/TM2.

The vegetation cover on areas with different moisture content was determined by the Normalized Difference Vegetation Index: NDVI=(TM4–TM3)/(TM4+TM3).

The result maps including the categories of “open water surface and area of high water content,” “waterlogged area,” “dry surface” were created by complex queries, in which the data of index images (WI, WM, NDVI) were taken into account. If one of the indices indicates water in an area, which is neither dry nor covered by water according to all indices, it is categorized as „area of high water content”.

From near-natural to present-day conditions – long-term changes of wetlands

On the basis of the entire data set the changes of the last 130 years can be analysed, but a more detailed analysis of the last 50 years – which are important in terms of aridification – is also possible (*Fig. 3*).

The data of the Third Military Survey in 1882 are interpreted as reference values; the river regulation had an effect on the extent of inundation, however, climate change did not. The effect of flood regulation and inland drainage is well demonstrated by the rapid drying up in the period of 1882-1960, when two thirds of the water disappeared. Beside the water management in which water considered to be harmful was drained quickly, in case of lakes and marshes recharging only from precipitation aridification also appeared in the second half of the 1970s. As a consequence, another two thirds of the remaining wetlands became characteristically dry surfaces until 1986. In 100 years the area of wetlands decreased by more than 88%. The extension of areas of high water content in 2002 and 2007 was similar to the unfavourable year of 1986; however, in the years of 2000 and 2006 there were high water content values (*Fig. 4*).

The proportion of wetlands was 32% in the study area at the time of the Third Military Survey, but in 1986 and 2007 it was only 4-5%. Until the end of the 1980s serious spatial and qualitative degradation could be observed in wetlands. The positive effects of the increasing precipitation levels observable from the end of the 1990s are not general, only the temporary marshes are able to regenerate, which hardly store water and their territorial

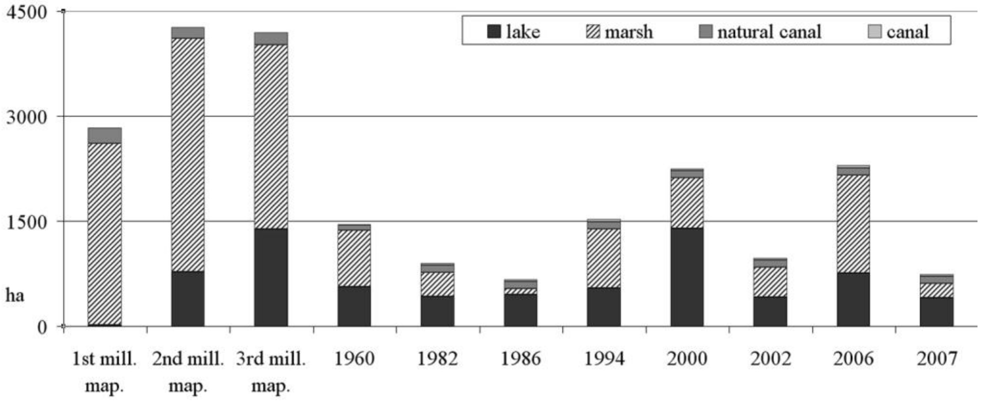

Fig. 4 Change in the extension of wetlands

values are variable. The landscape cannot regain its original state. One hundred and twenty years ago the waterlogged, marshy areas were much more characteristic and permanent, and they had a buffer zone and ecological corridor function. The decrease in the spatial extension of water patches, and the increase in their number indicate their isolation from each other and an increase in their vulnerability. In 1950 only 75% of the open channels were occupied by four lakes, but in 2002 it was actually 100%.

The analyses indicate that all the water surfaces are changing, therefore it is probable that not only the lakes, but also all the wetlands disappear. An area can be prognosticated at the Upper Kiskunság Lakes, which is drying up, but in the rainy periods gets active in a human lifetime.

The evaluation of instability

Besides the spatial and statistical analysis of the extremities and the instability, it is important to specify the changes found in the long-term research during the detailed evaluation of the five-year period between 1999 and 2003 (*Fig. 5*).

The ratio of precipitation amount for three months is the ratio of the precipitation sum for the month of recording and the previous two months to the sum of the average precipitation measured in the same months between 1873 and 2001 at the nearby station of Kecskemét. The retrospective index clearly shows that in recent times precipitation is the main source of water recharge. It explains the difference between the values measured in August and it is visible why the relative increase in precipitation in July and September 2000 did not have any effect on water level. At the beginning of 2000 the extension of wetlands was conspicuous according to the ratio of precipitation amount as well.

At maximum water content one-third of the study area is inundated. Due to the meteorological factors the values measured in April decreased within a short time (in 2000 three-fourths of the monthly mean temperatures were above the average). The extension of wetlands in June is half of that in April and by July this value is also halved. The extension of wetlands in October is only 10% of the maximum extension observed a few months earlier. Approximately 4000 ha of wetlands disappeared between April and October, which means an average decrease of more than 22 ha/day. In case of a shallow

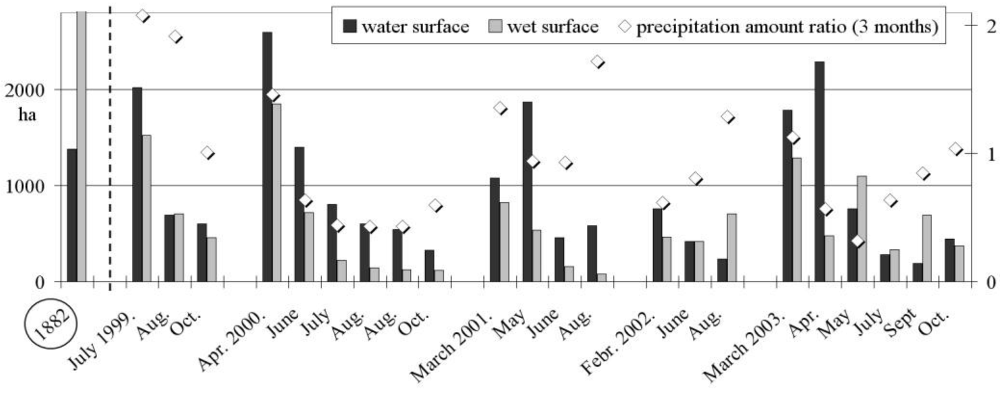

Fig. 5 Connection between the extension of water surfaces and the amount of precipitation

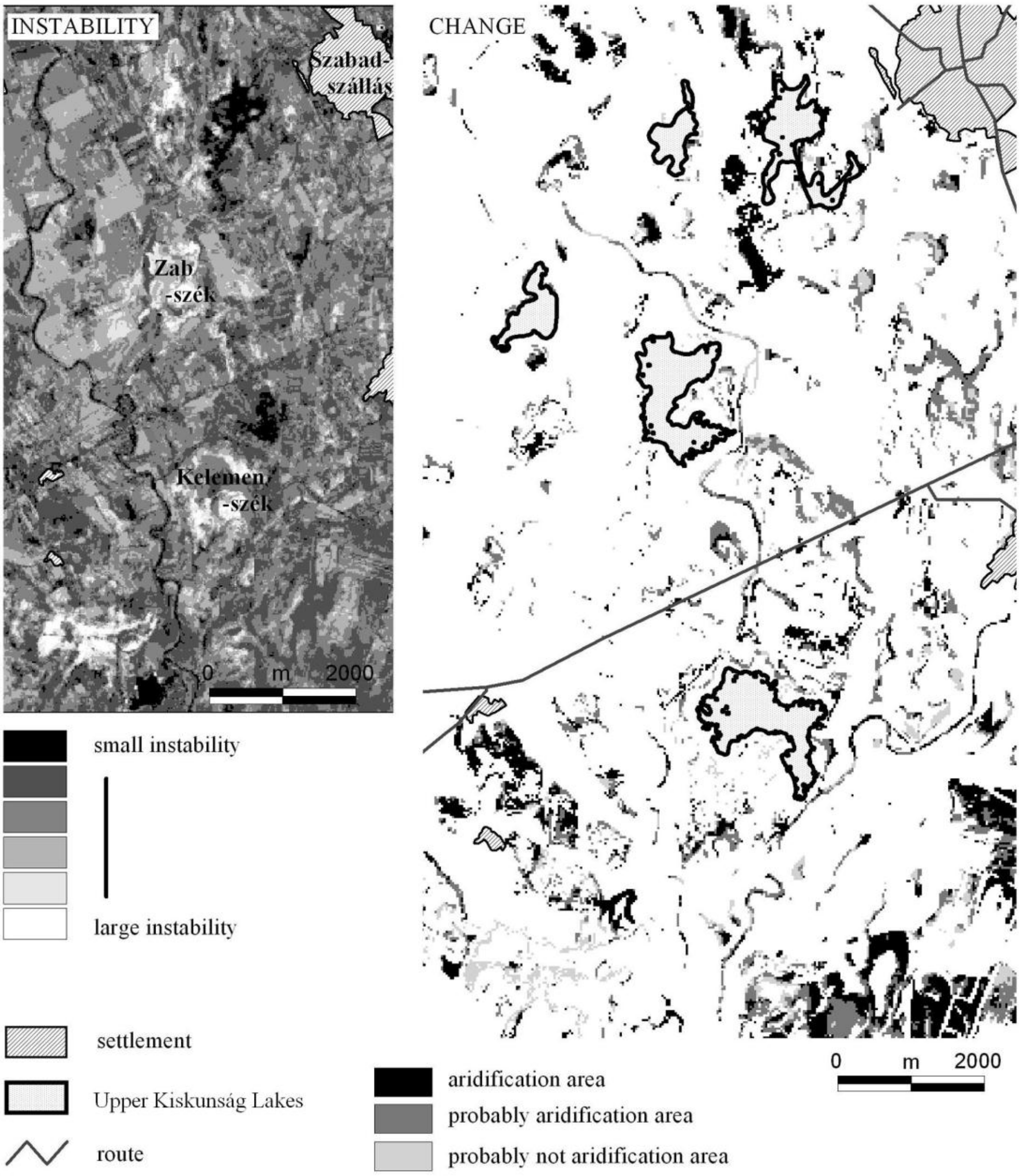

Fig. 6 Change and instability in the region of the Upper Kiskunság Lakes

average depth of 30cm, it means the evaporation and percolation of 0.12 km^3 of water. This is much greater than the ever known yearly water shortage or excess water in the area. Out of the two largest lakes, the Kelemen-szék and the Zab-szék, the latter one has the most stable boundaries. The rate of decrease is 1.1 ha/day on average, but maximum 2.6 ha/day.

In case of deviation from the average, the extension of wetlands halved from 2000 (1000ha) to 2001. In case of certain standing water this value modified from 30-100 ha to 8-35 ha by the next year. The year 2000 can be used for the modeling of a possible maximum inundation.

The precipitation values were under the average in the second half of the year 2000, in the second quarter of 2001, and in the first halves of 2002 and 2003. Despite the total amount of precipitation was above the average in 2001, low inundation values were registered both in this year and in 2002. Therefore it can be concluded that the effect of a favourable year is not enough for stopping the unfavourable processes. This was also experienced at Szappan-szék by Hoyk E. (2006). The mosaic of landscape features raises the hope that aridification is not irreversible. Surface water connection was observable between Kelemen-szék and Zab-szék in 2000. Despite the favourable precipitation conditions characteristic of the first half of 2001, the extension of inundated areas was only half as much as a year earlier on the basis of the photo taken in June. Twenty-three per cent of the area is changeable from the point of view of water content. The disappearance of Kis-rét is the most striking during the examination of the lakes. It was almost the largest lake in 2000, but it dried up very fast, and there are no data for the year 2002.

Co-spatiality of change and instability

In the change analysis those areas are more significant which turn out to be stable in the instability analysis (*Fig. 6*). The exact registration of change is more difficult in unstable areas, and processes, endangering even the more permanent phenomena, could be more dangerous. Those areas can also be highlighted, which are depicted as marshes, lakes, wetlands on a map, but appear as light areas on the instability map. It indicates a greater sensibility, a more possible drying up, and it can question the long-term processes. Aridification is represented by the shades of grey concerning both the whole area and the patches.

The categorization of certain changes is difficult by the comparison of the dates of several long-term changes; therefore, the created result map was classified from specific, optimistic and pessimistic viewpoints. The rate of aridification is 28% according to the pessimistic viewpoint, while it is 13% according to the optimistic one. If the spatiality of instability is also taken into account, even the very unstable areas, formerly classified as aridification areas, can be delineated. According to our analysis, these surfaces are probably not becoming more and more arid, they are only unstable. On *Fig. 6* a map representing the optimistic point of view can be seen, which is specified according to the aforementioned principle, and its value for the rate of aridification decreased from 13% to 11%. The value of our pessimistic analysis changed to 22%.

CONCLUSION

The mapping and monitoring of large areas of wetlands can be solved only by remote sensing methods. Besides the surveys carried out for different years, the short-term, high time-resolution analyses are also needed for the study of long-term change. A short but a geographically very interesting period has been studied on the basis of multispectral images, which made it possible to study and interpret the hydrological balance of the lakes, and the effect of the unfavourable climatic conditions. By the examination of wetlands the drying up and the aridification can be well evaluated. The positive effect of the increasing precipitation observable from the end of the 1990s is not general. The majority of the former wetlands can only partially regenerate, mostly as a periodic marsh. By the current change in a human lifetime an area can be prognosticated in Upper Kiskunság Lakes which is drying up, but is periodically activated in rainy weather. A possible shift of the range of values relevant to the water-level changes can be determined by a periodical instability mapping in the more and more arid Great Hungarian Plain. This is going to be taken into consideration in our change analysis ending in the near future.

Acknowledgement

The research was supported by the project “Development of an EXCESS WATER-INFO system” (Economic Operative Program: GOP - 1.1.1 - 08 / 1 -2008 – 0025) and by the Hungarian Scientific Research Fund (OTKA PD 78349).

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