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DEVELOPMENT OF AN INTEGRATED ANN-GIS FRAMEWORK FOR INLAND EXCESS WATER MONITORING

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Abstract

Inland excess water on the Great Hungarian plain is an environmental and economic problem that has attracted a lot of scientific attention. Most studies have tried to identify the phenomena that cause inland excess water and combined them using regression functions or other linear statistical analysis. In this article, a different approach using a combination of artificial neural networks (ANN) and geographic information systems (GIS) is proposed. ANNs are particularly suitable for classifying large complex non-linear data sets, while GIS has very strong capabilities for geographic analysis. An integrated framework has been developed at our department that can be used to process inland excess water related data sets and use them for training and simulation with different types of ANNs. At the moment the framework is used with a very high resolution LIDAR digital elevation model, colour infrared digital aerial photographs and in-situ fieldwork measurements. The results of the simulations show that the framework is operational and capable of identifying inland excess water inundations.

Keywords: inland excess water, artificial neural network, geographic information systems

INTRODUCTION

Inland excess water is a reoccurring problem in the Great Hungarian Plain. At the end of winter large parts of the flat terrain are covered by water. These inundations cause serious economic and environmental problems. Several studies have analysed the problem, with varying success (Bozán Cs. et al. 2005, Pásztor L. et al. 2006, Rakonczai J. et al. 2001, Rakonczai J. et al. 2003). Most studies have tried to identify the phenomena that cause the inland excess water and combined them using regression functions or other linear statistical analysis. In this article, a different approach using artificial neural networks (ANN) is proposed. This approach has many advantages compared to other statistical methods. First, it is independent of the statistical distribution of the data, and there is no need for specific statistical variables. Neural networks allow the target classes to be defined in relation to their distribution in the corresponding domain of each data source, and therefore the integration of remote sensing or GIS data is very convenient (Pradhan B. – Lee S. 2010).

Certain types of inland excess water can be forecast and those areas or points where action is needed for decreasing or even avoiding damage can be directly determined with the help of theoretical and practical means. This way the risk of inundation can be mitigated in numerous occasions, and this could lead to a shift from a reactive, defensive-type water management strategy towards a more proactive strategy, in order to decrease or even prevent damage.

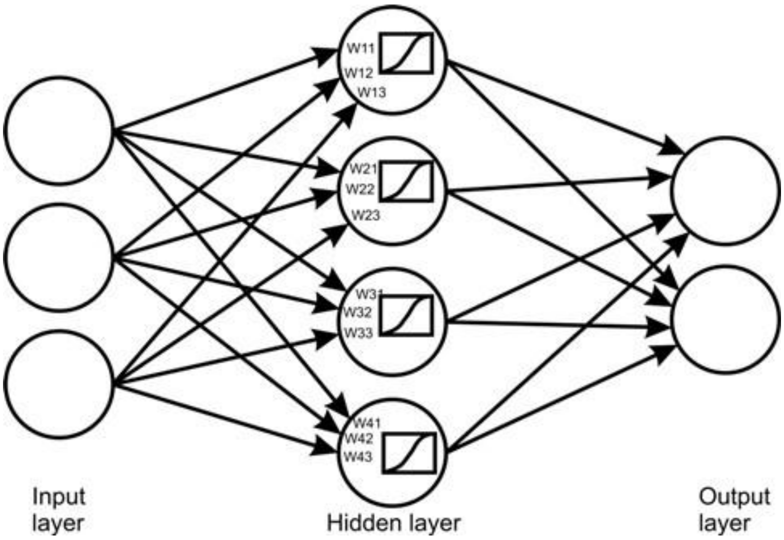

Fig. 1 A basic artificial neural network

ARTIFICIAL NEURAL NETWORKS

Artificial neural networks are computational models that imitate the functioning of the human brain. Several different types of neural networks exist but their basic structure always consists of multiple layers of interconnected nodes (*Fig. 1*). Every neuron processes the weighted sum of all inputs, and, via a so-called activation function it is determined if the signal is sent further.

The application of ANNs consists of two phases. The first phase is called the training phase. During this phase the ANN is fed with an input and an associate output data set. The training is an iterative process where the weights of the incoming signals are adapted in such a way that the overall average error between the requested output and the calculated results is minimized. The trained network can be used in the second phase where it is fed with new input data to calculate new output results. A more detailed description of ANNs goes beyond the scope of this article but can be found in Retter Gy. (2006), Hewitson B. C. and Crane R. G. (1994) and Zurada J. M. (1992).

ANNs have been proven themselves in many fields of science where complex data sets need to be analyzed to identify their underlying structures and properties. Neural networks have a large potential for analysis of complex spatial problems which are common in geographic research (Hewitson B. C. – Crane R. G. 1994). Inland excess water inundations on the Great Hungarian Plain are a clear example of such problems. The reoccurring inundations are caused by a multitude of interrelated factors.

The connection between the world of neural networks and GIS is still relatively new and needs to be developed further (Coleman A. 2008, Sárközy F. 1998). Just two GIS software exist that employ fully integrated GIS – neural network solutions; ArcGIS and IDRISI. These solutions have been investigated but were not used in this study because they employ only one type of neural network architecture, a multi-layer perceptron and a radial basis function network, respectively, and they do not offer integrated tools for the evaluation of the training and the simulation results.

Matlab 7.10.0 has an integrated neural network

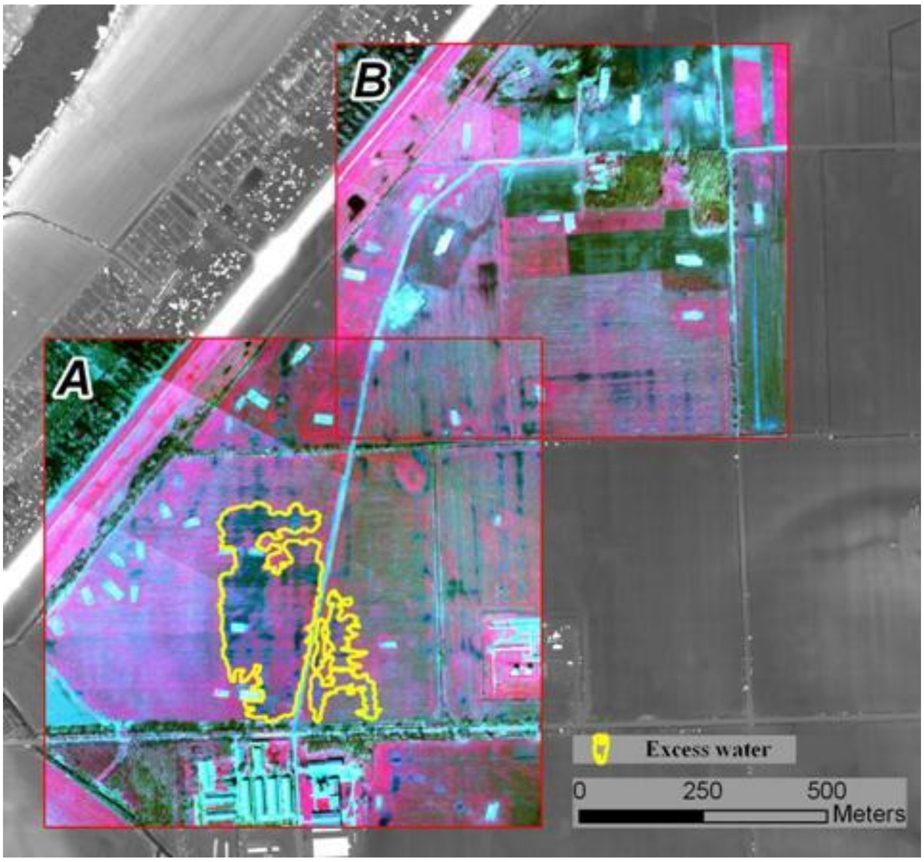

Fig. 2 The digital elevation model overlaid with CIR mosaics of 24 March 2010 showing the training (*A*) and simulation (*B*) area with the GPS fieldwork results in the Tápairét area

toolbox that ranges from simple solutions to extended neural network implementations. The determination of the network architecture constitutes one of the major and most difficult tasks in the use of neural networks (Barsi Á. 1997, Jafar R. et al. 2010). Since it is not exactly known what type of neural network with which settings is most appropriate to study the problem of inland excess water, it was decided to build a framework that facilitates the possibilities to experiment with several neural networks and settings in a GIS environment. ArcGIS 9.3 was used as the GIS environment because of its strong capabilities for geographic analysis, and its possibilities for customization.

STUDY AREA AND DATA

The Great Hungarian Plain covers an area of 52,000 km^2. The Tápairét area was selected from this region as a test site for the inland excess water research (*Fig. 2*). This study area is about 20 km^2 large and its maximum difference in elevation is 10 meters. Mainly agricultural activity takes place in the area, although there are also several oil stations. From the young sediments with high clay content of the Maros River, fluvisols and vertisols were formed (Marosi S. – Sárfalvi B. 1990). Because of the extreme mechanical properties – in large areas, the plasticity index (K_A) is above 60 (cm^3/gr) –, the exceptionally bad permeability characteristics result in accumulation of water in the lower areas.

Table 1 gives an overview of the data used in this research. All data were collected in the period 2009-2010.

Apart from the bad soil characteristics, the area consists of very flat terrain with large local depressions, without run-off. The average groundwater level varies between 2 and 4 meters below the surface. Remnants of river meanders can also be found in the area. Only in the former meanders, the groundwater may reach the surface. This research focuses on the genetic type of the inland excess water that is caused by a lack of runoff and infiltration, and not on the type that is due to high groundwater levels.

FRAMEWORK

A framework was created to handle input data, intermediate results and output data in a flexible way in both ArcGIS and Matlab (*Fig. 3*). In this way, it was possible to create the data files, test different network types and settings and evaluate the training and simulation results efficiently.

First, different artificial data sets were created in ArcGIS. These data sets were used to set up the framework and to evaluate the simulated results. Three artificial input maps of 100 by 100 pixels were created. Each map represented specific inland excess water related input parameters (e.g. local depressions, geomorphologic structures, soil types, height of the groundwater table, land use). A forth artificial map was created to represent the occurrences of inland excess water in the same area. The files were created using ArcGIS 9.3 and were stored in TIFF file format. The TIFF files were read into Matlab resulting in a 100x100 cell matrix for each map.

The neural network analyses were performed with the neural network toolbox of Matlab. This is an extension of the general Matlab functionality incorporating many artificial neural network architectures and tools for training and evaluation of the results (Demuth H. et al. 2010). The neural network toolbox needs data in a matrix format where every row represents an input data layer. A program was written to convert the separate input matrices to arrays and to combine the resulting 1x10000 arrays into one matrix with 3x10000 cells that could be read by the neural network toolbox. The output matrix, representing the occurrences of inland excess water was converted to an 1x10000 array as well. With the artificial data, only the standard neural net in the nftool from the neural network toolbox was used. This is a two layer feed forward network with maximum 20 neurons in the hidden layer. A smaller amount of neurons gave similar results but resulted in lower performance due to more iterations. The network was trained

Table 1 Input and output data

LIDAR /DEM/ local depressions	LIDAR data with a spatial resolution of 1.4 points per m^2 were collected from a 70 km^2 area during a flight campaign on 19 November 2009. Based on this data, a 1 meter resolution digital elevation model was created.
CIR (Colour-InfraRed) imagery	At the maximum of the inland excess water periods, on 24 March and 9 June 2010, flights were executed using a data collection system based on the MS3100 digital camera (Tobak Z. et al. 2008) to collect 800x600 meter images. From all individual images a 63 cm resolution mosaic covering an area of 60 km^2 was created.
Field measurements	On 5 March, 2010, a one day fieldwork was carried out in the south-western part of the study area. At that moment, the second level on the national inland excess water hazard scale was valid. In total 7.8 ha of inundated land was accurately measured by walking around them using hand-held GPS systems.

with 70% of the data, while 15% was used for validation and 15% for testing. The optimal network was saved to be used in the simulation phase. Simulation data was then imported from the GIS, converted to a matrix and fed to the neural net.

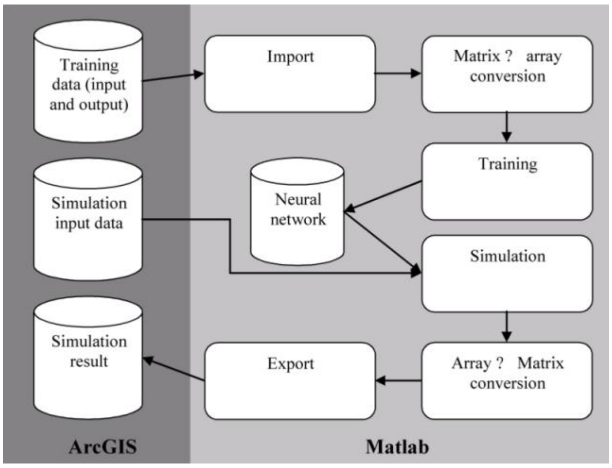

Fig. 3 Framework showing the workflow in ArcGIS and Matlab

The simulation result was again converted into a matrix. During the different conversion steps the data had to undergo various types of conversions to be compliant with the particular data formats. Finally, a continuous 8 bit TIFF file was generated which could be visualized in ArcGIS.

Apart from several pre-processing steps, the same workflow, as described above with the artificial data, was followed using the new, real data set as well (*Fig. 4)*. The training data consisted of 4 input and one output layers. The colour infrared images were split in three bands; green, red and near infrared. Using the fill tool in ArcGIS, the local sinks in the LIDAR based digital elevation model were filled (Tarboton D. G. et al. 1991). The original height values were subtracted from the sink map, resulting in a layer with the local depressions. The depression map was reclassified into three classes: very small depressions (<15 cm), middle (15-60 cm) and deep (>60 cm) depressions. The resulting map was used as the forth input layer in the training phase. The fieldwork measurements were rasterized and used as output map during the training. That time only two output classes were defined: open water and dry soil. Every data layer had a spatial resolution of 1 meter and was covering an area of 1000x1000 meter.

During the simulation phase the same type of CIR imagery and elevation data were used. The same pre-processing steps were executed as in the training phase; just the location of the data was several hundreds of meters further to the north (*Fig. 2*).

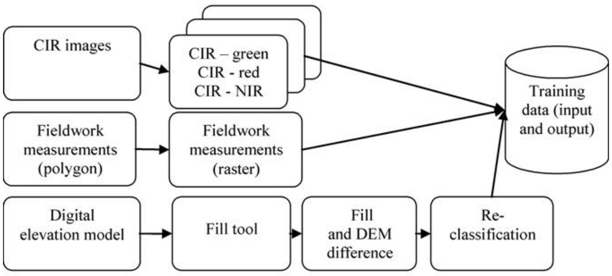

Fig. 4 The pre-processing of the training data

RESULTS

Several settings for the number of neurons in the hidden layer were tested. With an increase of the neurons, the RMSE decreased, however, the performance of

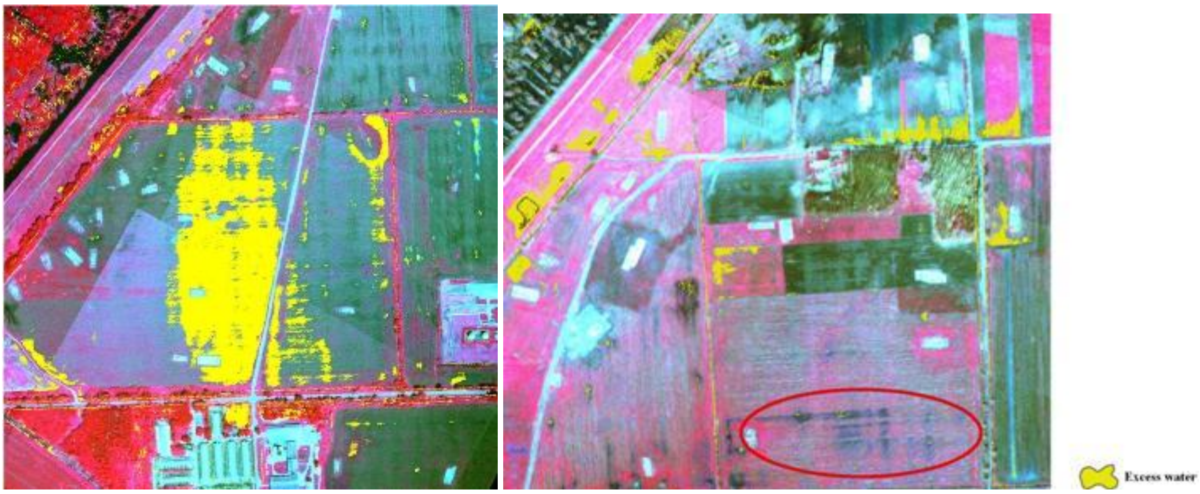

Fig. 5 The results of the training (left) and the simulation (right)

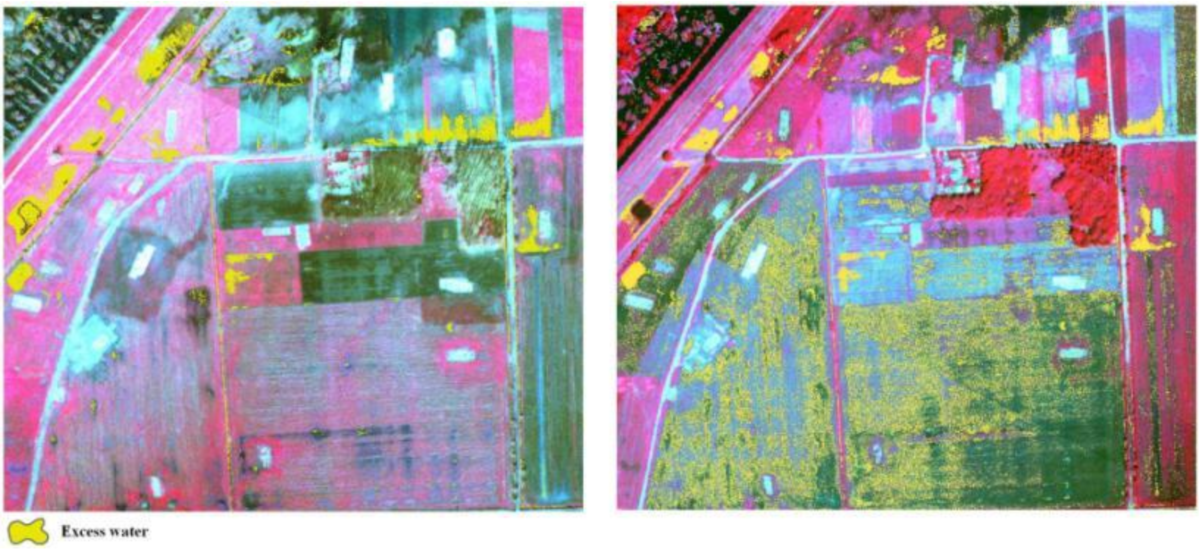

Fig. 6 The simulation results of two different times: 24 March 2010 and 9 June 2010

the training also decreased sharply. An optimum of 10 neurons was selected resulting in an overall RMS training error of 0.74. The result of the training is shown on the left side of *Fig. 5*.

The right side of *Fig. 5* shows the result of the simulation using the trained network. The yellow areas were classified as inland excess water. In the northern and north-western part of the area the results are good. The open water along the levee and the roads was detected. The inland excess water in the southern part of the images is not properly classified. Some pixels are correctly indicated as inland excess water but the majority is classified as dry land. These errors are probably due to the composition of the training set, where only water was incorporated but saturated soil and vegetation in water were omitted.

A second simulation was executed using the same trained ANN, but this time with different multi-spectral data. In this simulation, the colour infrared images collected on 9 June were combined with the same local depression data that was used in the first simulation (*Fig. 6*).

Although in general, the inland excess water areas that were identified on the images taken on 24 March, were also classified as water on the images taken on 9 June, on the second date much more inland excess water was detected. Furthermore, the second simulation shows that there is scattered water on the large parcels in the centre of the images. This may indicate that the soil in this area was completely saturated with water. Since no ground truth was collected for the area at the time of the data acquisition, it is not possible to quantify the simulation differences.

Fig. 7 Comparison of different classification methods: maximum likelihood (left), minimum distance (middle), artificial neural network (right). White colour indicates inland excess waters, all other areas are in black. The training data is shown with a red-coloured boundary

A comparison has been executed among the training results of the ANN and two traditional classification methods: maximum likelihood and minimum distance (*Fig. 7*). The ANN classification clearly shows the white area overlapping with the training area. Several other patches of inland excess water were also classified. For these areas no ground data was collected but they can easily be identified visually on the CIR images (*Fig. 2/A*). For the other two classifications only the pixels of the training area were used during the supervised training. For both traditional classifications this results in accurate classification of the inland excess water in the training data, but also in an extreme over-classification in the areas outside this area.

CONCLUSIONS

The framework works as expected with a small artificial test data set. The larger real data set also resulted in proper delineation of inland excess water, but further development is still needed. Due to the nature of spatial data, very large matrices are created as input data for the network. This results in performance problems. By reducing the amount of input pixels in the input data sets, the performance of the system can be improved. The result of the simulation shows a clear distinction between water and dry soils. In reality this is a fuzzy boundary. Intermediate classes like saturated soil and vegetation in water also exist. These classes were not taken into account in the training set. Extra field data will be needed to incorporate these classes and to be able to derive them in the simulation. This fieldwork data is also needed to be able to quantify the differences in results between the different classification methods. Furthermore, other input data sources, like soil maps, hydrological maps can be incorporated to extend the base of the training set. Finally, the integration between the GIS and the neural network has to be improved. The framework now consists of several loosely coupled programs and Matlab functions. To facilitate the most efficient prototyping their integration is inevitable.

Acknowledgement

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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 Kelemen-szék) (Schmidt A. 2003).

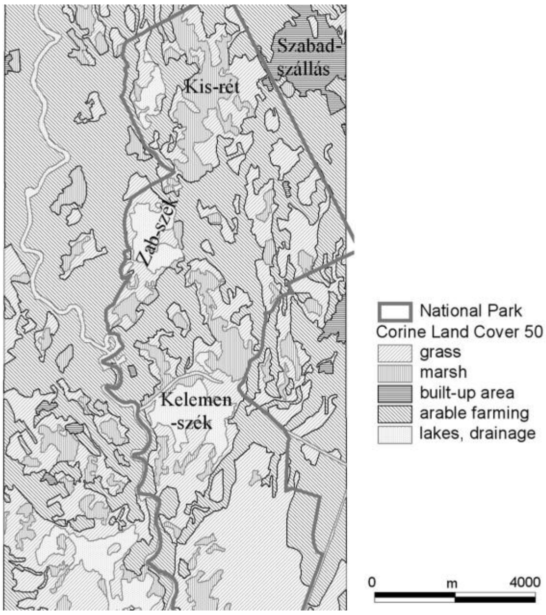

Fig. 1 Land cover of the Upper Kiskunság Lakes

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.

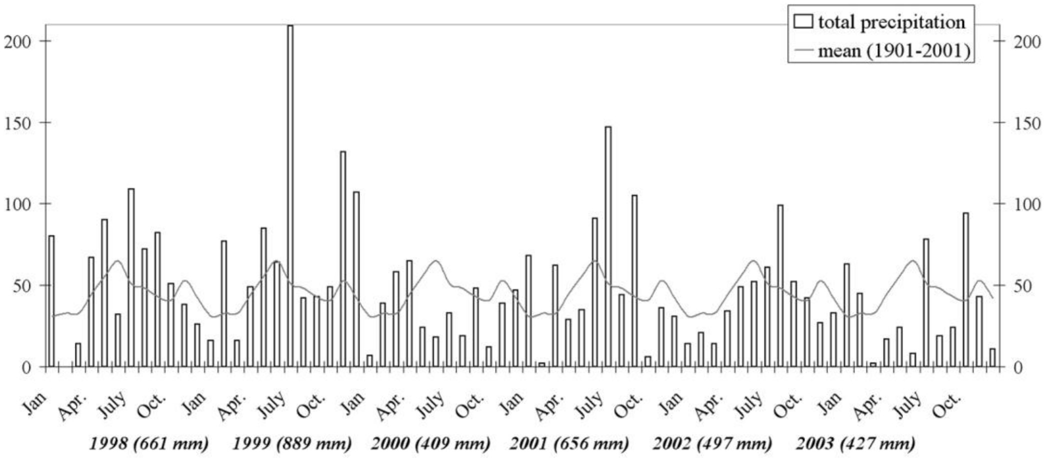

Fig. 2 Precipitation in Izsák in the period 1998-2003 (source: Hydrological Almanach)

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)

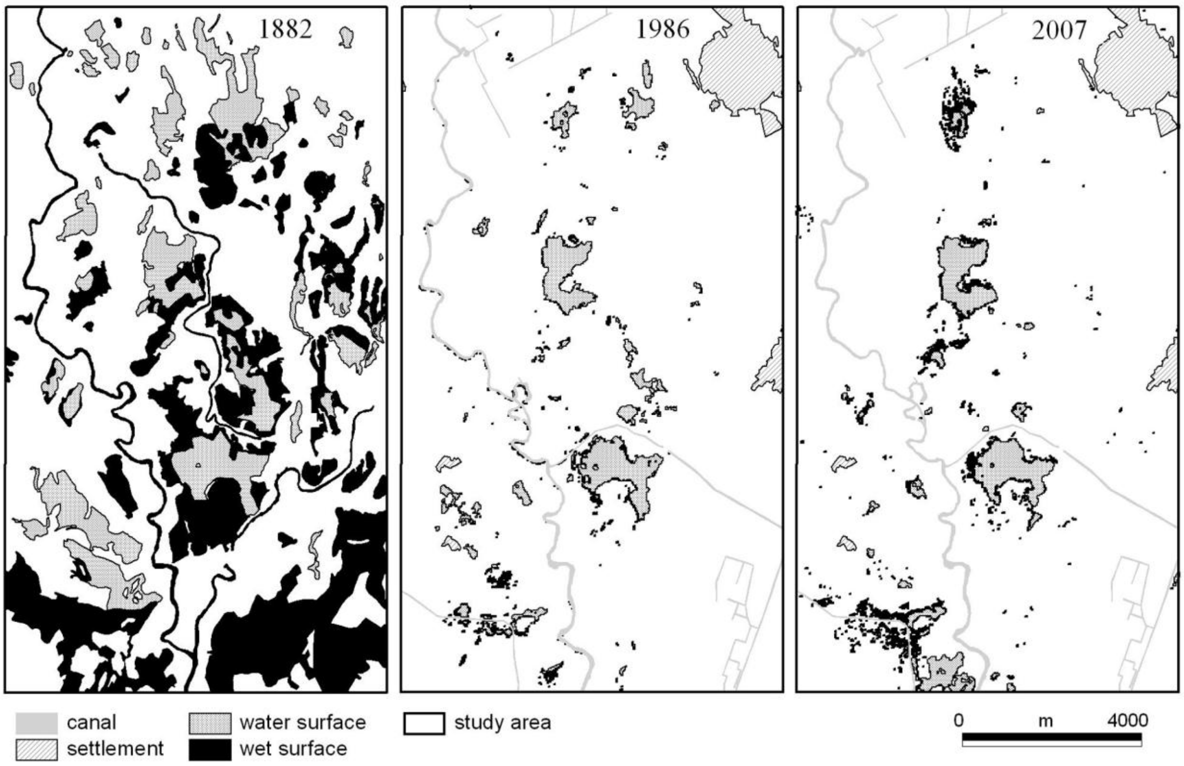

Fig. 3 Decrease in wetlands and transformation of the ecological network

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

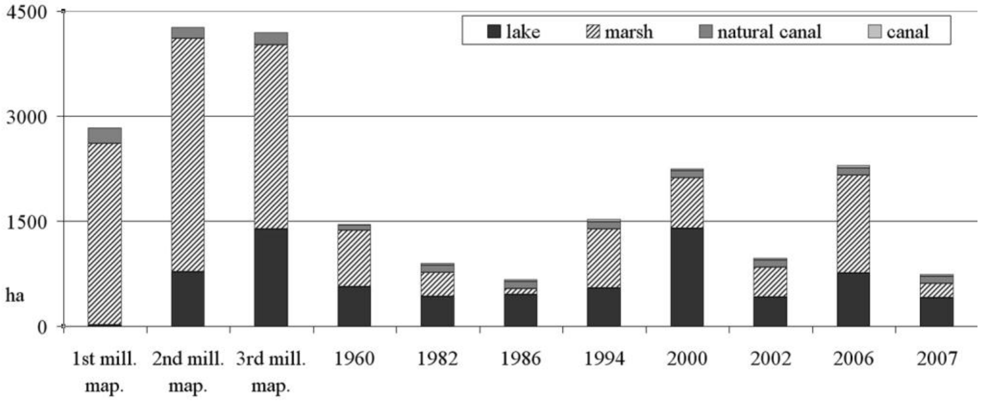

Fig. 4 Change in the extension of wetlands

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

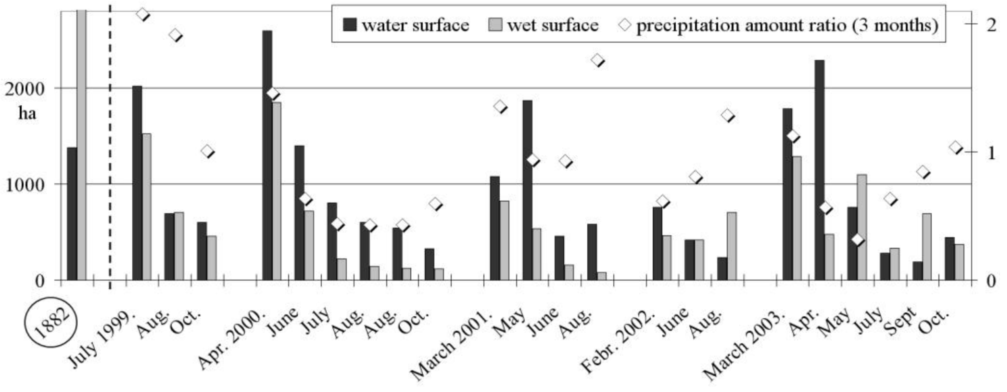

Fig. 5 Connection between the extension of water surfaces and the amount of precipitation

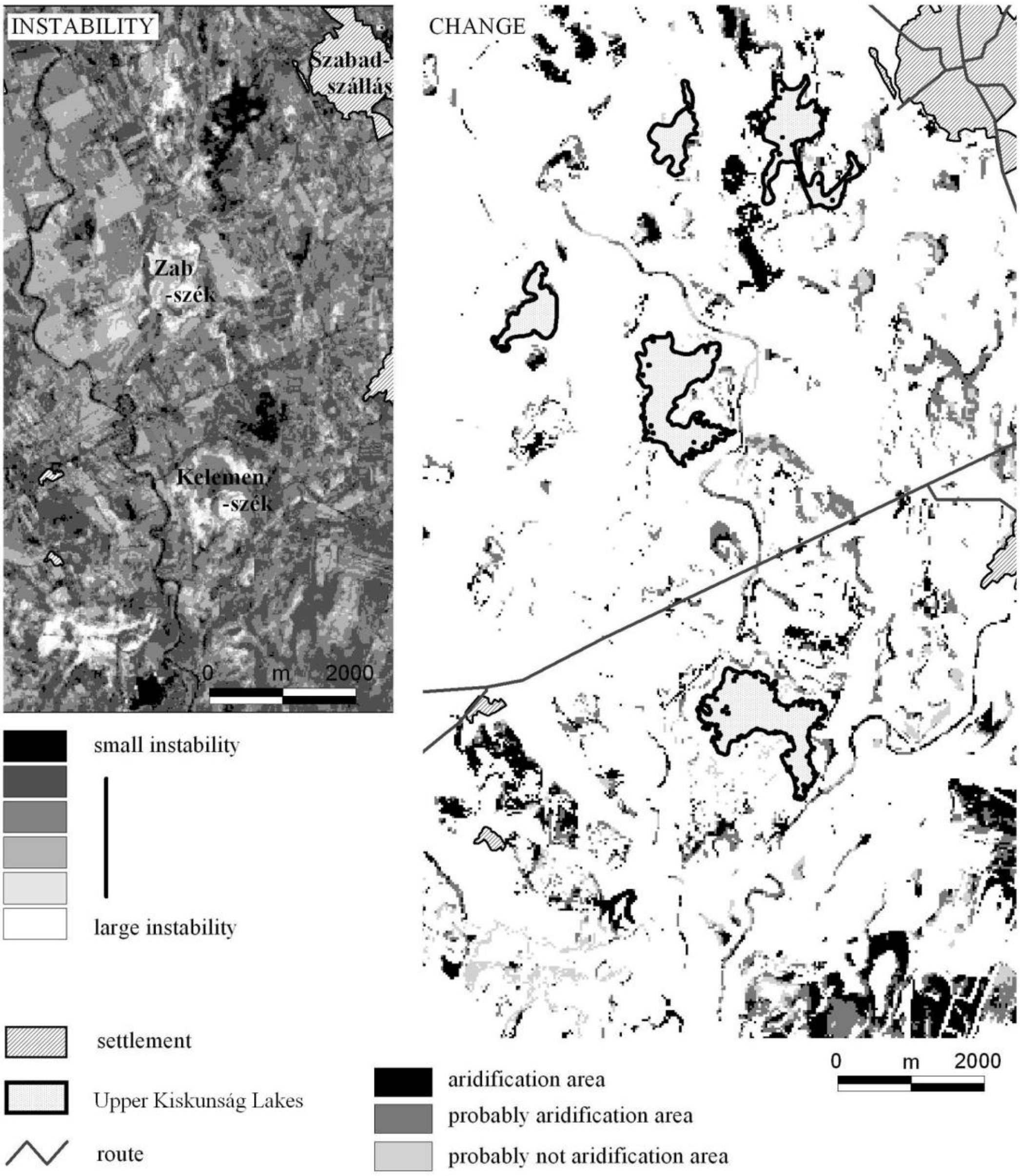

Fig. 6 Change and instability in the region of the Upper Kiskunság Lakes

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

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APPLICATION OF SELF-ORGANIZING NEURAL NETWORKS FOR THE DELINEATION OF EXCESS WATER AREAS

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Abstract

In recent times Artificial Neural Networks (ANNs) are more and more widely applied. The ANN is an information processing system consisting of numerous simple processing units (neurons) that are arranged in layers and have weighted connections to each other. In the present study the possible application of an unsupervised neural network model, the self-organizing map (SOM), for the delineation of excess water areas have been examined. By means of the self-organizing map high-dimensional data of large databases could be mapped to a low-dimensional data space. Within a data set, it is able to develop homogeneous clusters, thus it can be effectively applied for the classification of multispectral satellite images. The classification was carried out for an area of 88 km^2 to the south of Hódmezővásárhely situated in the south-eastern part of Hungary, which is frequently inundated by excess water. As input data, the intensity values of the pixels measured in six bands of a Landsat ETM image taken on 23rd April 2000 were used. To perform the classification, three different sized neural network models were created, which classified the pixels of the satellite image to 9, 12 and 16 clusters. By using the gained clusters three thematic maps were created, on which different types of excess water areas were delineated. During the validation of the results it was concluded that the applied neural network model is suitable for the delimitation of excess water areas and it could be an alternative to the traditional classification methods.

Keywords: Artificial Neural Networks (ANNs), excess water, multispectral classification

INTRODUCTION

In recent times Artificial Neural Networks (ANNs) are more and more widely applied. The ANN is an information processing system consisting of numerous simple processing units (neurons) that are arranged in layers and have weighted connections to each other. Their construction and operating principle are based on the biological neural networks, and their significant feature is adaptiveness, i.e. they solve the problems by learning from examples and not by means of programming. Since several types exist, the 'neural network' designation rather means a model range than a concrete process. Their field of application is quite varied; sample-association, classification, optimization and similarity identification. They are applied in various fields of science, also in geography. The significance of their application is based on the sharp increase in the amount of geographical data. In recent times several data collecting techniques are widely used e.g. the multi- and hyperspectral remote sensing, thus the resolution of the data rapidly increases both in geometric and attribute space. Neural networks could be a really effective alternative for the analysis of the high-dimensional data. Their application in the field of geography is discussed in more detail in the works of Agarwal P. et al. (2008) and Hewitson B. C. et al. (1994).

The aim of this study is to delineate excess water areas on the basis of satellite images by using a neural network. The study area is in the vicinity of the settlement Batida, situated on the left bank of the River Tisza, to the south of Hódmezővásárhely. The term of excess water was defined in a number of ways, and the main point was summarized by Rakonczai J. et al. (2001) as follows: 'Excess water is a kind of surplus water on the surface of a certain (drainage) area or in the pores of the arable land/near-surface formations, that inhibits the growth of vegetation and damages the man-made buildings.' Excess water is a yearly recurring problem which endangers 45% of the area of the country, 60% of the arable lands, more than 4 million hectares altogether. Therefore the exact delineation of these areas is highly important, for which the different remote sensing methods provide the most objective way (Rakonczai J. et al. 2001).

The delineation of excess water areas was carried out by the classification of medium spatial resolution multispectral satellite images. During the processing of multispectral satellite images, classification is a fundamental procedure, through which the pixels of the image are classified according to their spectral features, by mathematical methods. As a result a thematic map was created which makes it possible to visualize the information stored in satellite images in a more expressive way. The classification was performed via one type of the neural networks, the so-called self-organizing map that creates classes in the training samples by unsupervised learning. Several examples could be mentioned referring to the application of neural networks in multispectral classification. According to Awad M. (2010), the multispectral classification carried out by self-organizing maps is more precise than the Isodata classification. In the opinion of Aitkenhead M. J. et al. (2007) ANNs are a quick and accurate method for mapping land cover change. Pacifici F. et al. (2009) carried out urban land use classification on the basis of the sample analysis of high resolution satellite images, performed by neural networks. Barsi Á. (1997) could be mentioned from Hungary, who classified a Landsat TM image by one type of the neural networks. In his opinion, this method provides as accurate results as the traditional methods.

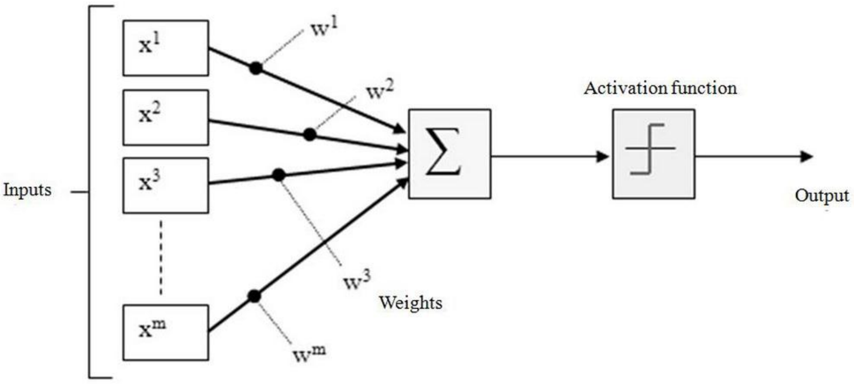

Fig. 1 Sketch of a neuron

ARTIFICIAL NEURAL NETWORKS (ANNS)

The structure of Artificial Neural Networks (ANNs) is similar to the human brain in that the storage of knowledge takes place in connected processing units (neurons). A processing unit converts the weighted sum of the incoming inputs by the help of an activation function. The most commonly used activation functions are the linear function, the sigmoid function and the step function. The result obtained is sent to other neurons through the outgoing connections of the neuron (*Fig. 1*).

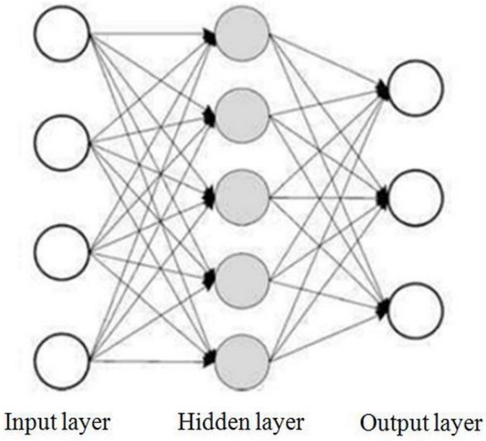

Fig. 2 Structure of an Artificial Neural Network (ANN)

The neurons are arranged into layers. Every net has an input layer for feeding input data and an output layer for visualization of the results. Between these layers a number of hidden layers could be found (*Fig. 2*). The learning of the net is realized by the modification of the weights between the neurons. Supervised and unsupervised learning methods could be distinguished. In case of supervised learning the training set includes both the input samples and the output samples. During an iteration process, the weights of the connections between the neurons undergo such changes that the appropriate result is added to the given input sample. In case of unsupervised learning only the set of input samples is known, while the output neurons compete for the input samples on the basis of certain similarity aspects. The weight vectors of winning neurons vary based on their added input value. By the help of such types of nets, regularities could be observed in the distribution of the sample data.

There are several types of ANNs, which could differ in certain elements from the general model. They have several advantages over the traditional methods, as their application does not depend on the statistical distribution of the input data, they are not sensitive to incomplete and disturbed samples and are able to process huge amount of data.

Self-organizing map

The self-organizing map (SOM, Kohonen Map) applied in this research was created by Kohonen (Kohonen T. 2001), and this is the most widespread ANN which carries out unsupervised learning. It classifies the n-dimensional input samples (n>2) by means of unsupervised learning, and adds them to the elements of a lower-dimensional output layer. The similar samples are associated with the neighbouring elements of the output layer, i.e. apart from the distribution of the samples in the input space, it also learns the topology between them. The self-organizing map performs data clustering and dimension reduction at the same time. Therefore it is suitable for the solution of different problems and it can be an alternative besides other methods e.g. the principle component analysis and the k-median clustering.

Self-organizing maps are made up of two layers, the input and output (or Kohonen) layers, that are connected with each other through all of their neurons (*Fig. 3*). Data is fed into the input layer, which has the same number of neurons as the number of input variables. Classification takes place in the Kohonen layer, the number of classes created during the learning process will be equal to the number of neurons located here. In this layer the neurons are located in a 1D, 2D or 3D topological position that enables connection between the neighbouring neurons. The 2D topology is the most widespread, in which the elements are arranged in square grid or hexagonal pattern. Each neuron has an n-element weight vector, where ‘n’ equals to the dimension of the input vector. The initial weight vectors of the neurons are usually determined by random numbers or, for the acceleration of the learning process, along the first two principle component vectors of the sample data.

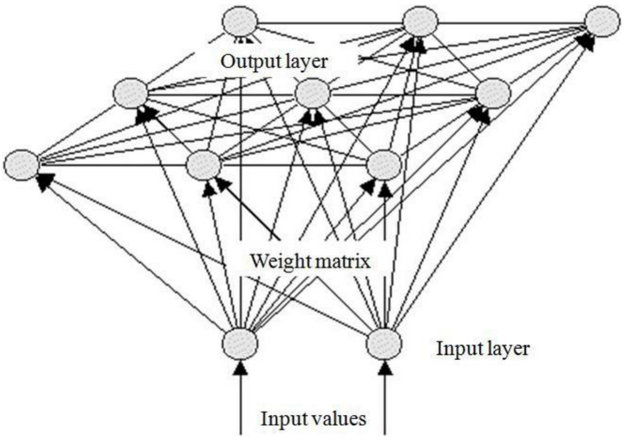

Fig. 3 Self-organizing map (Kohonen T. 2001)

The learning of the net takes place according to the Kohonen rule, on the basis of which the processing units learn competitively. The model searches for the weight vector of the most similar i.e. the winning neuron in each input sample. This is usually calculated on the basis of Euclidean distance. The model modifies and shifts the weight vector values of the winning neuron and those in its certain topological neighbourhood circle towards the value of the input sample. The degree of modification at *t* time is determined according to the Kohonen rule (Borgulya 1998):

$$\Delta W_j(t) = \eta(t)h_{cj}(t)(X(t)-W_j(t)),$$

where

- Wj is the weight vector of the j^{th} element
- η is the learning rate decreasing in time
- h_{cj} is the neighbourhood function, which decreases from the winning neuron ‘c’
- X is an input sample vector.

At the beginning of the learning process a larger learning rate and neighbourhood circle are used, which allow large-scale modifications providing the addition of the similar input samples to the neighbouring neurons. By the decreasing of the learning rate and the neighbourhood circle, the fine-tuning of the model is the next step towards the end of the learning process.

The learning algorithm of a self-organising map can be described as follows (Hewitson et al. 1994):

1. The initiation of the net by giving the geometry and the number of neurons.
2. Giving the initial weight vectors of the neurons.
3. Giving a sample case to the net.
4. Determination of the winning neuron connected to the sample.
5. Modification of the weight vectors of the winning neuron and the topologically neighbouring neurons based on the Kohonen rule.
6. Slight reduction of the learning rate and the neighbourhood circle.
7. Repetition of the last four steps until the convergence is reached.

The different types of visualization of the created model make the analysis of the results possible. If the distribution of the input sample in the data space is examined, the position of the neurons in the data space, their distance from each other or the component planes could be visualized. The component planes represent the strength of the neuron weights regarding each variable. Through the examination of the similarity of the component planes, the connections between the variables could be detected.

Self-organising maps can be used together with other visualization tools, thus in case of geographical applications they can be connected to geographical maps or integrated into geographical information systems.

STUDY AREA AND DATA USED

The 88 km^2 study area is situated in the vicinity of the settlement Batida, to the south of the town of Hódmezővásárhely, in the southern part of Tiszántúl (the region east of the River Tisza) in the Great Hungarian Plain. The area is covered by young alluvial deposits, on which vertisols and fluvisols were formed. Most of it is under agricultural cultivation. There are several abandoned river meanders and point bars in the study area. Classification was performed on the basis of medium resolution Landsat 7 ETM satellite images taken on 23rd April 2000. For the validation of the results color infrared aerial photographs of the Lower Tisza Valley region taken by the ARGOS Studio of VITUKI Plc. on 23rd March 2000 were used.

Numerous software exist for the training and visualization of self-organising maps, which were also included in some large software packages and in software made for this special demand (e.g. SOM_PAK developed by Kohonen). Their integration with geographical information systems has not really been widespread yet (Coleman A. M. 2008), but certain programmes offer such tools (e.g.

IDRISI). Matlab was chosen for our analysis, as it provides more complex analysing and visualizing methods. Matlab is a mathematical program system with a special programming language, developed for numeric calculations. It is applied in many fields and a large number of modules are available for the different applications. In our research the tools of the Neural Network Toolbox were applied, which can be used for the planning, simulation and visualization of different types of neural networks, among others the self-organising maps.

PROCESS OF ANALYSIS

Matlab offers many kinds of parameterization possibilities during the planning process of the self-organising map. The size of the net, the type of the topology and the neighbourhood function, the size of the neighbourhood circle and the number of the training iterations could be set. Three nets of different sizes were created for the classification, the output layers of which consisted of 3x3, 3x4 and 4x4 processing units arranged in a 2D hexagonal topology. The process of the analysis is going to be presented through the example of a net consisting of 4x4 neurons (*Fig. 4*).

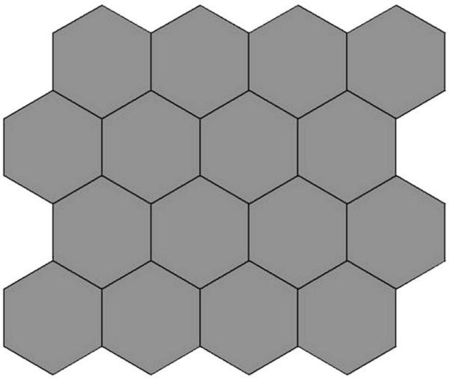

Fig. 4 Self-organising map consisting of 4x4 neurons

Intensity values measured on six bands (blue, green, red, near infrared and two medium infrared bands) of the pixels of the Landsat ETM satellite image were used as input data. The training process consisted of one thousand iterations, that is, the whole set of samples was fed one thousand times to each of the three nets. After training, the simulations of the models were run in case of each net. *Figure 5* demonstrates that how many input samples were added to the individual neurons, for instance how many pixels were sorted to each class in case of a net consisting of 4x4 neurons.

The further evaluation of the results was performed by ArcGIS software, and included the creation of thematic maps by merging the clusters according to the appropriate theme, and the creation of the required legend.

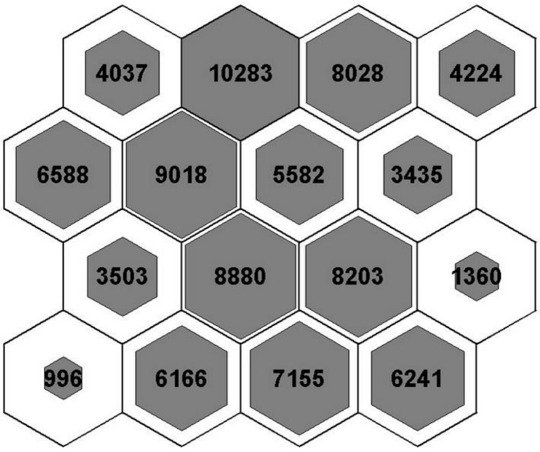

Fig. 5 Number of inputs added to the individual neurons

RESULTS

For the delineation of inland water areas it was practical to merge the clusters into a small number of classes, because the individual clusters could have been specified only by the help of an exact field work. Analysing the composite planes, it could be determined to which neurons were the pixels having different reflectance features added. On the basis of this the following 5 classes could be separated: open water surface, dry soil, water saturated soil, vegetation and vegetation in water. *Figure 6* shows that pixels with the same reflectance values were projected to the neighbouring neurons, as a characteristic of the self-organising map. The classes created were represented in a thematic map as well (*Fig. 7*).

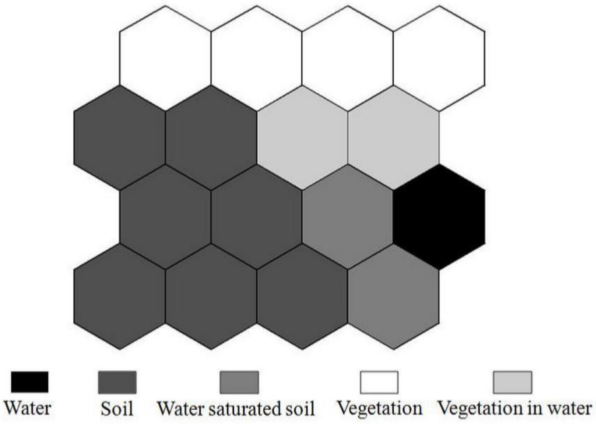

Fig. 6 Position of the classes of excess water mapping

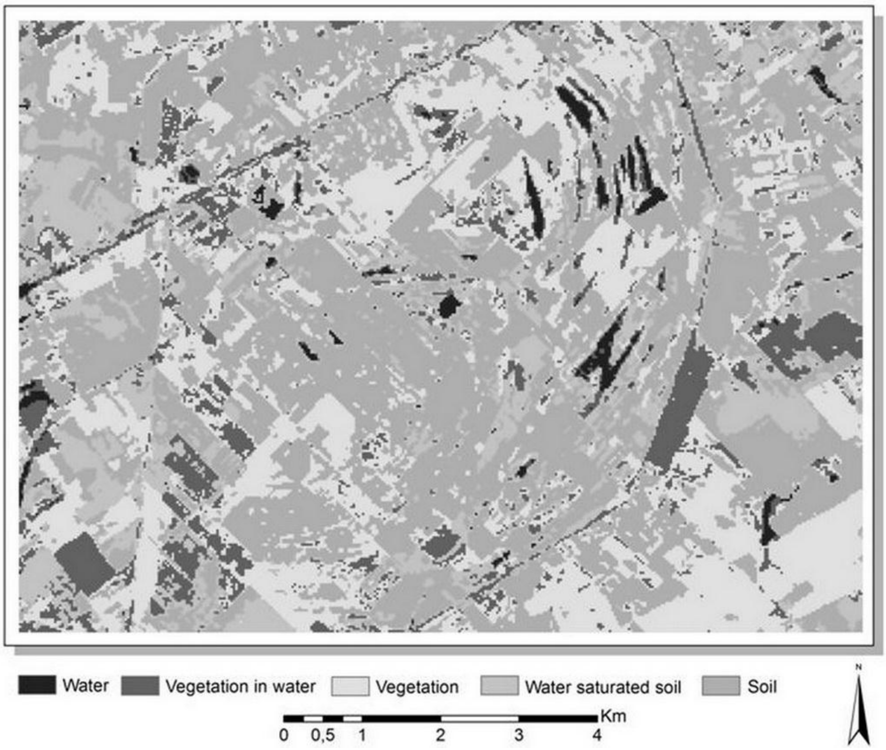

Fig. 7 Classification of the settlement Batida and its surroundings

Table 1 Differences in the extension of the classes for the three models

	3x3	**3x4**	**4x4**
Open water surfaces	2.03%	1.74%	1.45%
Water saturated soil	13%	19.65%	15.41%
Vegetation in water	12%	10.2%	9.62%
Dry soil	49.3%	41.48%	45.15%
Vegetation	23.65%	26.93%	28.35%

On the thematic map, created on the basis of the results of the three neural networks, open water surfaces and even those, which are not entirely covered with water are well separable. *Table 1* shows how large the differences were in the extensions of the different land cover types.

It was not possible to quantify the accuracy of the results owing to the lack of appropriate field survey data. However, excess water areas of great extension could be delineated in all the three cases by comparing the thematic maps with aerial photographs (*Fig. 8*). It is the delineation of transitional classes where there are more considerable differences as it is difficult to determine how high moisture content indicates another class. In our opinion, the application of more neurons makes it possible to determine this boundary more precisely.

CONCLUSIONS

As a result of this present research, it could be concluded that the type of neural network applied is suitable for the thematic classification of satellite images. By the help of this method excess water areas have been successfully delimited in the study area. For the examination of the effectiveness of this method, it will be required to compare the results with those gained from traditional classification methods. In the application of self-organising maps, the possibility of their extension is a great asset, since this way they can simultaneously manage data from different sources. Thus, besides the spectral information of the satellite images, other data could also be used for the classification, for instance elevation models and other thematic layers, e.g. soil and geomorphological

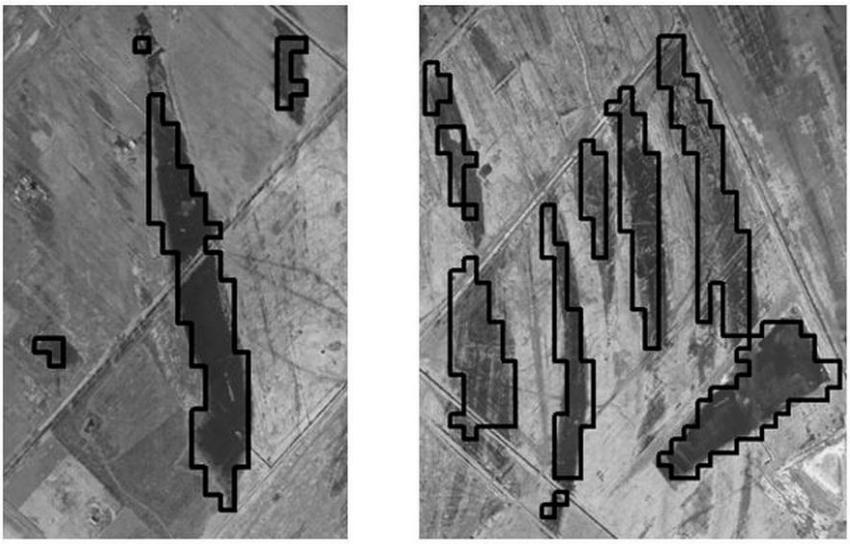

Fig. 8 Comparison of the delimited excess water areas with aerial photographs

maps. The shape recognition function of the self-organising maps could make it possible to identify frequently inundated landforms, for example abandoned river meanders and point bars.

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SMALL FORMAT AERIAL PHOTOGRAPHY – REMOTE SENSING DATA ACQUISITION FOR ENVIRONMENTAL ANALYSIS

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Abstract

Since February 2008, an advanced system has been developed to acquire digital images in the visible to near infrared wavelengths. Using this system, it is possible to acquire data for a large variety of applications. The core of the system consists of a Duncantech MS3100 CIR (Color-InfraRed) multispectral camera. The main advantages of the system are its affordability and flexibility; within an hour the system can be deployed against very competitive costs. In several steps, using ArcGIS, Python and Avenue scripts, the raw data is semi-automatically processed into geo-referenced mosaics. This paper presents the parts of the system, the image processing workflow and several potential applications of the images.

Keywords: small format aerial photography, data acquisition system, image processing, Python

INTRODUCTION

Acquiring aerial photographs and their digital analysis are traditionally long and expensive processes (Warner W. S. et al. 1996). As digital cameras, computers and GPS receivers became available at lower price ranges, the amount of time and cost needed for the acquisition process and the analysis is gradually reduced, which highly increases the operativity of the system (Licskó B. – Ditzendy A. 2003, Bakó G. 2010). Earlier the colour infrared small format digital cameras were mainly used for surface measurements (Warner W.S. et al. 1996). The near infrared spectrum is mainly used in vegetation monitoring but it also promotes the identification of the areas covered with water (Rakonczai J. et al. 2003, Tucker D. et al. 2005).

THE ADVANTAGE OF USING SMALL FORMAT AERIAL PHOTOGRAPHY

The development of a small format aerial photography system that is able to take colour infrared (CIR) aerial photographs was started at the spring of 2008 by the Department of Physical Geography and Geoinfomatics at the University of Szeged. Out of the numerous advantages of the system, its cost efficiency and its operativity can be highlighted. Beyond the price of the digital camera, that was a single investment of the department, only the costs of the flights and the wages of the human resources participating in the processing have to be paid. The fact that the system is easy to operate becomes particularly important in projects that investigate quickly changing phenomena (Bakó G. 2010).

Inland excess water, as a temporal water surface – depending on the weather conditions – can evolve rather quickly, but its extension can diminish relatively fast as well. To discover a mapping methodology for excess water and to be able to model its development, it is inevitable to know the actual extent of the area covered with water (Licskó B. – Ditzendy A. 2003). The country-wide aerial photography campaigns carried out every 5 years provide photographs with inappropriate time resolution. By using our small format aerial photography system, photographs can be taken at any time at any frequency, which provides basic data for further analyses.

Not only the time resolution, but the spatial and spectral resolution of the photographs adjusts better to the needs of the research. The size of the smallest object (pixel) on the surface that can be mapped falls within the sub-meter interval and it can be altered depending on the altitude of the flight. This harmonizes well with the size range of the examined excess water coverage. In comparison: while the satellite images provide only 4, 10 or 30-meter resolution data, the country-wide aerial photography data provides 1-meter resolution.

Our camera is able to record in 3 spectral bands of the electromagnetic spectrum: in the visible green (G), the red (R) and the near infrared (NIR) bands. Out of these, the near infrared band is of particular importance, as in this band the water surfaces nearly completely absorb the incoming radiation and thus they appear as dark, black territories, which are easy to detect both visually and also by using image-processing techniques. By using the red (R) and near infrared (NIR) spectra together, the vegetation can be differentiated. On the other hand, the traditional aerial photographs – provided by the country-wide aerial photography, for example – cover only the spectrum of visible light and thus they provide much less spectral information regarding the excess water areas.

INTRODUCING THE RECORDING SYSTEM

A Duncantech MS 100 CIR (colour infrared) digital multispectral camera forms the basis of the acquisition system. Additional components are an attached data storage computer – equipped with a framegrabber card –

Fig. 1 Hardware elements of the recording system (left)
and the Cessna 127 airplane with the CIR camera fixed into its luggage space (right)

and GPS receivers (Mobile Mapper CE and Garmin GPSMAP 296) that help the navigation and also record the flight path (*Fig. 1*).

The Duncantech MS3100 digital multispectral camera contains 3 single CCD sensors (*Fig. 2*). The sensors detect the photons of the red (R), green (G) and near infrared (NearIR) spectra separately, depending on the prism (which splits the light) in front of the sensors (*Table 1*). The 3 sensors can be programmed separately, which means that not only their gain but also the applied integrating time can be adjusted to the needs of the users. This way it is possible to strengthen the IR spectrum – which is used to take photographs of vegetation and water surfaces – taking advantage of their special NIR reflectance.

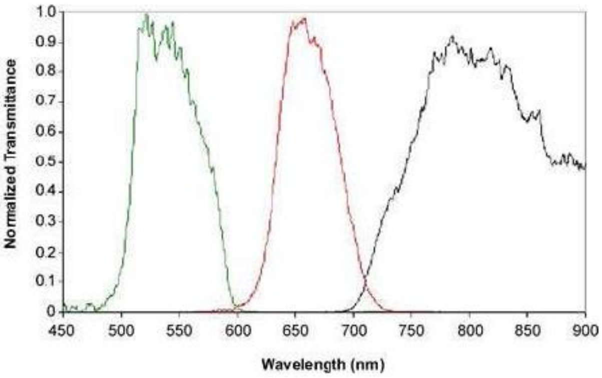

Fig. 2 Sensitivity of the green, red and near-infrared sensors

The sensors are built up of 1392x1040 pixels, the physical size of each is 4.65x4.65 micron. The radiometric resolution of the detectors is 10 bit therefore they are able to differentiate maximally between 2^{10}, i.e. 1024 intensity values. This way relatively low reflectance differences between recorded object can be identified. The ground resolution of the data always depends on the optics and flight height. Using the high-speed Tokina AT-X 17 AF Pro objective at a flight altitude of 2000 m the spatial resolution is 62 cm.

Table 1 Recording spectrum of the CIR camera

	CIR configuration (nm)		
Band	*Range*	*Center*	*Width*
Blue	-	-	-
Green	**530 – 570**	**550**	**40**
Red	**640 – 680**	**660**	**40**
NIR	**768 – 832**	**800**	**65**

A mini computer with a National Instruments IMAQ 1428 type framegrabber PCI card was used to store the photographs. The transportation of the data from the camera to the framegrabber is done through Camera Link connection, in three channels, each of which transports 10 bit data to the framegrabber. The further settings of the data recording – the frequency of exposure, the name and the place of the saved photos, the integration time and the sensitivity of the sensors – happens at the time of acquisition with the DT Control software supplied with the camera.

During the acquisition, navigation was carried out by a Garmin GPSMAP 296 aviation GPS device following the planned flight. The actual flight path was recorded with a Thales Mobil Mapper CE type GPS receiver. While the Digiterra Explorer mobile GIS software running on the Windows CE based device helps the navigation, the GPS Status application of the Thales records the GPS data in NMEA format. Subsequent processing of the GPS data provides one meter accuracy flight track.

To carry out the flight a Cesna 172 type airplane was used, which is the property of the partner company. In the four-seater airplane the person sitting next to the pilot directs the navigation and operates the camera. While the camera is in a construction fixed to the side of the plane, the data recording and energy supplier components – the batteries and the inverter – are in the luggage space of the plane.

The hardware elements of the system presented above cost nearly 13,000 Euro. The cost of operation is about 250 Euro for an hour long flight, which of course changes depending on the distance of the destination and the shape of the acquisition area. As our point of departure is the Szeged Airport, our primary destination is the southern part of the Great Hungarian Plain. Nevertheless the flexibility of our system allows its installation into any airplane that has got a door on its luggage space.

FLIGHT PLAN

While preparing the flight plan, it has to be decided in which way to cover the area to be recorded. Not only the planned flight paths have to be recorded, but also the necessary time intervals between the exposures. To do this not only the speed of the flight and the size of the area covered by a single photo – in case of a fixed objective, the latter depends only on the altitude of the flight – has to be known, but also the distance between the photos (b) and the distance between the rows of photos (d) have to be defined. To facilitate later processing, the photos have to overlap each other by a minimum of 50% in the flight direction by 20-30% on adjacent flightpaths. Taking these requirements into consideration, on a flight altitude of 2000 m, at the speed of 150 km/h the frequency of exposure is 1 photo/ 4 seconds and the distance of the neighbouring paths – in case the camera is fixed perpendicular to the flight direction – is 600 meters (*Fig. 3*).

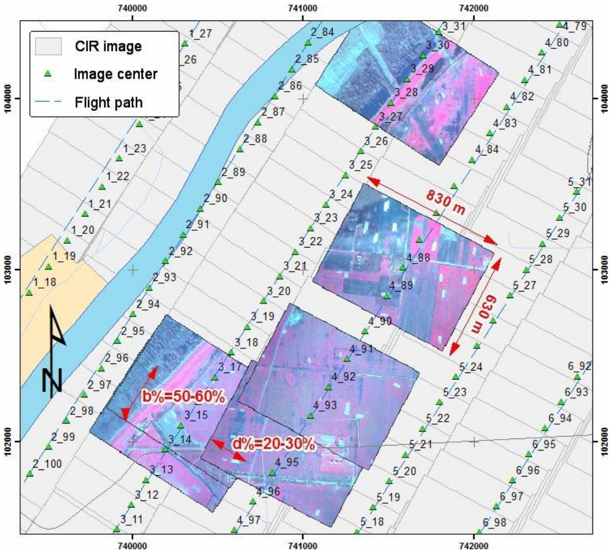

Fig. 3 A part of the recorded area with the planned and the actual flight paths, some sample images and characteristic parameters

Our inland excess water project had 3 sample areas (*Fig. 4*), the total extension of which was 69.7 km^2. Out of these sample areas area I (Tápairét) and area II (Batida) was recorded two times during the excess water period of spring 2010: on 24th March 2010 and on 9th June 2010. The recording was carried out based on the same flight path on both occasions. The 10 lines of flight, the nearly 100 CIR images captured at each line, resulted in 1804 (895+909) images by the end of the second day.

Acquisitions have already been carried out for previous projects of the department and for external partners as well. In the course of these projects approximately an area of 1000 km^2 was recorded (Tobak Z. et al. 2008, Kitka G. et al. 2010). For urban ecology research high spatial resolution – 50 cm pixel size – colour infrared (CIR) data has been acquired for the total area of Szeged (van Leeuwen B. et al. 2009).

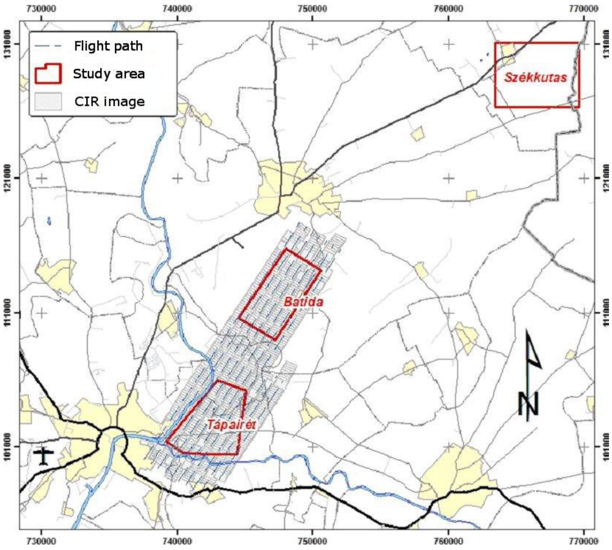

Fig. 4 Study areas covered with excess water and their surroundings with flightlines and the footprints of the images

IMAGE PROCESSING

During the preparation of the aerial photography, the flight and the processing of the raw data, different types of software had to be used. All through the work these software were customized to our needs and therefore the processing of the numerous photos could be made more automatic.

During the preparation of the flight plan, the flight altitude was determined on the basis of the size and the shape of the area under survey and the desired resolution. Having known the image sizes calculated from the altitude of the flight, the flight paths were determined. It is practical to orientate the lines in north-south or east-west directions, although it is possible to rotate the images in any directions at any angles by the processing software. The planned lines were loaded in Digiterra Explorer in shape file format based on the Hungarian national projection (EOV).

The image exposure can be controlled and its parameters can be set in real time during the flight. The data logger and the control software of the camera allow the modification of Gain and the Integration Time. This makes the adaptation to the different light conditions possible. New series of images were created for each line of flight for which separate log files, containing the parameters of the camera and the exact time of exposure, were generated by the program. The images were recorded in three-band TIFF files with 8-bit colour depth per band.

In the first step of processing the x, y and z coordinates and the time data of the flight were extracted from the NMEA file recorded every second by the GPS. Then based on these records a dBASE table was generated. The time field of the table is joined (Table Join) with the log file of the camera thus the records of the table are joined with the images. With this operation real EOV coordinates (x, y) were assigned to the central point of each image. In the next step these coordinates – and the spatial resolution – were used for the generation of the so-called world files.

World files are simple ASCII text formats, with which geographical coordinates can be assigned to JPEG and TIFF files. In this way, using the coordinates recorded by the GPS, geo-referenced images can be made from our images quickly and automatically. Only in case of image rotation angles of 0 or 180 degrees is the application of the world files an effective method, therefore the flight directions were chosen in a way to make this possible. The generation of the .tfw world files connected to the TIFFs requiring a rotation angle of 0 or 180 degrees was carried out with Avenue script in ArcView 3.2 software. In case of a different rotation angle the ArcGIS Rotate tool was also used in a Python script besides the world files. By means of the world files, a rough geometric correction was attained, the accuracy of which was better than 150-200 m, depending on the circumstances of the flight. In the next step the aim was to create an orthophoto mosaic of the whole studied area by the assembling and geo-correction of the single images. During the preparation of this process the TIFF with world file was converted to IMG format by another Python script. In the ERDAS Imagine image-processing software tie points between the images of the block (image series) were automatically generated, and after their filtering the block was transformed to EOV. A single, coherent image file was made from the individual images by mosaicing.

Fig. 5 summarizes the image processing workflow and demonstrates the data and operations used, the applied GIS and image processing technologies, and different types of software.

APPLICATION OF PROCESSED IMAGES

The geometrically corrected CIR images can be used in a wide range of studies. The common characteristic of these studies is that they require high spatial and temporal resolution and visible as well as near infrared spectral information.

All of the above-mentioned requirements are of major importance during the exact delineation of the areas covered with inland excess water. In the classification procedure based on the artificial neural network (ANN) under development in our department these images are the most important input data besides a high resolution

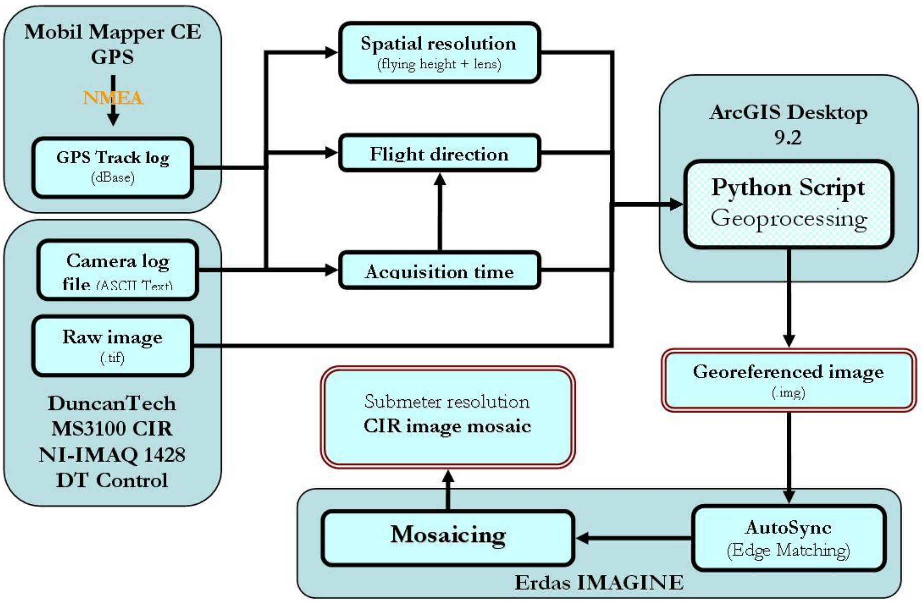

Fig. 5 Flow diagram of image processing from the raw images to the image mosaic

digital elevation model. The images supplied by the three bands are used as separate input layers both in the training and the simulation phases.

Besides the above-mentioned, ANN-based, method visual information can also be interpreted by the conventional image analyzing methods. During the mapping of sources of pollution harmful to the environment – for example, illegal landfills, water reservoirs etc. – high spatial resolution and operativity are key issues (Mucsi L. et al. 2004, Szatmári J. et al. 2008). A GIS database can be created from the different type of contaminating objects identified on the basis of the images (Warner W. S. 1994, Tobak Z. et al. 2008, Kitka G. et al. 2010).

The red and near infrared bands of the sensor are well applicable for the monitoring of vegetation. These ranges of the electromagnetic spectrum are used for most of the vegetation indices. The estimation of the amount of biomass and chlorophyll, the separation of different forest types and the assessment of vegetation health are research topics for which good quality data can be provided (Ladányi Zs. et al. 2011).

The monitoring of vegetation can be carried out in the urban environment as well. The remote sensing analysis of the complex and heterogeneous urban surfaces, with adequate spatial accuracy, can only be carried out if the geometric resolution is high. However, the spectral information content of the colour infrared images is narrow compared to the hyperspectral data. By their combination and by the development of multi-level classification methods, the advantages of both can be exploited.

FUTURE OPPORTUNITIES, CHALLENGES

Our system – in its present state – is not suitable to completely replace the traditional methods of aerial photography. It does not contain inertial or other spatial reference system therefore there is no possibility to eliminate errors arising from the irregular movements of the airplane. Positional errors depending on the weather conditions can partially be corrected by automatic switching point measurement.

Conversion of the energy values measured by the sensor (DN) to surface reflectance values would need further developments. Field reference samples should be used for this during acquisition. The differences between the histograms of the images can be corrected by histogram matching.

Both hardware and software developments are needed in the future. For greater spatial coverage and thus more cost-effective recording, the replacement of the small-format camera (1392x1040 pixels) to a medium-format one (7220x5410 pixels) is among our plans. The expansion of the GPS measurements with an inertial measurement unit (IMU) is planned for faster and more accurate geometric correction. The self-made programs carrying out automatic processing also need further development by which the time elapsed between the image exposure and the production of processed – and even analyzed – images can be reduced.

During the developments the targets set at the creation of the system are kept in mind. Although the value of the entire system increases due to financial investments, the costs of operation and processing are kept on a cost-effective level. In addition, operativity, which is the main advantage of the system, remains and is further improved.

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