Hungarian Geographical Bulletin 63 (4) (2014) 365–378.
DOI: 10.15201/hungeobull.63.4.1

Estimated changes of drought tendency in the Carpathian Basin

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Abstract

Drought conditions are often characterized by various drought indices. In this paper different types of indices (i.e. standardized precipitation anomaly index, Thornthwaite's aridity index, and Ped's drought index) are used to estimate the future changes in drought conditions in the Carpathian Basin. For this purpose 25 km horizontal resolution gridded outputs of several regional climate models are used from the project ENSEMBLES covering the period 1951–2100 and taking into account the A1B emissions scenario. The results suggest remarkable drying in the region, especially, in summer, which emphasize the importance of developing appropriate adaptation strategies addressing this issue.

Keywords: drought index, ENSEMBLES, regional climate model simulation, climate change

Introduction

Climatic conditions evidently affect the biosphere as well as the human societies. Anthropogenic activity influences the biosphere through land use change and agriculture (e.g. cultivating selected crops and thus decreasing biodiversity) for several centuries. Moreover, the 250 year long industrial activities (especially, fossil fuel combustion) resulted in increasing atmospheric concentration of greenhouse gases. As a consequence, global and regional warming has been detected (IPCC, 2013), which intensified drought conditions in many regions including Central and Southern Europe (IPCC, 2012). Hungary is certainly affected by this potential risk since it is located in the continental Central European zone. In the recent years, the entire continent was hit by a severe drought event in 2003, which included Hungary as well, as the whole Carpathian Basin (Tallaksen, L.M. *et al.* 2011). On the basis of

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the measurement recorded by the Hungarian Meteorological Service the annual precipitation of the country was only 75 percent of the climatic mean (for the period 1971–2000). In 2011 the annual precipitation in Hungary was even smaller, only 72 percent of the normal value. Parts of the country were affected by drought events in 2002, 2007 and 2012.

Due to the recent increasing frequency of unusual years, it is essential to assess the possible future conditions in the country using regional climate model (RCM) simulations. These tools are widely used to estimate the primary climatic conditions, i.e. temperature and precipitation. Projected changes are summarized for Hungary in Pongrácz, R. *et al.* (2011), according to which regional warming is very likely to continue and increase in this century. Projected precipitation changes are varying throughout the year. RCMs clearly estimate summer drying for this century, however, in the other seasons different RCMs estimate different tendencies both in intensity and sign. Drought conditions are not determined only by precipitation conditions but also by temperature changes, this bivariate dependence can be assessed by drought indices.

In this paper first, the different types of drought indices are summarized and the three indices used in this paper are presented in details. Then, data outputs of RCM simulations available from project ENSEMBLES are described, followed by the discussion of the results. Finally, the conclusions are drawn.

Drought indices

Several aspects of the climatic system are directly or indirectly affected by precipitation deficiency, i.e. drought events. Therefore different scientific communities use different approaches to define drought itself and measures to characterize it. For instance, atmospheric science defines meteorological drought as a long period of time with considerably less precipitation amount than climatic mean. Other aspects may highlight the agricultural consequences, and define agricultural drought when the soil moisture is inadequate, and yields are considerably less than average because of the water shortage. Furthermore, hydrological drought refers to a period of below normal stream-flow, thus, focusing on the hydrological impacts of the lack of precipitation, such as reduced groundwater levels. Finally, economic drought considers the monetary value of drought-related damages, which can happen when the water shortage has an effect on human activity and on economy.

One of the most often used measures of drought includes the definition of several drought indices, which are able to quantify the temporal and spatial range of dry periods. The can be classified into different categories. Typically, there are four main groups of indices, which are widely used: the precipitation, the water balance, the recursive and the soil moisture indices

(Faragó, T. *et al.* 1988). *Table 1* summarizes the traditional classification of drought indices, whereas *Table 2* lists most of the well-known drought indices according to Dunkel, Z. (2009).

Table 1. Classification of drought indices

Index types	Examples
Precipitation indices	Relative anomaly index Standardized precipitation anomaly index Relative precipitation anomaly index Precipitation anomaly index
Water balance indices	Lang's rainfall index De Martonne aridity index Thornthwaite index
Recursive indices	Foley's anomaly index Palmer's drought index
Soil moisture indices	Ped's drought index Relative soil moisture index
Remotely sensed indices	Vegetation index Normalized difference vegetation index

Precipitation indices are suitable for the separation of wet and dry periods, as well as for the determination of variability. They are simple and do not require large datasets. Water balance indices are more complex. In addition to precipitation they also take into account temperature, which is used as the main factor of evaporation from the output side of the water balance. Recursive indices consider cumulative effects of precipitation shortage since they use data from the preceding period and hence characterize longer time periods. Soil moisture indices are able to estimate crop loss and agricultural water shortage. The main advantage of the indices based on remotely sensed information is the good spatial coverage for large areas.

In order to keep a reasonable length of this paper, standardized precipitation anomaly index (*SAI*), Ped' s drought index (*PDI*) and Thornthwaite's aridity index (*TAI*) are used to estimate the projected trends of dry climatic conditions by the end of the 21st century in the Carpathian Basin (Thornthwaite, C.W. 1948; Ped, D.A. 1975).

One of the most simple indices is *SAI* (Katz, R.W. and Glantz, M.H. 1986). The main advantage of this dimensionless index that it can be calculated only from precipitation time series. In addition, *SAI* is a standardized measure for seasonal differences and for precipitation in different climatic areas. Based on the definition the negative/positive trend of *SAI* implies drier/wetter climatic conditions. The drought classification using *SAI* values is shown in *Table 3.*

TAI is widely used in agrometeorological studies (Thornthwaite, C.W. 1948). For calculating *TAI* temperature time series are also used in ad-

Table 2. Definition of drought indices

Nr.	Index	Temporal resolution	Definition	Used data
1.	Precipitation index [mm]	week, month, season	$P - m(P)$	– precipitation sum (P) – mean precipitation ($m(P)$)
2.	Standardized precipitation anomaly index (SAI) [%]	week, month	$\frac{P - m(P)}{d(P)}$	– precipitation sum (P) – mean precipitation ($m(P)$) – standard deviation of precipitation ($d(P)$)
3.	Relative precipitation amount	week, month	$\frac{P}{m(P)}$	– precipitation sum (P) – mean precipitation ($m(P)$)
4.	Relative precipitation anomaly index	week, month	$\frac{P - m(P)}{m(P)}$	– precipitation sum (P) – mean precipitation ($m(P)$)
5.	De Martonne index [mm/°C]	month	$\frac{12 \cdot P}{T + 10}$	– precipitation sum (P) – temperature (T)
6.	Thornthwaite index	month	$1.65 \cdot \left(\frac{P}{T + 12.2}\right)^{\frac{10}{9}}$	– precipitation sum (P) – temperature (T)
7.	Lang rainfall index [mm/°C]	any given time period	$\frac{P}{T}$	– precipitation sum (P) – temperature (T)

Table 2. Continued

Nr.	Index	Temporal resolution	Definition	Used data
8.	Selyaninov's hydro-thermal coefficient [mm/°C]	day	$\frac{P}{\sum_{T\geq 10} T}$	– precipitation sum (P) – temperature (T)
9.	Aridity index	–	$\frac{P}{PE}, \frac{P}{\frac{R_n}{L}}$	– precipitation sum (P) – evapotranspiration (PE) – radiation balance (R_n) – latent heat (L)
10.	Bowen ratio	day	$\frac{H}{LE}$	– sensible (H) and latent (LE) heat flux
11.	Ped's drought index, 1st approximation	–	$\frac{\Delta T}{d(T)} - \frac{\Delta P}{d(P)}$	– precipitation sum (P) – temperature (T) – standard deviation of temperature ($d(T)$) and precipitation ($d(P)$)
12.	Ped's drought index, 2nd approximation	–	$\frac{\Delta T}{d(T)} - \frac{\Delta P}{d(P)} - \frac{\Delta W}{d(W)}$	– precipitation sum (P) – temperature (T) – soil moisture (W)
13.	Relative soil moisture content	–	$\frac{W}{AWC}$	– actual (W) and available (AWC) soil moisture
14.	Foley's anomaly index (FAI) [mm]	month	$FAI_1 = \Delta P_1$ $FAI_k = FAI_{k-1} + \Delta P_k$	– precipitation sum (P)

Table 2. Continued

Nr.	Index	Temporal resolution	Definition	Used data
15.	Palmer drought severity index	month	$PDSI_0 = 0$ $PDSI_k = PDSI_{k-1} + \frac{Z_k}{3} - 0.103 \cdot PDSI_{k-1}$	– moisture anomaly index (*Z*)
16.	Bhalme-Mooley drought index	month	$i_k = c_1 \cdot i_{k-1} + \frac{SAI_k}{c_2}$ $BMDI = \frac{1}{n} \cdot \sum_{i=1}^{n} i_k$	– SAI index – region specific value for the coefficients (c_1 and c_2)
17.	Vegetation index	day	$\frac{NIR}{VIS}$	– reflected radiation in the near infrared electromagnetic wavelength (*NIR*) and in the visible electromagnetic wavelength (*VIS*)
18.	Normalized difference vegetation index (NDVI)	day	$\frac{NIR - VIS}{NIR + VIS}$	– reflected radiation in the near infrared electromagnetic wavelength (*NIR*) and in the visible electromagnetic wavelength (*VIS*)
19.	Crop water stress index (CWSI)	day	$\frac{PE - ET}{PE}$	– potential (*PE*) and actual (*ET*) evapotranspiration
20.	Stress degree day (SDD)	month	$SDD = \sum_k (T_C - T_A)$	– remotely sensed surface and standard air temperature (T_C and T_A, respectively)

Table 3. Drought categories defined on the basis of SAI values

SAI values	Category
> 2.0	extremely wet
1.5 to 2.0	severely wet
1.0 to 1.5	moderately wet
–1.0 to +1.0	near normal
–1.0 to –1.5	moderately dry
–1.5 to –2.0	severely dry
< –2.0	extremely dry

Table 4. Drought categories defined on the basis of TAI values

TAI values	Category
> 6.4	wet
3.2 to 6.4	semi-arid
1.6 to 3.2	arid
< 1.6	extremely dry

Table 5. Drought categories defined on the basis of PDI values

PDI values	Category
< –3	extremely wet
–3 to –2	severely wet
–2 to –1	moderately wet
1 to 2	moderately dry
2 to 3	severely dry
> 3	extremely dry

dition to precipitation (Kemp, D. 1990). Decreasing/increasing trend of *TAI* means drier/wetter climatic conditions. *Table 4* shows the different drought categories according to *TAI*.

For complex studies it can be useful to compare standardized values of temperature and precipitation in order to obtain a more accurate result. *PDI* (Bagrov, N.A. 1983; Ped, D.A. 1975) is a soil moisture index, which trends are opposite to *SAI* or *TAI*, namely, decreasing/increasing trend indicates wetter/drier conditions. *PDI* values close to zero (between –1 and +1) implies neutral states. Drought classification using *PDI* values is shown in *Table 5.*

Data

To assess uncertainty due to natural and anthropogenic forcing factors, future climatic conditions are estimated with an ensemble of climate models. For Europe the five-year-long project ENSEMBLES studied the projected climate changes (van der Linden, P. and Mitchell, J.F.B. 2009). The regional climate models (RCMs) run at 25 km spatial resolution for 1951–2100 used the SRES A1B emissions scenario, which estimates the atmospheric carbon-dioxide level to 532 ppm and 717 ppm by 2050 and 2100, respectively (Nakicenovic, N. and Swart, R. 2000).

The necessary initial and lateral boundary conditions were provided by outputs of global climate models (GCMs). Here we use 9 RCM experiments driven by ECHAM5 (Roeckner, E. *et al*. 2006) and HadCM3Q (Gordon, C. *et al.* 2000; Rowell, D.P. 2005) GCMs. These global models were run at the Max Planck Institute in Hamburg Germany, and the Hadley Centre of the UK MetOffice, respectively.

For the analysis of drought conditions in the Carpathian Basin gridded monthly mean temperature values and monthly precipitation amounts of the RCM outputs (*Table 6*) were used for the end of the 21st century (2071–2100). As a reference period 1961–1990 was selected.

Table 6. Used regional climate model simulations, their running institutes, and the driving global climate models

RCM	Institute, country	Driving GCM
HadRM3Q	METO-HC, United Kingdom	HadCM3Q
CLM	ETHZ, Switzerland	
RCA3	C4IR, Ireland	
RCA	SMHI, Sweden	
RegCM	ICTP, Italy	ECHAM5
RACMO2	KNMI, Netherlands	
REMO	MPI, Germany	
HIRHAM	DMI, Denmark	

Results

In order to investigate the future change of the Hungarian drought conditions seasonal mean drought index values have been calculated for the last three decades of the 21st century using the gridded outputs of each RCM, and compared to the reference period. For the spatial analysis the differences are mapped in *Figures 1, 2* and *3* using *SAI*, *TAI* and *PDI*, respectively. The four columns represent the different seasons.

The maps in the upper four rows show the results from the RCM simulations driven by HadCM3Q GCM, whereas the lower five rows contain the results from the ECHAM5-driven RCM simulations. Yellow and red colors of the scale indicate drier conditions, while green and blue colors suggest wetter climate. In case of *SAI* (standardized precipitation index) and *TAI* (Thornthwaite's aridity index) decreasing trends imply drying. Opposite to these indices, increasing *PDI* (Ped's drought index) values indicate drier conditions.

From the maps the drying tendency in summer is clearly seen in using any of the three indices. The other three seasons are also dominated by drying tendencies, however, winter is likely to become wetter according to *SAI* (*Figure 1*), which can be explained by the definition of this index, namely, it is based only on precipitation amount, whereas *TAI* and *PDI* also consider temperature.

The average seasonal projected changes are summarized in *Tables 7, 8* and *9* for Hungary using the grid-cells located within the country. Besides all the individual RCM results, the averages and the standard deviations of the 9-member-ensemble are calculated. The larger projected changes are indicated by italic characters. Since the scales of the three indices are different therefore different thresholds are used: in case of *SAI*, *TAI* and *PDI* large changes are defined as exceeding 0.3, 2.0 and 0.4 in absolute value, respectively. Again note that the signs of the *PDI* changes are opposite to those of *SAI* or *TAI* changes.

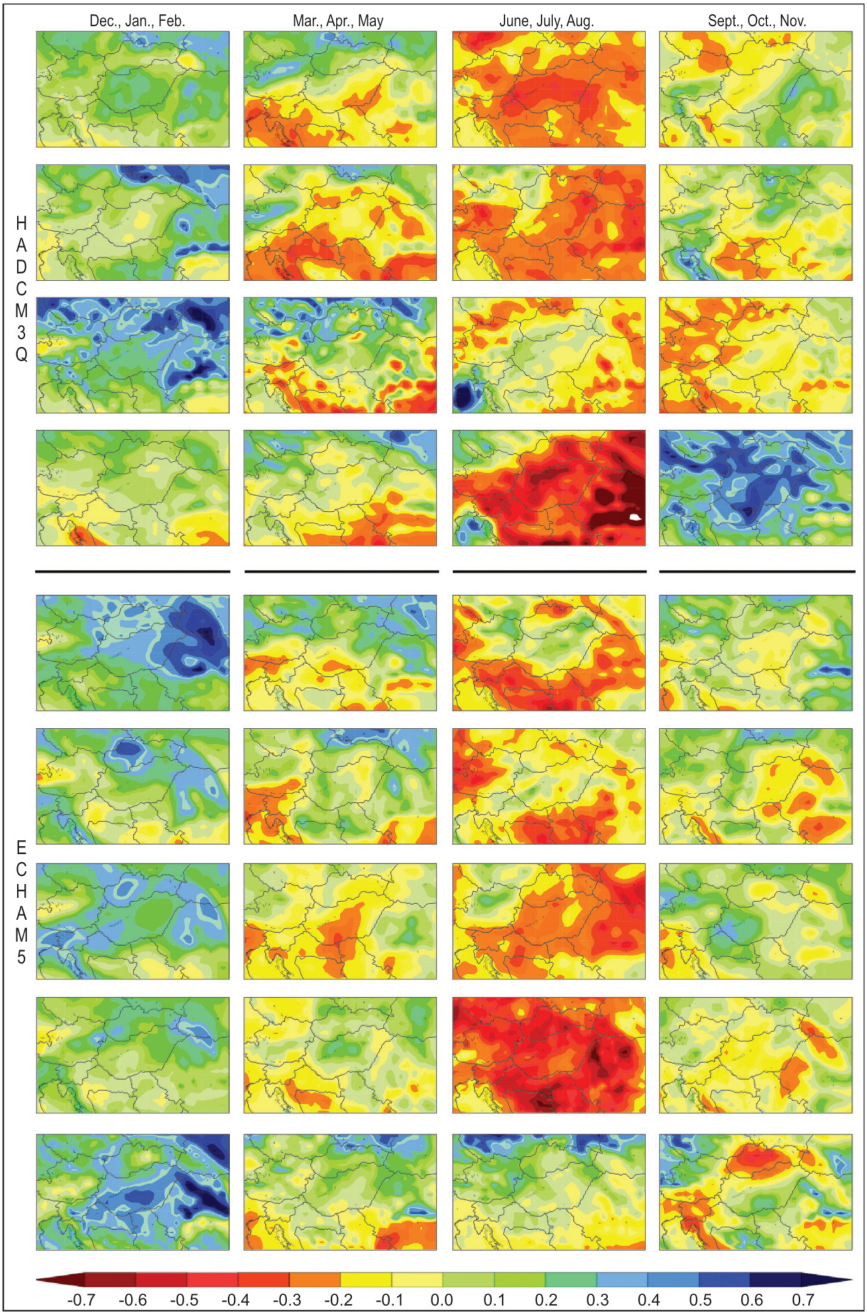

Fig. 1. Projected seasonal changes of *SAI* by 2071–2100 relative to the 1961–1990 reference period using 9 different RCM simulations

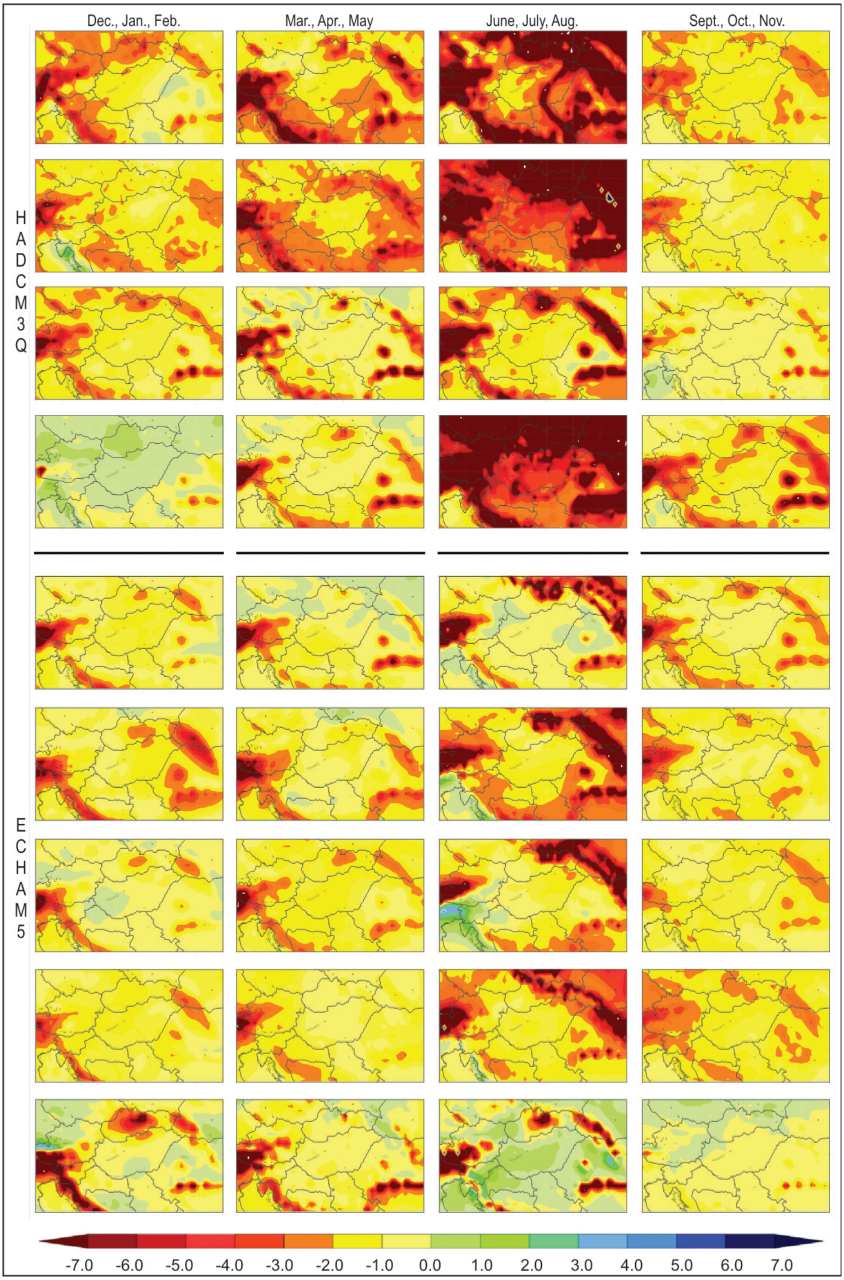

Fig. 2. Projected seasonal changes of *TAI* by 2071–2100 relative to the 1961–1990 reference period using 9 different RCM simulations

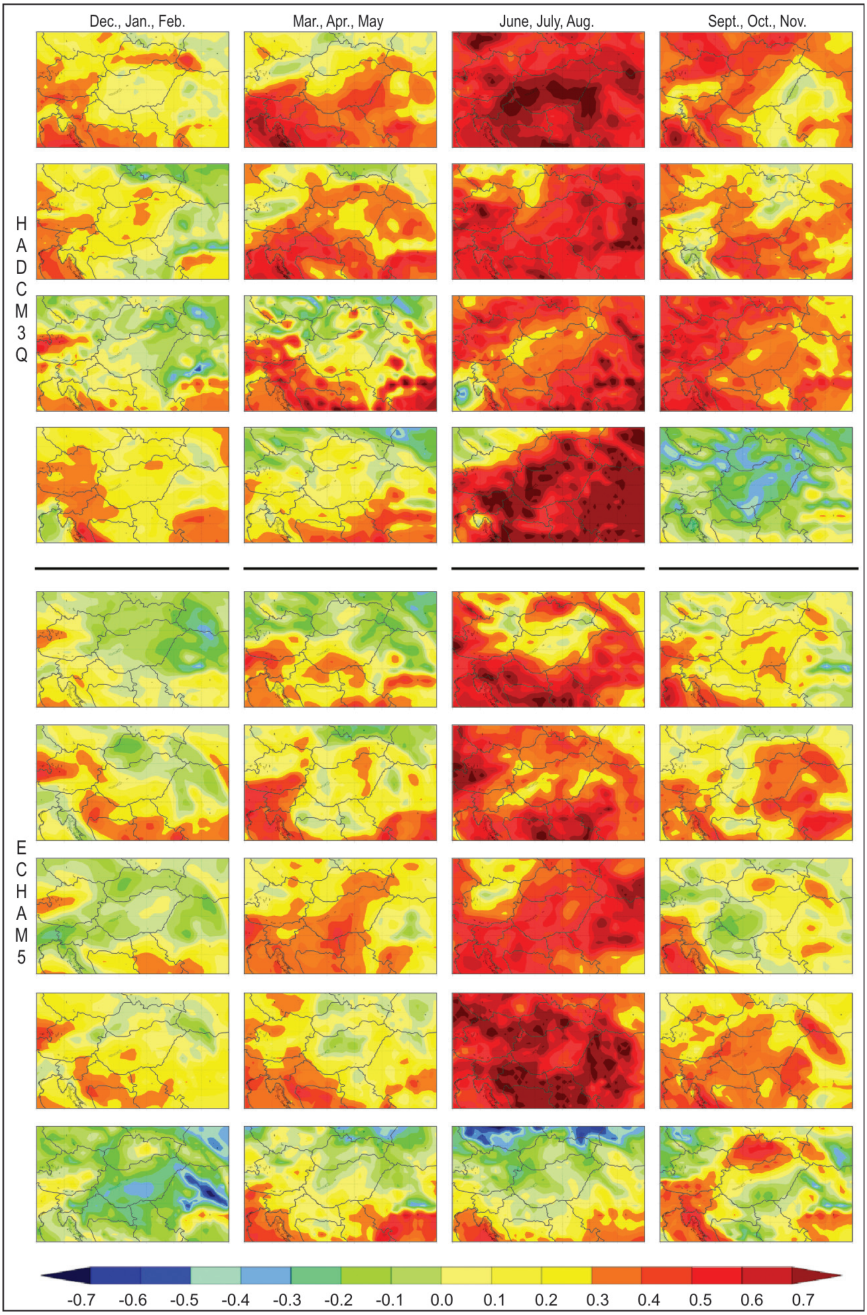

Fig. 3. Projected seasonal changes of *PDI* by 2071–2100 relative to the 1961–1990 reference period using 9 different RCM simulations

*Table 7. The average projected seasonal changes by 2071–2100 relative to the 1961–1990 reference period for Hungary in case of SAI using 9 different RCM simulations**

RCM	DJF	MAM	JJA	SON	Driving GCM
HadRM3Q	0.21	-0.10	*-0.37*	0.05	HadCM3Q
CLM	0.18	-0.18	*-0.34*	-0.16	
RCA3	*0.37*	0.05	-0.08	-0.19	
RCA	0.19	-0.09	*-0.50*	*0.39*	
RCA	0.19	-0.05	-0.15	-0.04	ECHAM5
RegCM	0.22	0.09	-0.07	-0.18	
RACMO2	0.29	-0.12	-0.19	0.00	
REMO	0.18	0.02	*-0.48*	-0.15	
HIRHAM	0.29	0.10	0.09	-0.03	
Ensemble-average	0.24	-0.03	-0.23	-0.03	
Standard deviation	0.07	0.10	0.20	0.18	

* Changes exceeding 0.3 in absolute value are indicated by italics.

*Table 8. The average projected seasonal changes by 2071–2100 relative to the 1961–1990 reference period for Hungary in case of TAI using 9 different RCM simulations**

RCM	DJF	MAM	JJA	SON	Driving GCM
HadRM3Q	-1.92	-1.91	*-6.17*	-1.80	HadCM3Q
CLM	-1.88	*-2.20*	*-11.80*	-1.76	
RCA3	-1.64	-1.66	*-2.18*	-1.11	
RCA	1.71	-1.72	*-6.79*	-1.92	
RCA	-0.57	-1.02	-1.89	-1.73	ECHAM5
RegCM	-0.87	-1.16	*-2.14*	-1.72	
RACMO2	-0.17	-1.79	-1.95	-1.76	
REMO	-0.93	-0.71	*-2.01*	-1.87	
HIRHAM	-0.58	-1.19	0.08	-0.40	
Ensemble-average	-0.76	-1.48	*-3.87*	-1.56	
Standard deviation	1.11	0.48	3.69	0.50	

* Changes exceeding 2.0 in absolute value are indicated by italics.

*Table 9. The average projected seasonal changes by 2071–2100 relative to the 1961–1990 reference period for Hungary in case of PDI using 9 different RCM simulations**

RCM	DJF	MAM	JJA	SON	Driving GCM
HadRM3Q	0.16	0.31	*0.74*	0.30	HadCM3Q
CLM	0.10	0.32	*0.63*	0.28	
RCA3	-0.04	0.28	*0.44*	0.36	
RCA	0.14	0.16	*0.72*	-0.11	
RCA	-0.13	0.14	0.38	0.19	ECHAM5
RegCM	-0.01	0.18	0.39	0.25	
RACMO2	-0.14	0.23	*0.48*	0.19	
REMO	0.11	0.17	*0.71*	0.28	
HIRHAM	-0.19	0.12	0.01	0.23	
Ensemble-average	0.00	0.21	*0.50*	0.22	
Standard deviation	0.13	0.08	0.23	0.13	

* Changes exceeding 4.0 in absolute value are indicated by italics.

The values suggest that the largest drying in Hungary is projected for summer. Compared to the summer changes less intense drying tendencies are likely to occur in spring and autumn. Winters may result more precipitation in the future (*Table 7*. – *SAI*), however, due to the warming trend *TAI* and *PDI* suggest overall drier winters in the late 21st century compared to the reference period (*Tables 8* and *9*, respectively). This can be explained by the increasing evaporation in the warmer environment.

Conclusions

Precipitation and temperature gridded monthly outputs of 9 RCM simulations (available from the ENSEMBLES project) were used to calculate different type of drought indices (*SAI, TAI, PDI*) for the Carpathian Basin considering the A1B emissions scenario. Based on the analysis presented in this paper the following conclusions can be drawn:

(i) Summers of the late 21st century are clearly projected to be substantially drier than the 1961–1990 reference period.

(ii) Winter precipitation tends to increase in the future. However, because of the regional warming and the consequent increase of evaporation climatic conditions are projected to become drier in winter, too.

(iii) Springs and autumns tend to become also slightly drier by 2071–2100 relative to the 1961–1990 reference period.

The overall drying tendency in the region highlights the necessity to develop the appropriate strategies to adapt to the regional climate change. This is especially important for end-users and decision-makers related to agriculture, food and drinking water security.

Acknowledgements: Research leading to this paper has been supported by the following sources: the Hungarian National Science Research Foundation under grant K-78125, K-83909 and K-109109, the European Union and the European Social Fund joint supports (FuturICT.hu TÁMOP-4.2.2.C-11/1/KONV-2012-0013, GOP-1.1.1.-11-2012-0164, and KMR-12-1-2012-0206). The AGRÁRKLÍMA2 project (VKSZ-12-1-2013-0001) and the EEA Grant HU04 Adaptation to Climate Change (EEA-C13-10). The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged.

REFERENCES

Bagrov, N.A. 1983. On the meteorological index of yields. *Meteorologiya i Gidrologiya* 11. 92–99.

Dunkel, Z. 2009. Brief surveying and discussing of drought indices used in agricultural meteorology. *Időjárás* 113. 23–37.

Faragó, T., Kozma, E. and Nemes, Cs. 1988. Quantifying droughts. In *Identifying and coping with extreme meteorological events.* Eds. Antal, E. and Glantz, M., Budapest, Hungarian Meteorological Service, 62–111.

Gordon, C., Cooper, C., Senior, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B. and Wood, R.A. 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics* 16. 147–168.

IPCC, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Eds. Field, C.B., Barros, V., Stocker, T.F., Dahe, Q., Dokken, D.J., Plattner, G-K., Ebi, K.L., Allen, S.K., Mastandrea, M.D., Tignor, M., Mach, K.J. and Midgley, P.M., Cambridge, UK – New York, USA, Cambridge University Press, 582 p.

IPCC, 2013. Summary for Policymakers. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Eds. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M., Cambridge, UK – New York, USA, Cambridge University Press, 544 p.

Katz, R.W. and Glantz, M.H. 1986. Anatomy of a rainfall index. *Monthly Weather Review* 114. 764–777.

Kemp, D. 1990. *Global environmental issues: a climatological approach*. London–New York, Routledge, 241 p.

Nakicenovic, N. and Swart, R. (eds.) 2000. *Emissions Scenarios. A Special Report of IPCC Working Group III.* Cambridge, UK, Cambridge, University Press, 570 p.

Ped, D.A. 1975. On parameters of drought and humidity. *Papers of the USSSR Hydrometeorological Center* 156. 19–38. (in Russian)

Pongrácz, R., Bartholy, J. and Miklós, E. 2011. Analysis of projected climate change for Hungary using ENSEMBLES simulations. *Applied Ecology and Environmental Research* 9. 387–398.

Roeckner, E., Brokopf, R., Esch, M., Giorgetta, M., Hagemann, S., Kornblueh, L., Manzini, E., Schlese, U. and Schulzweida, U. 2006. Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model. *Journal of Climate* 19. 3771–3791.

Rowell, D.P. 2005. A scenario of European climate change for the late 21st century: seasonal means and inter-annual variability. *Climate Dynamics* 25. 837–849.

Tallaksen, L.M., Stahl, K. and Wong, G. 2011. Space-time characteristics of large-scale droughts in Europe derived from stream-flow observations and WATCH multi-model simulations. *Technical Report* No. 48. Oslo, University of Oslo. 16 p.

Thornthwaite, C.W. 1948. An Approach Toward a Rational Classification of Climate. *Geography Review* 38. 55–94.

van der Linden P. and Mitchell, J.F.B. 2009. *ENSEMBLES: Climate Change and Its Impacts: Summary of research and results from the ENSEMBLES project*. Met Office Hadley Centre, UK, 160 p.

Hungarian Geographical Bulletin 63 (4) (2014) 379–400.
DOI: 10.15201/hungeobull.63.4.2

Spatial analysis of groundwater level monitoring network in the Danube–Tisza Interfluve using semivariograms

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Abstract

Over the last thirty years water-scarcity has been the main factor restraining agricultural activity and the size of the nature reserve areas of the Kiskunság National Park in the Danube–Tisza Interfluve. Fluctuation of water resources affecting the plain areas in general is indicated by the decrease of the groundwater level, summarizing the effects of all the influencing phenomena. After that, the decreasing trend of groundwater level has been realized, studies aiming to determine the causes and the extent of the phenomenon have been carried out. Contrary to previous investigations, the present study does not analyze the different groundwater levels as time series. Instead, it deals with the spatial relationship of the measurements at certain moments of time using spatial semivariogram analysis on hydrographs of shallow groundwater data, in order to (i) analyse the spatial structure of the groundwater level monitoring well system and (ii) to recalibrate it. The results indicated a very strong, periodically changing correlation between groundwater level and elevation. Furthermore it was shown that the spatial variability of groundwater-level variations can be observed with half as many, more optimally arrenged stations as the existing ones.

Keywords: geostatistics, groundwater level, range, variogram analysis

Introduction

In the last thirty years, water-scarcity has been the main factor restraining agricultural activity and the size of the nature reserve areas of the Kiskunság National Park in the Danube–Tisza Ridge. This phenomenon has led to total or partial drying up of wetlands and degradation of certain habitats (Biró,

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M. *et al.* 2013a,b; Ujházy, N. and Biró, M. 2013). Fluctuation of the volume of water resources affecting the plain areas is indicated by the decrease of the groundwater-level. This process summarizes the effects of all the influencing phenomena. The tendency of decreasing groundwater-level was first detected in hydrographs at the beginning of the 1980s. After that, several studies aiming to determine the causes and the extent of the phenomenon have been carried out (Major, P. and Neppel, F. 1988; Major, P. 1993; Szodfridt, I. 1993; Ladányi, Zs. *et al.* 2009, 2010).

Hydrographs are time series consisting of trend periodicity and noise, which are commonly analyzed separately. The study of smaller and larger decreases of ground water level and their spatial extension (e.g. mapping the groundwater level differences at certain moments of time) is a possible way of analyses (Pálfai, I. 1994, 1996; Rakonczai, J. and Bódis, K. 2002; Szalai, J. *et al*. 2008, 2011). A major part of this research-approach is the analysis of annual and multiannual periods of groundwater level fluctuation. Examples on the analysis of the former ones can already be found from the 1950s (Ubell, K. 1953; Szabó, Gy. 1959, 1960; Réththe, L. 1974; Rónai, A. 1985; Kovács, J. *et al.* 2011a).

The peculiarity of the phenomena showing periodic changes is that the expected annual period may not recur, i.e. certain periods may not turn up. Annual periods are extremely important from an agricultural point of view, since the yield depends on precise planning. Therefore groundwater level data should be assessed by methods that are capable of determining the existence and the possible non-existence of a period. Wavelet spectrum analysis is a reliable method to estimate the precise temporal fluctuation of periods (Kovács, J. *et al*. 2004, 2010.)

Some researchers applied multivariate data analysis techniques in order to determine the groundwater level fluctuation pattern of the studied area and the spatial distribution of the fluctuations (Szalai, J. *et al.* 2011; Kovács-Székely, I. and Szalai, J. 2009; Ladányi, Zs. *et al.* 2009, 2010; Rakonczai, J. 2011). According to the new research trend of the last decade, groundwater level fluctuation is associated with subsurface flow systems (Mádlné Szőnyi, J. *et al.* 2005).

Previous approaches used a shallow groundwater monitoring network as data source. It should be noted that samples taken from a monitoring system at a given point of time only represent one sample realization. A proper sample should reflect all the important characteristics of the statistical population and to allow the approximation of the unknown z parameter's value in the x,y coordinates of the sample area with adequate accuracy (Kovács, J. and Kovács-Székely, I. 2006a, b). Besides the above-mentioned conditions, it is required that the functioning of the monitoring system should be as economic as possible. The higher the variability of z is within an h distance, the denser the sampling should be. Variability can be described by means of several functions.

In this particular work the semivariogram range is to be used for estimating spatial sampling range. Range is one of the main characteristics of the semivariogram, which is derived from the basic function of geostatistics, the variogram (Matheron, G. 1965). In the Hungarian technical literature this function has been primarily used to determine the temporal sampling range of water chemistry parameters in order to estimate the adequate frequency of sampling (Kovács, J. *et al*. 2011b; 2012; Hatvani, I.G. *et al*. 2011, 2012a). Nevertheless, there are examples for spatial variogram analysis as well (Kovács, J. *et al*. 2005; Hatvani, I.G. *et al*. 2012b, 2014).

In the view of these studies, the main aim of the present research has been to not just analyse the different groundwater levels as simply time series; instead, it deals with the spatial relationship of the measurements at certain moments of time, in order to (i) analyse the spatial structure of the groundwater level monitoring well system and to (ii) recalibrate it, based on the results of the study.

Materials and method

Location and characteristics of the studied area

The study area is bordered by the Danube and Tisza rivers, the southern state border and Gödöllő Hills, so it is nearly 10,000 km^2 area with featuring diversified landforms. The entire area consists of four geographical units: (i) an alluvial plain along the Danube, (ii) Danube–Tisza Ridge and (iii), Bácska Plain and (iv) Lower Tisza Plain (Hajdú-Moharos, J. and Hevesi, A. 1999; Mezősi, G. 2011a,b) (*Figure 1*).

The western border, the Danubian Plain is an alluvial cone flatland with a length of 240 km and a width of 20 to 25 km, the former flood area of the river. The most complex landforms in the region can be found in the vicinity of Budapest. The higher areas feature terrace remnants, while the lower-lying parts were truly flood plains.

The terraces are made up by silty sand and aeolian sand, while the flood plains are made of fine-grain fluvial sediment. The southern part of the area is a perfect flatland intersected by microforms. The lower flood plains are covered by impermeable muddy-clayey sediment, while the higher flood areas are covered by overbank deposits and in some parts remobilized aeolian sand. Saline lakes are unique characteristics of the area. These were formed in the abandoned river beds partially filled with sediment without any outlets. A 10–20 m thick layer of gravel is located underneath the surface formations in the North, which continuously thickens toward to the South, and comes to the surface at the Kalocsa Plain (Kalocsai Sárköz) (Mezősi, G. 2011a,b).

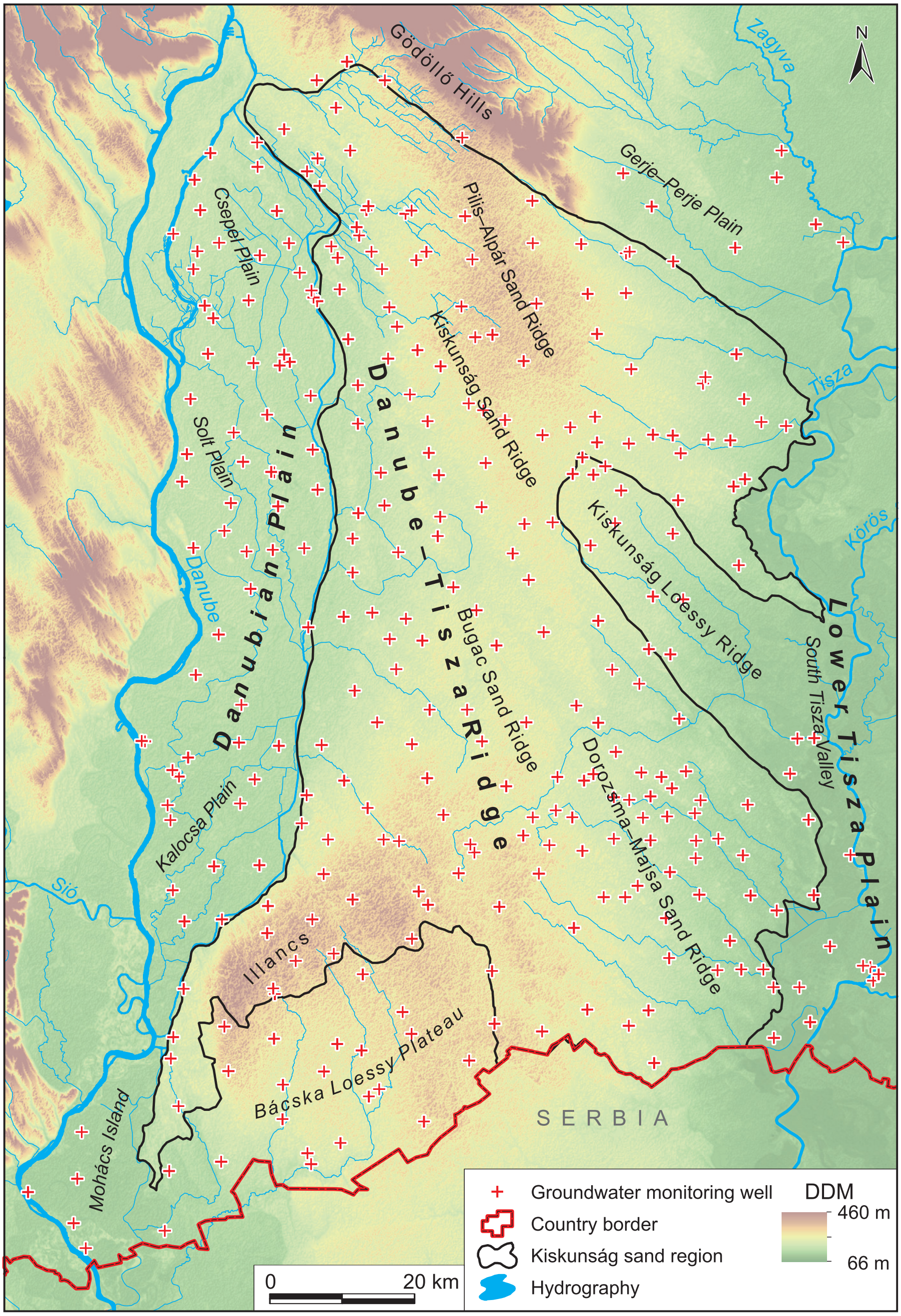


Fig. 1. The location and borders of the Danube–Tisza Interfluve and the shallow groundwater monitoring network

The Bácska Loessy Plain located separately on the south-western part of the Danube–Tisza Interfluve, with an altitude varying between 100 to 175 m asl.. The area breaks off towards the west over the valley of the Danube with a steep edge, while in the west, towards the Danube–Tisza Ridge the transition is gradual.

The eastern border section of the Danube–Tisza Interfluve is called the Lower Tisza Plain featuring a very low-lying area of 79 to 85 m asl. with a Holocene alluvial flatland. Towards the east, its surface is diversified by loop lakes, ox-bow lakes and formations created by wind activity with eroding edges.

According to Biró, M. *et al.* (2009) the centre of the Danube–Tisza Interfluve is the Danube–Tisza Ridge with an altitude of 100 to 130 m asl., stretching from Gödöllő Hills to Bácska Plain covering a total area of 7,400 km^2. The surface forms have been mainly created by the wind and only secondly by water. The curved formations located in the western part of the region have been formed by the side branches of River Danube. These areas were flooded by the river and were filled up by fine-grain sediment. Diversified sand forms were formed owing to the aeolian surface-forming activity. The extensive flat or slightly undulating plains are broken up by island-like sand-dunes. In general, these sand dunes are only a few km wide, but some of them have a diameter of over 10 km.

The areas covered by aeolian sand are characterized by mesoforms such as: wind grooves, hummocks and remnant ridges, and even parabola dunes (Kiss, T. and Tornyánszki, É. 2006). Wet and boggy areas often without outlets, lakes and meadows – temporary covered by water – were formed in the grooves between the sand dunes (Lóki, J. 1999; Mezősi, G. 2011a). Underneath the boggy areas very often limestone deposits were formed with a total thickness of 20 to 30 cm.

The geological characteristics of the Danube–Tisza Interfluve and the lack of water

The Neogene sediments of the area do not form a cohesive aquitard, thus the region is characterized by a unified water flow system. Two flow regimes can be distinguished: (i) gravity driven flow regime with precipitation as main water source and (ii) over pressured saline flow regime (Mádlné Szőnyi, J. *et al.* 2005). In the ridge region of the Interfluve (i.e. recharge zone) the infiltrated water flows towards the Danube and Tisza valleys (flow regions) due to differences in the altitudes of the two regions. Gravity driven meteoric waters are "hydraulically supported" by deep waters, but the latter are upwelling locally through migration routes such as faults on the Ridge.

Water resources coming from the Ridge through the gravity driven flow reach the surface at discharge areas, as they move towards the Danube valley. The major part of these waters are hydraulically trapped or accumulated in groundwater reservoirs. (Mádlné Szőnyi, J. and Tóth, J. 2007). The local and intermediary flow systems are hierarchically structured on the regional water flow system of the Danube–Tisza Interfluve. In the case of the local water flow systems, the direction of water flow is determined by the geomorphological characteristics of the region. In the case of sand dunes, infiltration of rainwater can be observed, while the gaps between adjacent sand dunes are characterized by water discharge. On a local level these processes can be considered a system.

In the Danube–Tisza Interfluve precipitation surplus was experienced up to the middle of the 1960s, followed by a stagnation period until the middle of the 1970s. As a result of the surplus waters the ground water level has been increased. Saline flat areas and deflation coves were inundated very often. At this time (i) the drainage water channel system construction was completed, and (ii) larger areas were planted with tree species with high water demand, mostly with poplar.

From the beginning of the 1970s to the middle of the 1990s the precipitation level dropped below the climatic mean, a shortage of nearly 1000 mm in precipitation was experienced in the area.

As a result, ground water level started to drop, significant portion of the former lakes and boggy areas dried up (Major, P. 1994; Liebe, P. 1994). During this time extensive ground water exploitation took place mostly for irrigation purposes, which also contributed to the further reduction of ground water level.

The exact amount of water exploited in the territory of the investigated area is unknown. The shortage of rainfall was mitigated by the middle of the 1990s, as a result the intensity of ground water level dropping slowed down and in certain areas the water table started to rise (Szalai, J. 1996). Besides the lack of precipitation, the fluctuation of the groundwater level is influenced by the exploitation of artesian water, too. At the beginning of the 2000s, with the decrease of the exploitation of artesian water, the pressure heads began to rise (Liebe, P. 1994).

Preparation of groundwater-level data

Four Water Management Directorates have a system for detecting groundwater level comprising 398 groundwater wells. The database contains data from shallow-groundwater wells that have ceased their activity for different reasons. One of the reasons can be the drop of groundwater-level in the vicinity of a given groundwater well, when the water level reached the bottom screening section, the well theoretically aridified and it became useless for regular measurements (Szalai, J. and Nagy, Gy. 2006).

Data preparation was conducted on groundwater level time series with different lengths and quality. Besides filtering the data, hydrographs have been derived which helped to spot clearly incorrect or incomplete data (obvious typos, date entry mistakes etc.). Some hydrographs had to be modified since their pipe rim was changed. If such mistakes could not be corrected in an obvious way, the data sets were discarded.

Besides GIS-based solutions, the visual presentation of the data sets had an important role too. The first step of spatial error filtering comprised visual presentation. Using Golden Software Surfer 11 and Scripter isoline maps were created by linear interpolation for 60 months. The isoline maps showed the outstanding values of the data sets. The values corresponding to the given values were identified in the data source.

After the visual interpretation, the rasters were interpolated from the remaining points and cross validation was carried out. In cases where the difference between estimated and measured values were outstanding, further investigations were carried out to determine whether they were due to extreme values or measurement errors.

Measurement errors were corrected when it was possible or the sampling sites were omitted from further analysis. After correcting and filtering the data, 321 groundwater level monitoring wells were left for analyses (*Figure 1*). The spatial distribution of the groundwater monitoring wells is uneven. The distance between the closest groundwater monitoring wells is 3.61 m while the largest distance is 12 km. The average is 8,186.56 m and the standard deviation is 2,645.74 m.

Sixty sample realizations were chosen from the monthly averages of the measurement period between 1980 and 2010 to form the basis of the variograms to present the spatial correlation between the data sets. Data measured for every January, April, July and October from every second year were chosen, in order to achieve the 60 sample realizations.

Thus, the annual periods could be followed, which is a key characteristic of groundwater level. Moreover, it is known that analysing every second year is enough to observe the fluctuation of time series (Shannon, C.E. 1949). In the period of 2002–2004 the highest number of wells reached 289, but until the 1990s this number was less than 200, with a minimum of 188 functioning wells. As an average it can be stated that the time series of only 234 wells could be used.

An average of 44 months was available out of the total 60. 53 monitoring stations (16.5%) had complete data sets. The median and standard deviation wer 51 and 16.87, respectively.

Semivariogram function derived from the variogram are the most suitable function to analyze the spatial dependence of the groundwater level data. The function can be described the following way (Füst, A. 1997; Molnár, S. and Füst, A. 2002; Molnár, S. *et al.* 2010): Let $Z(x)$ and $Z(x+h)$ be the values of a parameter sampled at distance $|h|$ from each other. The variance of the difference of $Z(x)$ and $Z(x+h)$ is

$$D^2[Z(x) - Z(x+h)] = D^2[Z(x)] + D^2[Z(x+h)] - 2COV[Z(x), Z(x+h)]$$

In the case of samples taken from the same population (stationarity) we could assume that

$$D^2[Z(x)] = D^2[Z(x+h)] \quad \text{, so that}$$

$$D^2[Z(x) - Z(x+h)] = 2D^2[Z(x)] - 2COV[Z(x), Z(x+h)] = 2\gamma(h)$$

The function $2\gamma(h)$ is called the parameter's variogram, while $\gamma(h)$ is its semivariogram. If we introduce the simplified notation $D^2[Z(x)] = D^2(x)$, and $COV[Z(x), Z(x+h)] = g(h)$, then $\gamma(h) = D^2(x) - g(h)$. The semivariogram could be calculated by the Matheron algorithm (Matheron, G. 1965): where $N(h)$ is the number of pairs within the lag interval h.

In practice, $Z(xi) \geq 0$ ($i = 1, 2, \ldots, n$) and $D^2[Z(x)] \geq g(h) \geq 0$, so that theoretically the semivariogram can only take values from the $0 \leq \gamma(h) \leq D^2[Z(x)]$.

The most important properties of the function are the follows (*Figure 2*):

(i) If the function does not start from the arbitrary point of the coordinates ($C_0>0$), it will be called "nugget effect". The value C_0 of the semivariogram at the origin provides information of the sampling error.

(ii) If the semivariogram does not have a rising part, the points of the semivariogram will align above the abscissa parallel to it. A semivariogram such as this is called of a nugget effect type. In this case no range can be estimated, i.e. the sampling frequency is insufficient.

(iii) The level at which the variogram stabilizes is the sill ($C+C_0$); it is equal to the variance for stationary processes. The value C itself is the reduced sill.

(iv) Range is the distance within the samples still have an influence on each other (Webster, R. and Oliver, M.A. 2007).

If $\gamma(h)$ is an increasing function (if $h \to \infty$ then $\gamma(h) \to \infty$), the parameter is non-stationary Kovács, J. *et al*. 2012).

Empirical semivariograms can be approximated by many theoretical functions. (Deutsch, C.V. and Journel, A.G. 1992; Wackernagel, H. 2003). The estimation of sampling frequency using variograms is based on the range.

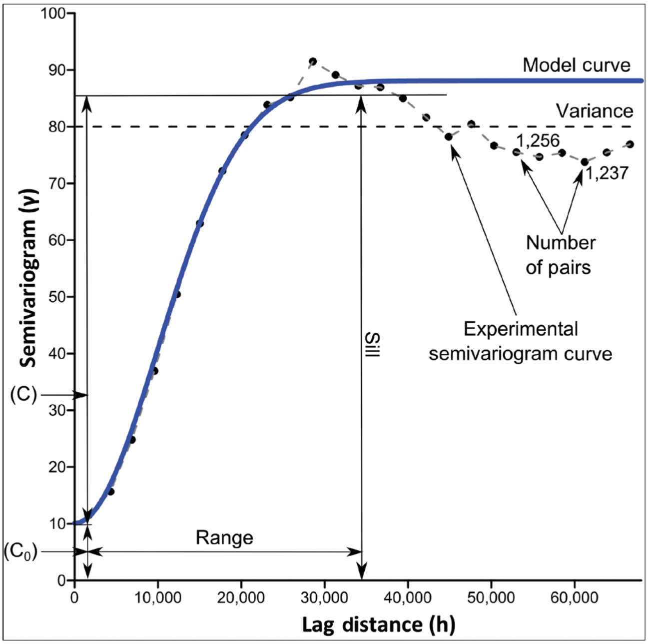


Fig. 2. The properties of the semivariogram

Samples that are outside the range are uncorrelated. If we want to find adequate information about the circumstances and processes that led to the depletion of the groundwater, the sampling network should be optimized in a way so that is unifying spatial ranges (i.e. areas defined by ranges around the sampling points) we could cover the whole sampling site (Füst, A. and Geiger, J. 2010; Füst, A. 2011). If the range of a studied parameter is undirectional, then the phenomenon is isotropic and the spatial range will be circular. Otherwise anisotropy is produced and the special range will be of an elliptic nature. If parameters are isotropic, the sampling points should be placed in a grid composed of squares or equilateral triangles, while if parameters are anisotropic sampling points, they should be located in a grid composed of isosceles triangles.

In order to gain information referring/covering to the whole area, it is insufficient to only have a square grid with an edge length that is twofold of the estimated range. On the contrary, the edge length should be $a\sqrt{2}$ (*Figure 3*., a) in case of square grid and $a\sqrt{3}$ (*Figure 3*., b) in case of triangular grid. In the case of an ellipse range area the same values can be approximated by an edge length of $a\sqrt{2}$ and $b\sqrt{2}$ in the case of a *rectangular grid, while* $a\sqrt{3}$ and $b\sqrt{3}$ in the case of an isosceles triangular grid.

Two adjacent equilateral triangles form a rhombus while two adjacent isosceles triangles form a parallelogram (*Figure 3.,* c). It is clear that these networks are much more favorable than the ones formed of squares or rectangles, as using these networks a larger area can be covered with the same number of sample points. Thus the number of sampling points necessary to cover the sample area is 23% less.

In case of rectangular and rhomboid grids the side lengths of the cells should be adjusted to the direction of the smallest and largest ranges of the parameter analysed (Füst, A. 1997).

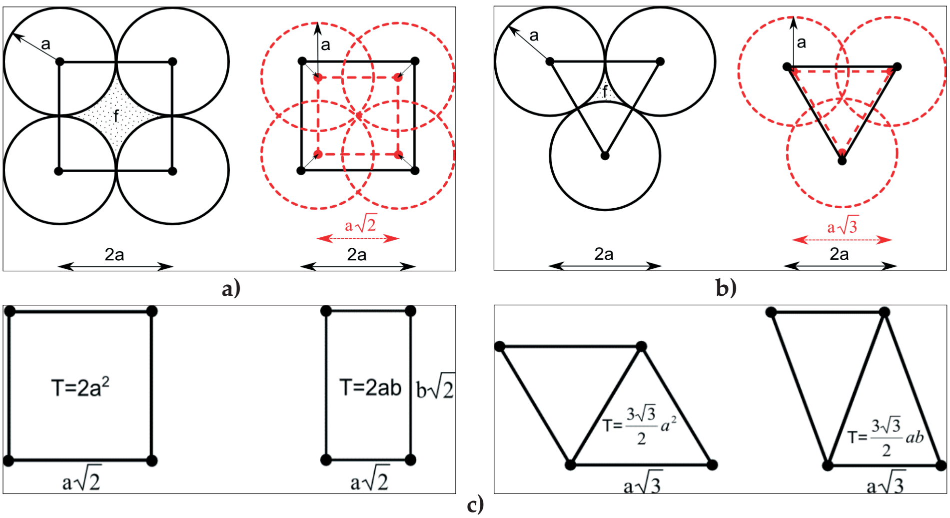


Fig. 3. The relationship between range and sampling network in the case of square grid (a); between range and sampling network in the case of triangular grid (b); Comparing the configuration of the sample networks (c) (based on Füst, A. 1997)

Preliminary data analysis, representative examples from the empirical semivariograms of the sample area

Variogram analysis was carried out on the pre-processed data series. As the same operation had to be performed sixty times in the case of each chosen point in time, therefore a script was written in Scripter in order to batch the operation sequence. The script generated n variograms based on the x, y, z_1, z_2, … z_n structured ASCII type input files and on the set parameters. The following parameters were adjustable: maximum lag distance, number of lags, direction of pairs, tolerance, the detrend type, the *.dat files comprise the x, y coordinates of the variograms (h, γ), while the *.jpg file includes graphic representation of the *n* variograms (http://gis.elte.hu/geostat). First, the program was compiled using the default settings of the Surfer, specifically the maximum lag distance was set to 68,000 m, the number of lags 25, the direction of pairs is 90° (undirectional). In this case trend has not been removed. Each of the obtained functions reached the sill at a 40 km long range and a variance of 200 m^2.

Since area is part of a ridge and the surface of the groundwater more-or-less adjusts to the topographic surface, therefore the anisotropy of the parameters is assumed. As the number of elements in the sample realisations is high enough to calculate directional empirical semivariograms, these were computed in the four main directions (W–E, NW–SE, N–S, NE–SW). The script was computed with the following modified settings: the tolerance was set to 30° and the direction was set to 0° (W–E). Then the operation was carried out with the same tolerance (0°) and the direction being 45° (NW–SE), 90° (N–S) and 135° (NE–SW). Studying the obtained 240 functions the previous assumptions have been proved to be correct.

The preliminary variograms were calculated from the data of October 2006 to explore whether the functions have different ranges and different variances (anisotropic structure). The most peculiar semivariogram was related to the N–S direction, as it showed a monotonic increase that can be traced back to trend-like changes.

If the trend subtraction proved to be successful, then – after subtracting an adequate order trend – the semivariogram of the residuals will be stationary and the variance can be determined and thus the range, too (Füst, A. 1984). Therefore as a next step, linear trend was subtracted using the same settings. The results were the same, thus in the following step the *quadratic trend was subtracted*. Unlike the linear trend, the *X* and *Y* direction trends provide a model with an adequate approximation to the general inclination of the Danube–Tisza Ridge. Thus after the subtraction of the quadratic trend we could determine the range in each of the four directions. This was automatically carried out onwards.

After these steps, the directional semivariograms were merged to facilitate the recognition of the anisotropy and the definition of the range. Moreover, a semivariogram surface was created for the same reason (*Figure 4).* Based on the above mentioned semivariograms, the anisotropy direction is NNE–SSW while the range is approximately 20 and 30 km.

Results and discussion

Determining the smallest spatial structure

To examine the phenomena – describable with the smallest spatial structure – governing the groundwater level, the distance among the monitoring wells

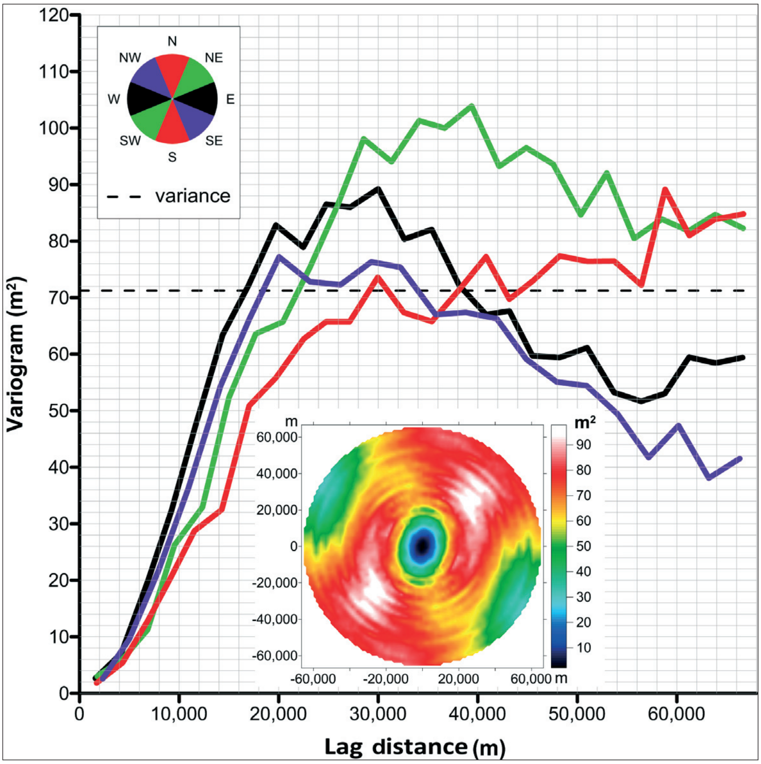


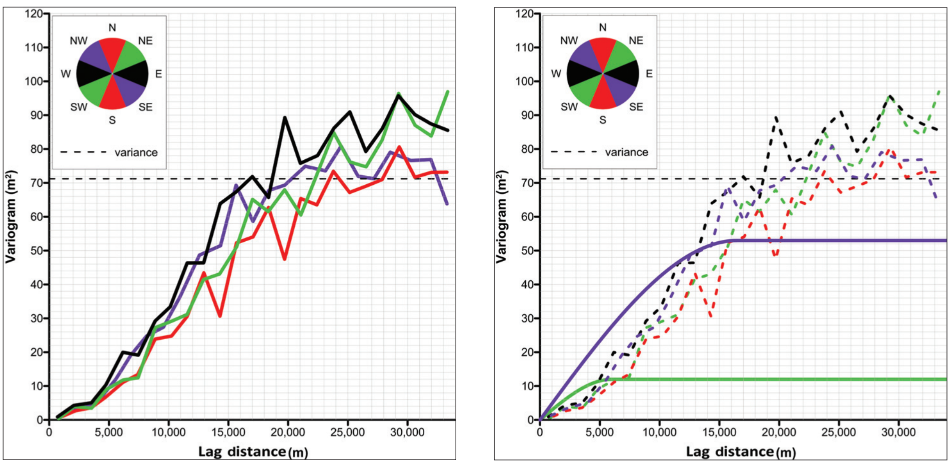
Fig. 4. Regional semivariogram-surface derived for the groundwater level data measured in October 2006 visualized by colour ramp

has to be shorter than the characteristic action radius of the monitored process. Therefore, the smallest range has to be estimated from the empirical semivariograms.

In order to recognize the assumed smallest ranges, the resolution of the semivariogram has to be increased. To achieve this either the maximum lag distance could be decreased or the number of lags could be increased. Hence, the script was modified in the following way: maximum lag distance was decreased to 34,000 m while the number of lags remained 25; thus the achieved *resolution doubled compared to the original situation*. At this resolution more than one range became noticeable (*Figure 5.*, a).

The presence of multi-sill structures can be explained by different processes building up on one another. In such cases fitting of the multiple sill semivariograms should be carried out. However, the currently available applications do not facilitate this process. Therefore the smallest range could only be determined by manually fitting a theoretical model to the empirical semivariogram. Moreover, the direction of the anisotropy has changed, too. While on the regional level, the direction of the major axes was NE, on a local level its direction has changed to SE (*Figure 5.,* b). In the case of the sample realizations with data available from a minimum of 250 ground water level monitoring wells, the smallest range appeared at a lag distance of 3,000 meters.

However, in the case of such a small search radius, the number of pairs was insufficient from a statistical point of view. Therefore, in the case of this particular semivariogram (*Figure 5.,* b) the smallest range was determined at the second sill with a value of 6 km in the NE direction, while in the SE direction the smallest range was 14 km.



a) b)

Fig. 5. The four directional empirical semivariograms based on data measured in October 2006 with doubled resolution (a); Spherical theoretical semivariograms visualised together with the semivariograms indicating the smallest range at ~ 2,500 m and the ones significant base on the number of pairs at ~ 6,000 m and ~ 14,000 m (b). The colours of the semivariograms correspond to the direction in the inset pie-chart

Applying this method, the data measured in other years gave the same results with a standard deviation was 16.6%, consequently the range was reduced with the value of the standard deviation, to ensure the full coverage of the area. In the forthcoming analyses, the range value of 5 and 11.67 km were used.

Outlook on the diversity of relief and shallow groundwater

The example of the Fülöpháza sand dune region is presented to show explicitly that the shallow groundwater fluctuation is the main governing factor regarding the first sill.

The proportion and the direction of the axis basically overlap, while the ranges are smaller than parameters defined in the case of groundwater (*Figure 6)*. It can be assumed that the smaller ranges exist in the case of groundwater levels, too, but especially in these areas with a variable relief, the distance between data pairs is larger than the assumed minimal range. Based on the above-mentioned observations, it is assumed that in the 1980s and in the first part of the 1990s, in certain areas, the sampling network was not dense enough to enable tracing of the groundwater changes determined by the meso-forms. In other areas it was too dense. In the subsequent years more groundwater level detection wells were established, so blank spots disappeared but at the same time the proportion of overrepresented areas increased.

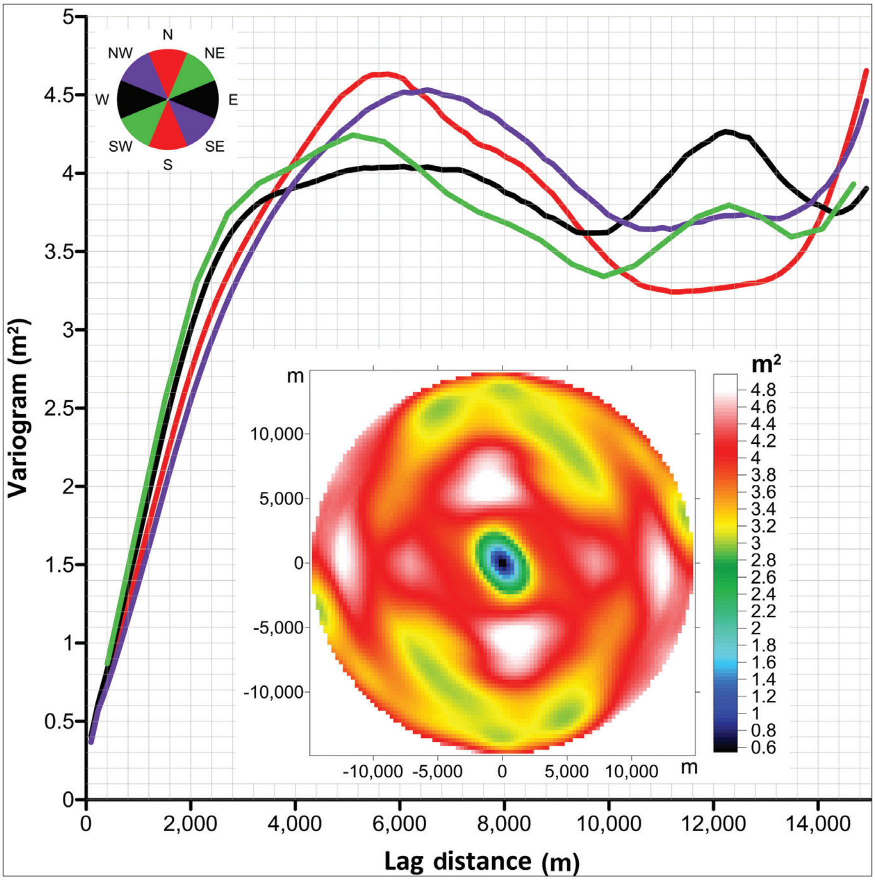


Fig. 6. The four directional empirical semivariograms of the Fülöpháza dune region in the four main directions corresponding to the colours of the inset pie-chart (upper left) and the surface of the variogram (bottom right)

Using the coordinates of groundwater level monitoring wells that disposed of data in the studied period (1981–2010), the previously determined spatial ranges (ellipses) were plotted. It helped to determine the extent of optimal groundwater level monitoring well network with adequate accuravy in the Danube–Tisza Interfluve in the different periods. By this way, it became possible to find out that there were unmonitored areas that had not been covered by the spatial ranges of any of the existing groundwater monitoring wells, thus information was lacking regarding these areas. Additional important aspects regarding the present and future monitoring plans are (i) whether the existing groundwater level monitoring well network fully covers the area of the Ridge, and (ii) which are the areas where the network is too dense.

October 1982 was the month when the smallest number of monitoring stations were available (*Figure 7.*, a), while the most favourable case occurred in October 2010 (*Figure 7.*, b) with the highest number of wells operating in the system. It is clear that the coverage was much sparse in 1982.

On the one hand the most outstanding pattern is the extent of the areas with incomplete data sets, the so called blank spots. The most predominant is the white spot in the Késleshalom, Jánoshalma and Borota regions, where the reduction of the groundwater level is the most significant up to

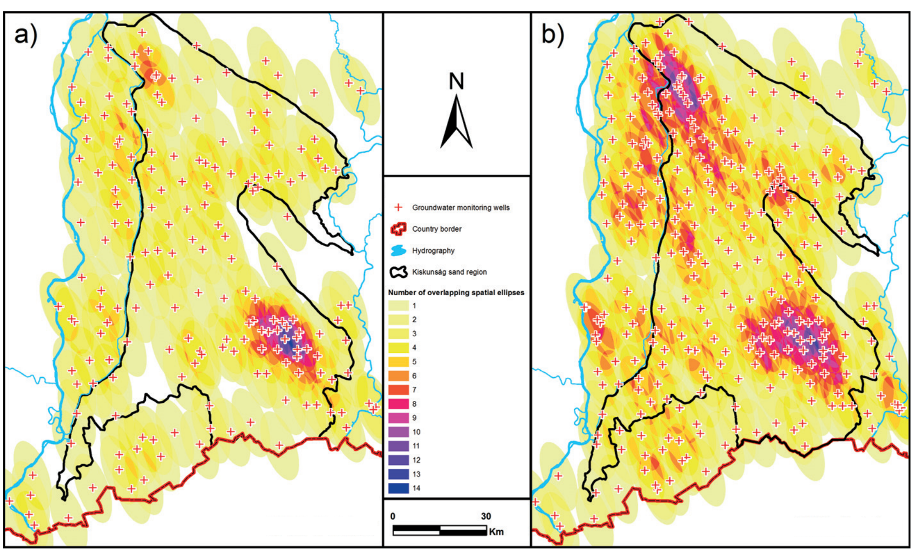


Fig. 7. The number of overlapping spatial range ellipses in the Danube–Tisza Ridge in October 1986 (a), and in October 2010 (b)

this day. Moreover, significant blank spots exist in the Baja, Bátmonostor and Fülöpjakab, Bugac regions as well. On the other hand the network is needlessly dense around Kömpöc and Balástya, where some areas are covered by the spatial ranges of 14 monitoring stations.

The map of October 2010 (*Figure 7.,* b) shows a situation similar to the present conditions. The number of blank spots is negligible in the area of the Kiskunsági sand region, which is important from the point of view of groundwater level depletion. In the case of this sample realization the only area with incomplete data sets is that of Mórahalom. On the contrary, the number of areas that are covered by multiple monitoring wells increased. Furthermore, the number of monitoring stations around Kecskemét and Dabas has increased. *Figure 7* indicates the two extreme values, but it can be generally stated that if the available data is scarce then the spatial density of the network will be insufficient and vice versa. This was mainly true for the 1980s and the first half of the 1990s. From the second half of the 1990s, with the increase of the monitoring stations that could be used in the analyses, the number of blank spots has minimalized, and the proportion of the areas that were covered by 10–14 monitoring points has increased.

An idealised groundwater level monitoring well network has been obtained on the bounding box of the Kiskunság sand region *(Figure 8)* based on the relationship between the ranges determined using the multiple sill directional empirical semivariograms and the research network described above. This network can be established with a minimal number of wells. The network functioning at the end of 2010 is generally much denser than the ideal measuring network plotted based on the ranges, while there are still areas characterized by the absence of data, as shown before.

Obviously, this is a theoretical, geometric model, optimized to the higher areas of the Danube Tisza Interfluve mainly affected by aridification. The state border had to be taken into consideration while other objective restraining factors (e.g. paved roads, gravel pits) were not considered.

In order to expand the model to the lower areas bordering the Ridge, further intermediate points need to be determined, so that each intersection would lie on the territory of the Danube–Tisza Interfluve and the spatial range ellipses placed around these points would fully cover the territory between the two rivers. Thus the ideal location of the monitoring points cannot be determined only by a geometric model.

Conclusion

The main purpose of the study was to estimate the minimal number of monitoring wells that are necessary to track the spatial processes that can be followed with

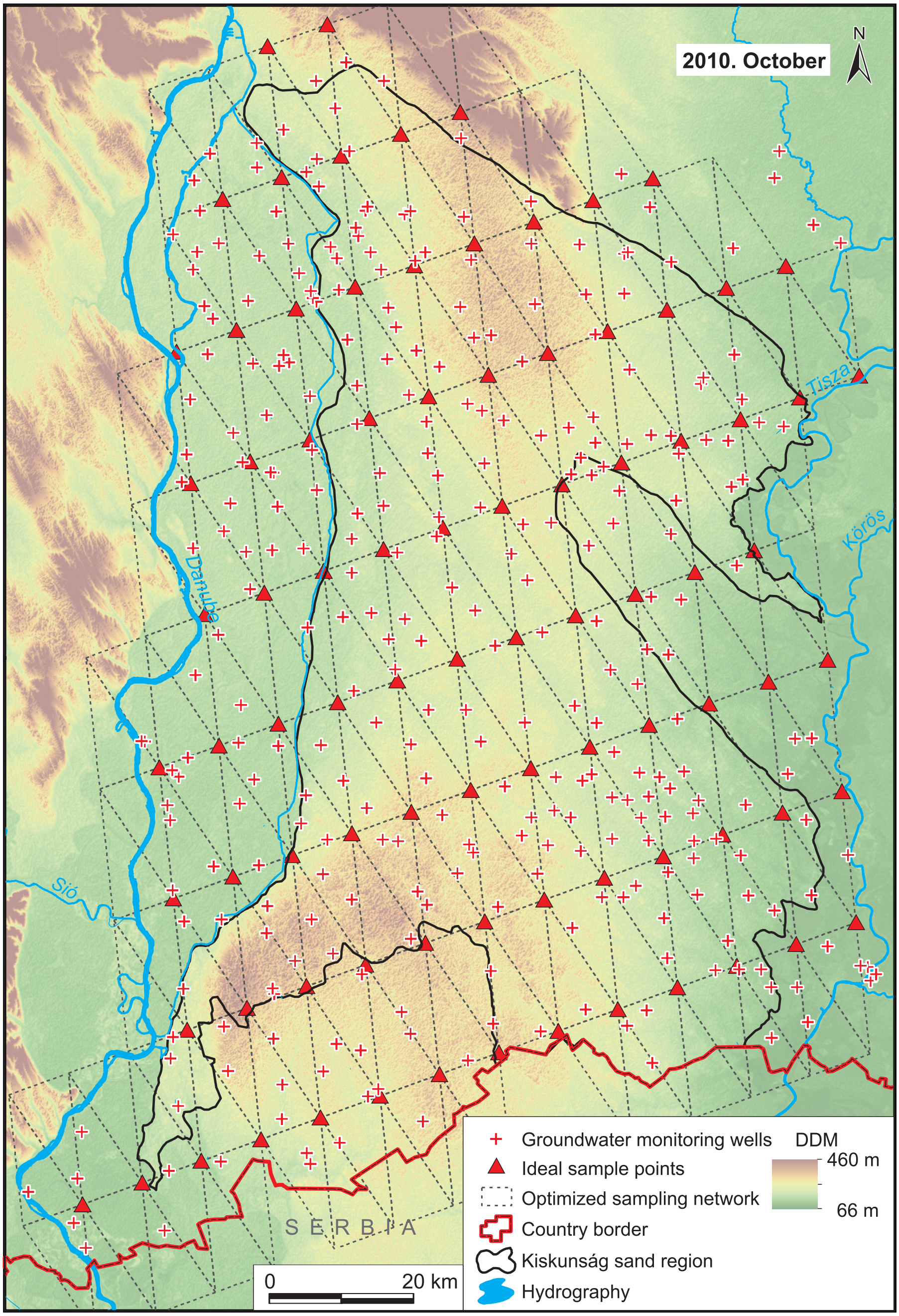


Fig. 8. The relationship between proposed sampling network and the monitoring wells in October 2010 in EOV projection

the existing network, given that the monitoring wells are located in an adequate way. The spatial structure of groundwater was analysed with the aid of directional empirical semivariograms at the Danube–Tisza Interfluve (1981–2010).

The conclusion has been reached that the *multiple sill structure* indicated by the semivariograms originates from the geomorphological units with different scales (Kiss, T. and Tornyánszki, É. 2006).

In the largest regional structure characterized by a range around 20 and 30 km and anisotropy with a direction of NNE–SSW. The direction of the axis linking the highest parts of the Ridge was determined, while the ranges reflect the variability related to the alluvial cone. The smallest ranges identified, were at the second sill with a value of 5 and 11.67 km.

The correlation between the groundwater level and the elevation is periodically changing, but it is very strong. The more variable the relief of the area, the higher the variability of the groundwater level will be. Thus, if one wants to determine the smallest spatial structure of the groundwater level fluctuation during monitoring network recalibration, the geomorphological characteristics of the area have to be taken into account.

According to the results, the spatial variability of groundwater-level variations can be observed with half as many stations as the existing network if they were optimally arranged. By establishing a couple of new detection wells or repositioning a few of the existing ones, even finer spatial processes could be monitored, thus the progression of the depletion could be interpreted in a more profound way.

Acknowledgement. The research of Balázs Kohán was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 'National Excellence Program'.

REFERENCES

Biró, M., Lelleiné Kovács, E., Kröel-Dulay, Gy. and Horváth, F. 2009. A Kiskunsági homokvidék tájökológiai térképe (Landscape ecologycal map of the Kiskunság sand region, Hungary). In *Válogatás az MTA Ökológiai és Botanikai Kutatóintézete kutatási eredményeiből.* Eds: Török, K., Kiss, K.T. and Kertész, M. Vácrátót, MTA Ökológiai Kutatóközpont Ökológiai és Botanikai Intézet, 29–35.

Biró, M., Czúcz, B., Horváth, F., Révész, A., Csatári, B. and Molnár, Zs. 2013a. Drivers of grassland loss in Hungary during the post-socialist transformation (1987–1999). *Landscape Ecology* 28. (5): 789–803.

Biró, M., Szitár, K., Horváth, F., Bagi, I. and Molnár, Zs. 2013b. Detection of long-term landscape changes and trajectories in a Pannonian sand region: comparing land-cover and habitat-based approaches at two spatial scales. *Community Ecology* 14. (2): 219–230.

Deutsch, C.V. and Journal, A.G. 1992. *GSLIB Geostatistical Software Library and User´s Guide*. New York–Oxford, Oxford University Press, 363 p.

Füst, A. 1984. Adalékok az instacionárius paramétermezők kutatási optimumának meghatározásához (Improvemements for non-stationary parameterization in deteremining the exploration optimum). *BKL-Bányászat* 32. (1–4): 93–112.
Füst, A. 1997. *Geostatisztika* (Geostatistics*).* Egyetemi jegyzet. Budapest, Eötvös Kiadó, 427 p.
Füst, A. 2011. A természeti folyamatok monitoring hálózatainak tervezése és működtetése (Planning and operating monitoring systems of natural processes). *BKL-Bányászat* 144. (2): 19–25.
Füst, A. and Geiger, J. 2010. Monitorigtervezés és -értékelés geostatisztikai módszerekkel I. Szakértői véleményen alapuló, "igazoló" mintázás geostatisztikai támogatása (Monitoring planning and evaluation using geostatistics, I. Geostatistical support for verification sampling based on professional opinion). *Földtani Közlöny* 140. (3): 303–213.
Hajdú-Moharos, J. and Hevesi, A. 1999. The land that is Hungary – geology, geography and cartography of Hungary and its surroundings. In *Pannon Encyclopaedia.* Ed. Karátson, D., Budapest, Kertek 2000 Publishing House, 274–284.
Hatvani, I.G., Kovács, J., Barcza, M., Kovácsné Székely, I., Jakusch, P. and Bernáth, Gy. 2011. Adatelemző módszerek alkalmazásának feltételei és lehetőségei a felszíni és felszín alatti víz védelmében (The requirements and possibilities of applying data analysis methods in surface- and sub-surface water protection). In *A fenntartható fejlődés, valamint a környezet- és természetvédelem összefüggései a Kárpát-medencében*. Eds. Bunyevácz, J., Csonka, P., Fodor, I. and Gálosi-Kovács, B., Pécs, MTA Pécsi Akadémiai Bizottság.
Hatvani, I.G., Kovács, J. and Korponai, J. 2012a. Mintavételezési gyakoriság optimalizálása variogram függvénnyel a Kis-Balaton Vízvédelmi Rendszer példáján (Optimization of sampling frequency using variograms on the example of the Kis-Balaton Water Protection System). *Természetvédelmi Közlemények* 18. 202–210.
Hatvani, I.G., Reskóné, N. M., Kovácsné Székely, I., Tanos, P., Korponai, J. and Kovács, J. 2012b. Determining the temporal sampling frequency of Kis-Balaton and the spatial sampling frequency of Lake Velence (W Hungary) using variograms. In *CMA4CH: Use of Multivariate Analysis and Chemometrics in Cultural Heritage and Environment*. Ed. Visco, G., Rome, Marco Valerio Editore. 62–63.
Hatvani, I.G., Magyar, N., Zessner, M., Kovács, J. and Blaschke, A.P. 2014. The Water Framework Directive: Can more information be extracted from groundwater data? A case study of Seewinkel, Burgenland, Eastern Austria. *Hydrogeology Journal* 22. (4): 779–794. DOI: http://dx.doi.org/10.1007/s10040-013-1093-x (available online).
Kiss, T. and Tornyánszki, É. 2006. Futóhomok területek geomorfológiai vizsgálata a Duna–Tisza közén (The geomorphological analysis of the quicksand regions in the Danube–Tisza Interfluve). In *III. Magyar Földrajzi Konferencia Tudományos Közleményei*. Budapest, MTA Földrajztudományi kutatóintézet, CD-ROM.
Kovács, J. and Kovácsné Székely, I. 2006a. A minta értelmezési problémái: elmélet és gyakorlat (Problems in interpreting the sample: theory and practice.). *Földtani Közlöny* 136. 139–146.
Kovács, J. and Kovácsné Székely, I. 2006b. A földtani adatok adatelemzésének nehézségei (Difficulties in data geologycal analysis). In *Karsztfejlődés XI. Konferencia*. Ed. Veress, M., Szombathely, Berzsenyi Dániel Főiskola Természetföldrajzi Tanszék, 25-35.
Kovács, J., Hatvani, I.G., Korponai, J. and Kovácsné Székely, I. 2010. Morlet wavelet and autocorrelation analysis of long-term data series of the Kis-Balaton water protection system (KBWPS). *Ecological Engineering* 36. 1469–1477.
Kovács, J., Kiszely-Peres, B., Szalai, J. and Kovácsné Székely, I. 2011a. Periodicity in shallow groundwater level fluctuation time series on the Trans-Tisza Region, Hungary. *Acta Geogarphica Geologica et Meteorologica Debrecina* 4–5. 65–70.

Kovács, J., Hatvani, I.G., Kovácsné Székely, I., Jakusch, P., Tanos, P. and Korponai, J. 2011b. Key question of sampling frequency estimation during system calibration, on the example of the Kis-Balaton Water Protection System's data series, Georgicon for Agriculture. *A Multidisciplinary Journal in Agricultural Sciences* 14. (1): 53–68.

Kovács, J., Korponai, J., Kovácsné, Sz.I. and Hatvani, I.G. 2012. Introducing sampling frequency estimation using variograms in water research with the example of nutrient loads in the Kis-Balaton Water Protection System (W Hungary). *Ecological Engineering* 42. 237–243.

Kovács, J., Reskóné Nagy, M. and Kovácsné Székely, I. 2005. Mintavételezés gyakoriságának vizsgálata tér–statisztikai függvénnyel a Velencei–tó példáján (Estimation of sampling frequency in Lake Velencei by spatial statistics). *Hidrológiai Közlöny* 85. (6): 68–71.

Kovács, J., Szabó, P. and Szalai, J. 2004. Talajvízállás adatok idősoros vizsgálatai a Duna–Tisza közén (Time series analysis of shallow groundwater level In the Danube–Tisza Interfluve). *Vízügyi Közlemények* 86. (3–4): 607–624.

Kovács-Székely, I. and Szalai, J. 2009. The impact of climate change on production conditions of Hungarian agriculture, especially on shallow groundwater supply. In *Proceedings of Budapest Business School.* Eds: Majoros, P. and Zimler, T., Budapest, Budapesti Gazdasági Főiskola, 79–96.

Ladányi, Zs., Deák, J.Á. and Rakonczai, J. 2010. The effect of aridification on dry and wet habitats of Illancs microregion, SW Great Hungarian Plain, Hungary. *AGD Landscape & Environment* 4. (1): 11–22.

Ladányi, Zs., Rakonczai, J., Kovács, F., Geiger, J. and Deák, J.Á. 2009. The effect of recent climatic change on the Great Hungarian Plain. *Cereal Research Communications* 37. (4): 477–480.

Liebe, P. 1994. *A rétegvízkészletek és a nyomásszintek változása a Duna–Tisza közi hátságon és azok kihatása a talajvízszintekre* (The alteration of the aquiferic water supplies and the pressure levels and their impact on the groundwater level in the Danube–Tisza Interfluve). A Nagyalföld Alapítvány Kötetei 3. Békéscsaba, Nagyalföld Alapítvány, 25–30.

Lóki, J. 1999. A tiszai Alföld (The area beyond the Tisza). In *Pannon Encyclopaeia Magyarország földje.* Ed. Karátson, D., Budapest, Kertek 2000 Publishing House, 300–301.

Mádlné Szőnyi, J. and Tóth, J. 2007. „A Duna–Tisza köze vízföldtani típusszelvény" és a szikesedés összefüggései (The relationship between the hydrogeologic segment of the Danube–Tisza Interfluve and the aridification). *Földrajzi Közlemények* 131. (55.) (4): 343–360.

Mádlné Szőnyi, J., Simon, Sz., Tóth, J. and Pogácsás, Gy. 2005. Felszíni és felszín alatti vizek kapcsolata a Duna–Tisza közi Kelemen-szék és Kolon-tó esetében (The relationship between the surface water and the groundwater int he case of the Kelemen-szék and Kolon Lake in the Danube–Tisza Interfluve). *Általános Földtani Szemle* 30. 93–110.

Major, P. 1993. A Nagyalföld talajvízháztartása (The groundwater resources of the Great Hungarian Plain). *Hidrológiai Közlön*y 1. 40–44.

Major, P. 1994. *Talajvízszint-süllyedések a Duna–Tisza közén* (The depletion of the groundwater level in the Danube–Tisza Interfluve). A Nagyalföld Alapítvány Kötetei 3. Békéscsaba, Nagyalföld Alapítvány, 17–24.

Major, P. and Neppel, F. 1988. A Duna–Tisza közi talajvízszint süllyedések (Groundwater level depletions in the Danube–Tisza Interfluve). *Vízügyi Közlemények* 70. (4): 605–626.

Matheron, G. 1965. *Les Variables Regionaliées et leur Estimation* (Regional variables and their distribution). Masson et Cie. Paris, 305 p.

Mezősi, G. 2011a. Az Alföld természeti képének kialakulása (The development of the landscape of the Great Hungarian Plain). In *Környezeti változások és az Alföld*. Ed. Rakonczai, J. A Nagyalföld Alapítvány Kötetei 7. Békéscsaba, Nagyalföld Alapítvány, 15–24.

Mezősi, G. 2011b. *Magyarország természeti földrajza* (The physical geography of Hungary). Budapest, Akadémiai Kiadó, 393 p.

Molnár, S. and Füst, A. 2002. *Környezetinformatikai modellek I.* (Models in enviromental informatics I.). Gödöllő, Szent István Egyetem Kiadó, 103 p.

Molnár, S., Füst, A., Szidarovszky, F. and Molnár, M. 2010. *Környezetinformatikai modellek.* (Models in enviromental informatics). Gödöllő, Szent István Egyetem Kiadó, 191 p.

Pálfai, I. 1994. A Duna–Tisza közi hátság vízgazdálkodási problémái (The water management problems of the Danube–Tisza Interfluve). In *A Duna–Tisza közi hátság vízgazdálkodási problémái*. A Nagyalföld Alapítvány kötetei *3.* Ed. Pálfai, I., Békéscsaba, Nagyalföld Alapítvány, 111–126.

Pálfai, I. 1996. A talajnedvesség és a talajvízállás változásai az Alföldön (The alterations in soil moisture and groundwater level in the Great Hungarian Plain). *Vízügyi Közlemények* 2. 207–218.

Rakonczai, J. 2011. Effects and consequences of global climate change in the Carpathian Basin. In *Climate Change – Geophysical Foundations and Ecological Effects.* Eds. Blanco, J. and Kheradmand, H., Rijeka, InTech, 297–322.

Rakonczai, J. and Bódis, K. 2002. A környezeti változások következményei az Alföld felszín alatti vízkészleteiben (The effecs of environmental changes on the groundwater supplies of the Great Hungarian Plain). In *Jakucs László, a tudós, az ismeretterjesztő és a művész.* Eds. Mészáros, R., Schweitzer, F. and Tóth, J., Pécs, Pécsi Tudományegyetem – MTA Földrajztudományi Kutatóintézet, 227–238.

Rétháti, L. 1974. Talajvíz-idősorok homogenitás vizsgálata (The homogeneity analysis of the groundwater time series). *Hidrológiai Közlöny* 54. (1): 1–48.

Rónai, A. 1985. Az Alföld negyedidőszaki földtana (The Quaternary geology of the Great Hungarian Plain). *Geologica Hungarica, Series Geologica* 21. 140–142.

Shannon, C.E. 1949. *Communication in the presence of noise.* Proceedings of the IRE, 37. 10–21.

Szabó, Gy. 1959. Pest belterületének hidrogeológiai viszonyairól (About the hydrogeologic situation of Pest). *Hidrológiai Közlöny* 59. (6): 416–424.

Szabó, Gy. 1960. A talajvízszint változása Pest belterületén (The changes in the groundwater level of Pest). *Hidrológia Közlöny* 60. (2): 106–115.

Szalai, J. 1996. *A talajvízszintek változása a Duna–Tisza közén a későőszi-téli időszakban.* (Changes in shallow groundwater level in the Danube–Tisza Interfluve during the late autumn-winter period). Budapest, VITUKI Rt. 12 p.

Szalai, J. and Nagy, Gy. 2006. *Az utóbbi évtized időjárási eseményeinek hatása a talajvízszintek alakulására a Duna–Tisza közén* (The effects of the weather events of the last decade on the shallow groundwater level in the Danube–Tisza Interfluve). Magyar Hidrogeológiai Társulat XXIV. Országos Vándorgyűlése Konferencia, Pécs, Magyar Hidrológiai Társaság, 729–745.

Szalai, J., Kovács, J. and Kovácsné Székely, I. 2011. A Duna–Tisza köze csapadék és talajvízszint-adatainak vizsgálata klaszteranalízissel (Clustering the precipitation and shallow groundwater level data series of the Danube–Tisza Interfluve). In *Környezeti változások és az Alföld*. A Nagyalföld Alapítvány Kötetei 7. Ed. Rakonczai, J., Békéscsaba, Nagyalföld Alapítvány, 111–118.

Szalai, J., Kovács, J., Kovácsné Székely, I., Lázár, M. and Molnár, M. 2008. A talajvízszint tér- és időbeli alakulása a Duna–Tisza közén a XX. század közepétől napjainkig, kilátások (Changes in shallow groundwater level in the Danube–Tisza Interfluve from the mid 20th century until today, expectations). In *MHT XXVI. Országos Vándorgyűlés,*

Miskolc, 2008.07.2–4., Paper 26. Ed. Szlávik, L., Miskolc, Magyar Hidrológiai Társaság. CD-ROM
Szodfridt, I. 1993. Az erdő és a talajvizek kapcsolata a Duna–Tisza közi hátságon (The relationship between shallow groundwater and forests in the Danube–Tisza Interfluve). *Hidrológia Közlöny* 1. 44–45.
Ubell, K. 1953. Talajvíztározódás csapadékvíz hatására (The storage of shallow groundwater due to precipitation). *Vízügyi Közlemények* 35. (2): 448–469.
Ujházy, N. and Biró, M. 2013. A vizes élőhelyek változásai Szabadszállás határában (The alterations in wetlands near Szabadszállás). *Tájökológiai Lapok* 11. (2): 291–310.
Wackernagel, H. 2003. *Multivariate Geostatistics.* Berlin, Springer Verlag, 381 p.
Webster, R. and Oliver, M.A. 2007. *Geostatistics for Environmental Scientists.* 2nd ed. Chichester, John Wiley and Sons, 330 p.

Hungarian Geographical Bulletin 63 (4) (2014) 401–423.
DOI: 10.15201/hungeobull.63.4.3

An evaluation of EU-DEM in comparison with ASTER GDEM, SRTM and contour-based DEMs over the Eastern Mecsek Mountains

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Abstract

The availability of global coverage digital surface models (DSMs, like ASTER GDEM or SRTM) and the variation of fused models based on these (like EU-DEM) still has a great impact on scientific researches, as they provide a fairly good base dataset with a low production time and expenses. However, validation reports of the initial DSMs convinced different characteristics and errors, thus it is essential to examine these height datasets prior to application. A verifying process for EU-DEM is more important, because it has been published without a formal validation. Although the base of the EU-DEM was a corrected ASTER GDEM dataset, the visual assessment and the error statistics suggest more similarity to the SRTM DSM. This study goes further than just identifying the errors, it attempts to correct the height differences. For this reason altering the false values of the land cover and filtering the occurring noise was implemented. The geomorphometric analyses carried out as part of the verification methods propose each improved model as potential base for geomorphological studies, if they meet the certain effective resolution requirements.

Keywords: EU-DEM, ASTER GDEM, SRTM, denoising, geomorphometry, open source GIS

Introduction

In the past decade the general availability of SRTM and ASTER GDEM versions provided public domain digital height datasets[2] for a growing number of earth science studies (Bolch, T. *et al.* 2005; Bubenzer, O. and Bolten, A.

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[2] The SRTM and ASTER GDEM datasets are considered as digital surface models, although as stated by Takeda, R. and Takeuchi, W. (2010) DSM and digital elevation model (DEM) are not distinguished precisely in these models, because they include the height of the vegetation and buildings, but the resolution is much larger than the size of these surface elements.

2008; Drăguț, L. and Eisank, C. 2012; Gichamo, T.Z. *et al.* 2012; Grohmann, C.H. and Sawakuchi, A.O. 2013; Seres, A. and Dobos, E. 2009; Siart, C. *et al.* 2009). The models are potential data sources for geomorphological researches due to the reasonable information content about the surface topography and acceptable spatial resolution, although multistep pre-processing work might be necessary (Guth, P.L. 2010; Hengl, T. and Reuter, H. 2011).

After the acquired data was distributed, several attempts were made to create a fused digital surface model (DSM) product in order to improve the reliability and applicability by taking advantage of the complementary nature of the optical and radar remote sensing technologies (Kääb, A. 2005; Karkee, M. *et al.* 2008; Robinson, N. *et al.* 2014). Recently, a continent-wide fusion dataset has been published, only for the European Union, called EU-DEM (Bashfield, A. and Keim, A. 2011; EU-DEM Metadata). Assuming that the dataset is accurate and reliable enough, it might fill a data gap in this field. Different characteristics of the applied source models and the steps of the data compilation significantly affect the quality of the final DSM product, so this paper focuses on exploring these effects and the applicability of the EU-DEM. It is necessary to reveal the specifications of the DSM and also analyse the most commonly occurring errors, in order to be clear about how accurate the results obtained using this model could be.

While the data gathering was carried out in two weeks for the SRTM, the creation of satellite images for the ASTER GDEM required years. Therefore only the former model provides well-defined, immediate snapshot of the Earth's surface. Furthermore, the quality of the GDEM varies in each region, as the quality of the source images and the number of available scenes for the elevation data preparation can be different (ASTER GDEM Validation Team 2009; Farr, T.G. *et al.* 2007; Frey, H. and Paul, F. 2012; Urai, M. *et al.* 2012). Another known issue of the models is the overall negative bias for ASTER GDEM and positive bias for SRTM in bare surface areas (ASTER GDEM Validation Team 2009, 2011; Forkour, G. and Maathuis, B. 2012; Mukherjee, S. *et al.* 2013). An appearance of the artefacts – 'residual clouds', 'bumps', 'pits', 'mole runs' on GDEM, voids due to radar shadow on SRTM – is also a well-known problem of the models. All these were taken into consideration during the fusion process of EU-DEM by carefully removing the data with possible error and applying a terrain slope-dependent, weighted averaging method for the compilation (Bashfield, A. and Keim, A. 2011).

Although, GDEM and SRTM versions have been studied in different regions of the Earth (e.g. Hirano, A. *et al.* 2003; Jacobsen, K. and Passini, R. 2009; Li, P. *et al.* 2012; Reuter, H.I. *et al.* 2009; Szabó, G. and Szabó, Sz. 2010; Szabó, G. *et al.* 2013; Winkler, P. *et al.* 2006; Zhao, S. *et al.* 2011), as a part of this study a quality assessment and comparison of the ASTER GDEM V2 and SRTM V4.1 is also applied to review the specifications of the models over the

Eastern Mecsek Mountains. Previous papers reported better results for the SRTM (Frey, H. and Paul, F. 2012; Suwandana, E. *et al.* 2012), but the validation report and newer studies convinced the improvements of GDEM V2 (ASTER GDEM Validation Team 2011; Sadeq, H. *et al.* 2012; Urai, M. *et al.* 2012). As the DEM-based automated or semi-automated landform classification, geomorphometric analysis is a prosperous subdivision of geomorphological researching (Drăguţ, L. *et al.* 2011; Drăguţ, L. and Eisank, C. 2011; Saadat, H. *et al.* 2008; van Asselen, S. and Seijmonsbergen, A.C. 2006), thus it is necessary to obtain proper data sources. If the DSMs are corrected with certain pre-processing steps, it is assumed that they could become a potential elevation database for further geomorphological researches in this area.

Study area

The study is carried out on a 350 km^2 large part of the Eastern Mecsek Mountains and its northern and southern foreland, located between 591,000; 800,00 (SW) and 605,000; 105,000 (NE) EOV coordinates (*Figure 1*).

From a geomorphological point of view, the area is divided into a low mountainous and hilly and a piedmont region, the elevation ranges from approx. 139 m up to 682 at Zengő as the highest peak. Landforms of the investigated area are determined by geological structure and palaeoclimatic conditions. Thus, before the GIS-based analyses it is required to overview the general geologic settings and landform evolution.

Within geological structure of the study area three main units can be distinguished. The central part of the study area is a low mountainous region builted up by Mesozoic marine, fluvial and lacustrine sediments and crossing rift-type volcanic rocks. The Upper Triassic Karolinavölgy Sandstone is the oldest formation that can be found on the western boundary of the area. It is overlain by Liassic fluvial–lacustrine–palustrine sediments with interbedded paralic coal-swamp deposits (Mecsek Coal Formation). The opencast coal mining affected the elevation values over the study area therefore it was taken into consideration during calculations. The rapid subsidence of Mecsek half graben in Early and Middle Jurassic indicates increasing carbonate content and marl with limestone intercalations become characteristic (e.g. Hosszúhetény Marl F.). Siliceous and carbonate deep-sea sedimentation developed in the second half of the Jurassic. The Early Cretaceous basaltic magmatism penetrated the Jurassic layers and a basalt–tephrite–phonolite series occurs (Mecsekjános Basalt F.). It is covered by conglomerate and sandstone deposits (Haas, J. 2012). A radial horst range is dominant in this part of the study area and it has been dissected by a complex, dense erosional valley network due to the erodibility and impermeability of Mesozoic rocks (Ádám, L. *et al.* 1981).

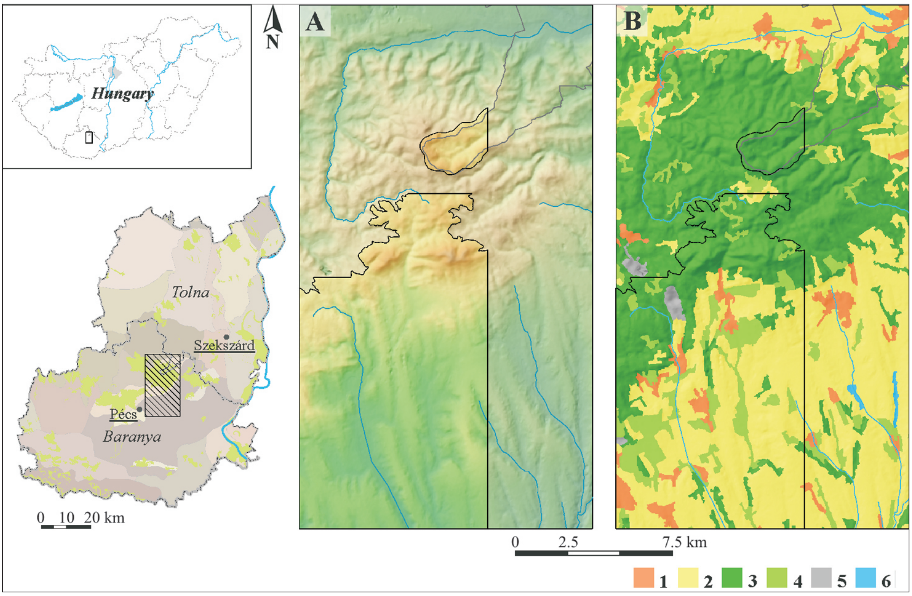

Fig. 1. Location of the study area (also showing the boundaries of micro regions* and Natura 2000 SCI areas**) and its EU-DEM image (A) overlying highlighted reference DEMs and the aggregated land cover categories of CLC2006 (B). – 1 = urban and associated areas; 2 = areas considered as bare surface; 3 = forests; 4 = permanent crops, shrub, semi natural and agricultural area, dumpsites; 5 = mineral extractions; 6 = water bodies
* http://www.novenyzetiterkep.hu/?q=magyar/node/407
** http://www.eea.europa.eu/data-and-maps/data/natura-4#tab-gis-data

The second main unit built-up by Miocene alluvial, marine and lacustrine sediments that encompasses the higher central part. Northern side of this unit is characterized by chiefly older (Szászvár Formation), while the southern by younger (Leitha Limestone F.) Miocene strata. As the Mecsek was an island in the Late Miocene, and the long-life Lake Pannon developed its sediments, which can be observed on both sides of Mecsek Mountains. (Nagymarosy, A. and Hámor, G. 2012). These parts of the study area are characterized by a lower hilly surface.

The third unit consists of a young aeolian loess series intercalated by paleosoils (Lovász, Gy. 1977; Pécsi, M. *et al.* 1988) on the top of the interfluves and proluvial deposits in the dry valleys and on the slopes. The Mecsekalja region is characterised by fragmented, lowering hills with general gentle sloping to south, while steeper slopes and deeper valleys can be found on Mecsekhát (the northern section).

The landscape and landform evolution of the study area was described as a classical pedimentation process that formed a typical piedmont surface. This piedmont *sensu* Pécsi, M. (1963) is generally younger than the Pannonian layers that were cut with a gentle plain, but older than Quaternary erosional valleys with fluvial terraces. On the southern slopes of Mecsek Mountains. different pre-pedimentation denudation levels were observed (*cf.* Figure 7 in Pécsi, M. 1963 p. 199 and Figure 3a in Pécsi, M. *et al.* 1987, p. 42) that was formerly described as Middle and Late Miocene abrasion terraces or etchplains (Kovács, I.P. *et al.* 2013). Formation of the Mecsekalja piedmont surface started after retreating Lake Pannon approx. 7 Myr ago (Magyar, I. *et al.* 1999) and continued in Early Pliocene under arid steppe climate (Schweitzer, F. 1997; Sebe, K. *et al.* 2008). On Mecsekalja a dislocation zone (neotectonic fault system) developed that results a subsidence from Okorág towards Pécs, Ellend and Bóly, where basins were evolved as tectonic subsidence moved eastward. On Western Mecsekalja Pécs basin dissected the original piedmont surface thus it changed the valley and water network considerably. Obsequient valleys sloping to North have cut deep into Upper Miocene and Pliocene beds (Fábián, Sz.Á. *et al.* 2005; Sebe, K. *et al.* 2008), while subsequent valleys captured consequent streams. These river captions characterize the eastern and east-southern part of Pécs basin, and Eastern Mecsekalja is also affected by the processes.

The study area consists the last remain of original piedmont surface on the western section of Eastern Mecsekalja, however the traces of neotectonic subsidence (e.g. river captures, valley asymmetry) have already appeared (Kovács, M. 2013). Beyond main goal of this paper, a GIS-based geomorphological analysis was also attempted to identify these relict, hardly modified classical piedmont surfaces.

Nowadays, the area has only a sparse settlement network because of the large nature reserves and Natura 2000 areas of the Mecsek Mountains region. As a result of the strict protection, a wide forested area of about 145 km^2 is present in the study site, influencing the elevation values of the DSMs. The extensive agricultural fields represent the other relevant land cover category.

The low mountainous and piedmont topography completed with land cover conditions mentioned above seems appropriate for the chosen study showing the typical challenges related to the application of satellite-based DSMs (Vágó, J. and Hegedűs, A. 2011).

Methods and materials

The components are organized into a flow chart for a better perspicuity, as the quality assessment process and the attempted error correction consist of several steps (*Figure 2*).

Since the topic of satellite-based DSMs has been studied, it is essential to review the available official validation reports and other papers before further examinations. In addition, for the GDEM a QA file (NUM file) is also available, which provides information about the amount of stereo image

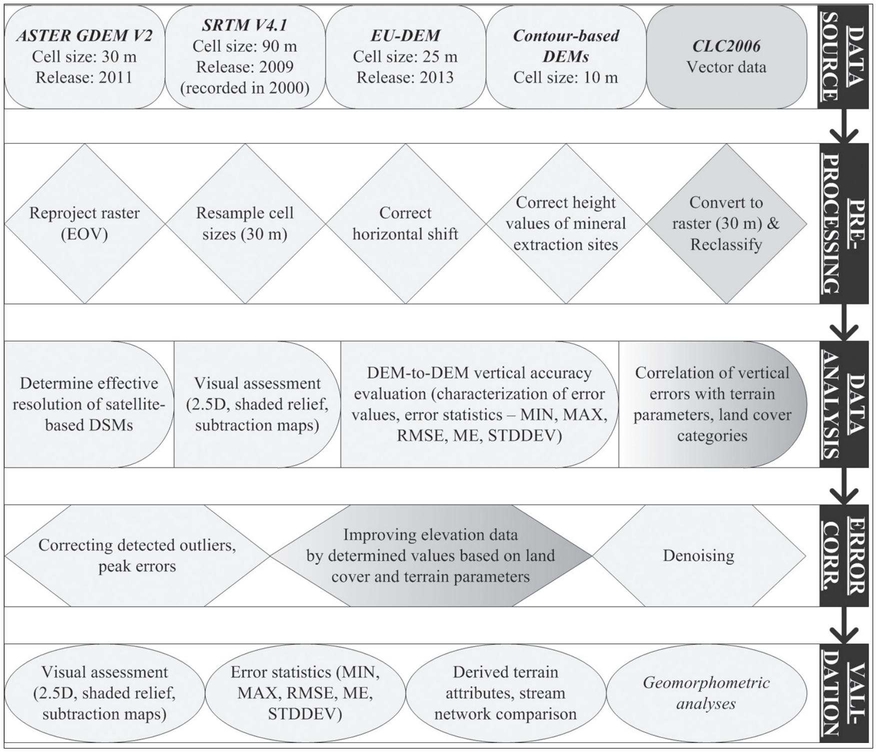

Fig. 2. The flow chart of the study

pairs used for the determination of the elevation values[3]. The ASTER GDEM Validation Team (2011), Urai, M. *et al.* (2012) proved that a higher number of 'stacks' resulted in better height values, and the concept of the EU-DEM creation is also based on this characteristic.

During the pre-processing the elevation datasets were converted to a common projection and cell size, the horizontal misfit (ASTER GDEM Validation Team 2011; Frey, H. and Paul, F. 2012) was corrected and the cells of mineral extraction sites were reinterpolated to avoid their misleading errors.

The data analysis included computing the effective resolution of the models (Guth, P. L. 2010), and visualizing the representation of the surface and errors. An important task was the thorough examination of the vertical accuracy. According to Mukherjee, S. *et al.* (2013) the assessment of the models based on a few sample points is not a proper method. Similar to the cited research surface-to-surface comparisons of the satellite based DSMs and the contour-based DEMs were performed and the error statistics were calculated. Based on

[3] This is also called 'stacks' and it is understood as the number of valid elevation data.

previous studies (Frey, H. and Paul, F. 2012; Szabó, G. *et al.* 2013; Zhao, S. *et al.* 2011) the correlation of height errors with terrain characteristics and land cover types was assumed and therefore examined. An attempted method was applied to improve the DSMs. The outstanding errors were corrected and the whole dataset was modified according to the topography and land cover, in order to make the models more representative regarding the real surface. Finally, a denoising algorithm was implemented (Stevenson, J.A. *et al.* 2010).

Due to the modifications the accuracy of the resulted models required retesting. For the validation both error statistics and characteristics of the digital surface relevant to geomorphological researches were examined. The geomorphometric maps of the study area were generated based on the Topographic Position Index of Weiss, A. (2001).

It is important to emphasize that all steps were carried out using GNU GPL (General Public License), open-source software including GRASS GIS 6.4.3 (http://grass.-osgeo.org/), SAGA GIS 2.1.0 (http://saga-gis.org) to create and process the datasets and R (http://www.r-project.org) to perform the statistical analyses. The *spgrass6* package (Bivand, R. 2013) provided the R – GRASS interface, making it available to analyse the maps' statistics with the built-in and user-defined functions of R, and create graphs representing the results.

The EU-DEM V1 dataset

The EU-DEM is a middle-precision surface model with a horizontal resolution of about 25 m, published in October 2013. It was created by an automated data fusion of improved ASTER GDEM data with SRTM data, using a weighted averaging approach. Substantial steps of the data preparation was the removal of the GDEM's elevation values where the number of scenes was less than 5, cloud cover caused errors or extremely differing height values occurred, and the filling of the voids with SRTM data. The concept of the model was to combine the advantages of both digital surface models with additional improvement by a new hydrography dataset and NEXTMap data (Bashfield, A. and Keim, A. 2011). The DSM is a realisation of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry. The EU-DEM is available in 5°×5° tiles from the website of the European Environment Agency[4] (EEA) or the European Commission[5]. As the data was provided without a formal validation, prior information about the horizontal and vertical accuracy has not been available yet (EU-DEM Metadata).

[4] http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-european-data

[5] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/digital_elevation_model

The SRTM V4.1 dataset

The Shuttle Radar Topography Mission acquired interferometric radar data for approx. 80 percent of the Earth in February 2000, using dual radar antennas (Farr, T.G. *et al.* 2007). The Consortium for Spatial Information (CGIAR-CSI) of the Consultative Group for International Agricultural Research (CGIAR) made available a post-processed, seamless, void-filled and complete elevation dataset for download[6] as 5°×5° tiles with 90 m (3″) horizontal resolution[7]. The vertical error of the SRTM DSM is reported to be less than 16 m, although accuracies are varying by continent and region (Rodriguez, E. *et al.* 2005; Farr, T.G. *et al.* 2007).

The ASTER GDEM V2 dataset

The Ministry of Economy, Trade and Industry (METI) of Japan and the National Aeronautics and Space Administration (NASA) developed GDEM jointly that covers 99 percent of the land surface (ASTER GDEM Validation Team 2009). The basic difference from SRTM is that the ASTER GDEM was produced by extracting elevation values from a large amount of scenes collected between 2000 and 2010 by the Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) on NASA's Terra spacecraft using nadir- and aft looking infrared cameras (ASTER GDEM Validation Team 2011; Urai, M. *et al.* 2012). The dataset is available from multiple websites (e.g. Japan Space Systems ASTER GDEM webpage[8]) as 1°×1° tiles, with 30 m cell size. The validation studies provide different accuracy values in different regions of the globe using different ground truth data, but in all the absolute vertical accuracy is reported to be approx. 17 m (ASTER GDEM Validation Team 2011).

The reference DEMs

The contour-based DEM of two sites over the study area was interpolated in SAGA GIS using the Triangulation method with 10 m cell size. The extent of these areas is approx. 130 km^2. The created elevation models were used to represent the ground-truth values for the error estimation methods after downsampling to 30 m in GRASS. Manually digitising the contour lines and elevation points from the EOTR (Unified National Map System) topographic

[6] http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp
[7] http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1
[8] http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html

maps in scale of 1:10,000 provided the most accurate database at the lowest cost for the area. As stated by Engler, P. and Mélykúti, G. (2000) and Winkler, P. *et al.* (2007) the terrain information contents of the maps meet the accuracy requirements of the T.1. Regulation, thus the accuracy of created DEMs is considered adequate to provide an acceptable quality assessment of the above-mentioned satellite DSMs and the fused EU-DEM dataset.

The CORINE Land Cover 2006 database

The seamless vector database of CLC2006 (Büttner, G. *et al.* 2012) was downloaded from the EEA's site[9] and converted into a 30 m resolution raster dataset. Analysing the impact of the land cover on the elevation models was executed on 6 aggregated categories (*Figure 1b*), that was based on the height of the features (vegetation, buildings) or the potential error of the elevation values (mineral extraction, water bodies).

Results and discussion

Data preparation

All analysed satellite-based DSMs were projected to the Hungarian Unified National Projection (EOV) from lat/long (SRTM and ASTER GDEM) and ETRS-LAEA (EU-DEM) projections[10]. For the comparison the models were upsampled or downsampled from their native resolutions to the common 30 m cell size – either as part of the reprojection process, or using the resample tool in GRASS. The univariate statistics (minimum, maximum, mean, standard deviation) confirmed that the resampling did not affect the data content significantly (*Table 1*).

Table 1. The univariate statistics of the models before (OR) and after resampling (RS)

Indicator	Minimum (m)		Maximum (m)		Mean		STDDEV	
	OR	RS	OR	RS	OR	RS	OR	RS
ASTER GDEM	73.0	83.0	690.0	689.2	259.4	272.0	92.8	95.6
SRTM	123.0	124.8	680.0	680.0	257.4	269.8	91.9	94.8
EU-DEM	123.4	123.7	677.4	677.4	269.5	270.0	94.6	94.6
ref. DEMs	138.8	138.8	680.0	679.8	273.2	273.4	101.7	101.8

[9] http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-2#tab-metadata

[10] It has to be noted that the models were created using different vertical datums and geoids, that also causes the deviation of the elevation values, but based on previous information (Kenyeres, A. *et al.* 2010; Winkler, P. *et al.* 2006) the height differences are much smaller than the reported vertical accuracy of the models.

The location of three peaks – Zengő, the middle peak of the Hármashegy and Dobogó was compared to check the horizontal misfit of the models. Using the displacement values the DSMs were moved, and the height errors for every new location were calculated by subtracting the models from the reference DEMs. The suitable horizontal offset was determined by checking spatial distribution of the errors that still suggests horizontal shift, and examining the absolute mean error and standard deviation of the errors. The difference in the East–West direction was similar – around 70–80 m to the East, while the shift in the North–South direction varied from 12 to 42 meters to the North.

Quality assessment

The ASTER GDEM Validation Team (2011) reported that the error values decrease significantly as the 'stack' number increases between 1 and 10 and there is only little improvement over 15. According to Bashfield, A. and Keim, A. (2011) the cells with less than 5 'stacks' were removed from the EU-DEM during the preparation process. The examination of the QA file showed that over the study area the cells with 'stacks' less than 10 is not reaching 1 percent of the total area, and 91.6 percent of the values were determined from more than 16 'stacks'.

The mentioned validation reports and independent studies (Guth, P. L. 2010; ASTER GDEM Validation Team 2009, 2011) revealed that although the GDEM V2, GDEM V1 and the full-resolution SRTM has approximately 30 m spacing of postings none of the DSMs have 30 m horizontal resolution. This also suggests that the EU-DEM fused model has a lower horizontal resolution as well. The effective resolutions (*Table 2*) were determined using the method of Guth, P.L. (2010). The reference DEMs were resampled to 10 different resolutions (10 to 100 m) and the mean slope values derived from every model were compared.

Table 2. The effective resolution of the DSMs

Indicator	Spacing (m)	Resolution (former studies*) (m)	Resolution (in this paper) (m)
ASTER GDEM	30	~71	~56
SRTM	90	~97	~92
EU-DEM	25	..	~68

* There are different values published. The values presented were calculated based on the standard deviation of downsampled non-LiDAR DEMs and the DSMs over test areas in Japan and West Virginia (ASTER GDEM Validation Team 2011). .. means no data.

The shaded relief maps (*Figure 3*) and 2.5D visualization (NVIZ) are simple but effective tools to obtain preliminary information about the quality of the datasets. The EU-DEM looks well-smoothed in NVIZ, which was expected

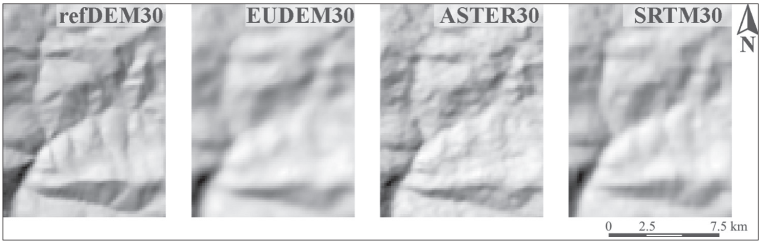

Fig. 3. Shaded relief maps of the models showing the Zengő and the upper parts of the Vasas-Belvárd stream's valley

according to the production method. However, the strong smoothing resulted in a loss of surface details, as it is shown on the 'blurry' shaded relief map.

The noise of the ASTER GDEM is conspicuous on the 2.5D map and on the shaded relief map also, suggesting necessary denoising. The 2.5D view of SRTM visually indicates a relatively correct representation of the surface, which is confirmed by the hillshading, too. The subtraction maps provided the numerical data for the further error analysis, but they were useful to check the spatial distribution of positive and negative errors with the proper colour table (see figures at the validation). As expected, generally the DSMs are above the reference datasets in the forested low mountainous parts and in the valleys (Paul, F. 2008), while under or near to the real surface on the piedmont. Although, the error values on the subtraction map of the ASTER GDEM show a higher variation.

First of all the analysed models were compared to each other by determining their correlation. From the satellite-based DSMs the SRTM and EU-DEM shows the strongest correlation, while compared to the reference DEMs the SRTM has the highest and the ASTER GDEM the lowest value. The correlation of the height differences (*Figure 4*) show a strong positive association, the highest value occurs between the SRTM and EU-DEM.

The error statistics[11] – with no respect to terrain parameters or land cover types – give a general overview for the study area. The mean absolute error (MAE), the standard deviation of errors (SD) and the root mean square error (RMSE) are the highest in case of the ASTER GDEM, although the range of errors is the lowest. This indicates that higher number of cells has vertical error. The range of errors is the highest for SRTM, suggesting that outstanding errors are present in the model. Aguilar, F.J. *et al.* (2007) declare that outliers can corrupt the true statistical distribution of errors, thus the '3σ rule' i.e. three times the standard deviation was applied to remove errors. The 3σ RMSE

[11] Height differences were determined by subtracting the reference DEMs from the satellite-based DSMs, thus negative values represent areas where the reference models have higher elevation values.

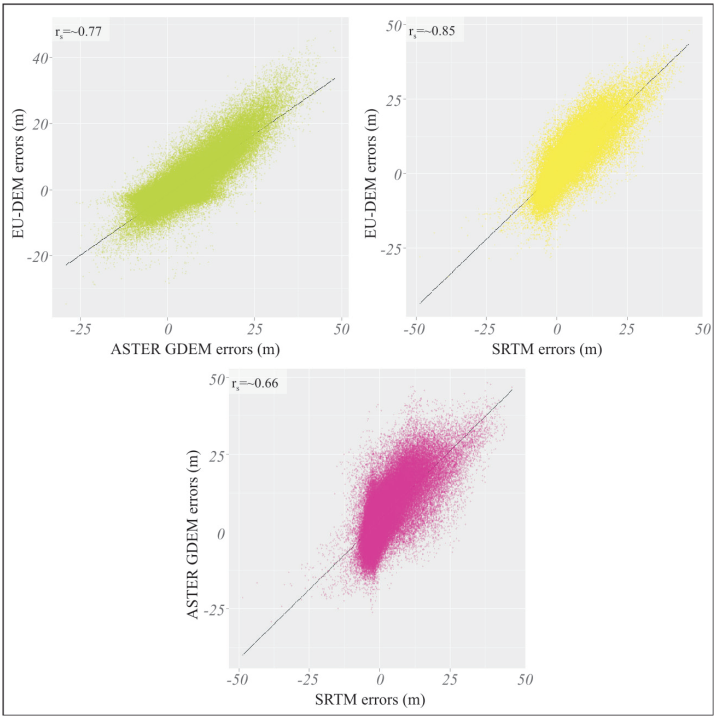

Fig. 4. Simple scatter plots between the errors of the satellite-based DSMs

suggests the significance of outstanding errors, but as it is shown by the new RMSE values the outlier correction method was not able to remove these errors (*Table 3*). Despite an expected consequence of the applied corrections, the EU-DEM has not got the lowest error statistic values.

Examining the frequency of errors also showed that the GDEM has more cells with error. The high kurtosis of SRTM and EU-DEM proves that outliers and significant vertical errors affect a small percentage of the cells. The positive 'skewness' indicates that the models are overall above the ground truth DEMs.

The accuracy assessment was also implemented by segmenting the models based on land cover types to analyse the difference of errors in bare

Table 3. The change in RMSE values

Indicator	Initial RMSE (m)	Initial 3σ RMSE (m)	Outliers corr. RMSE	Final corr. RMSE
ASTER-GDEM	10.1	8.9	10.1	6.1
SRTM	7.3	5.8	7.3	5.3
EU-DEM	7.8	6.6	7.8	6.0

surfaces and forested areas. The correlation of the errors to terrain parameters (elevation, slope, aspect) was also checked.

Over the forested area the range of errors is the same as the overall value, while in the case of the bare surface it is much smaller, suggesting that the outliers appear in the forested parts. This is also convinced by the small difference between the RMSE and 3σRMSE of the bare regions.

Looking at just the error statistics of the bare surface the ME of the ASTER GDEM is positive, showing that the GDEM have a significant number of values above the reference DEMs, while the negative ME of the SRTM and EU-DEM indicates that these models slightly underestimate the elevation values. This difference can also be observed in the forested areas, as the MAE and ME of ASTER GDEM is higher with 2–3 metres. Although, in the latter case it is also related to the acquiring method, as the SRTM represent the elevations within the vegetation and the GDEM provided 'first return' data from the canopy top (Hofton, M. *et al.* 2006; Li, P. *et al.* 2012). The absolute relief on the reference DEMs' area is only 542 metres, thus significant correlation of the errors was neither expected nor found. The same was determined in case of the slope gradiens.

Former studies suggest that the slope aspect can affect the accuracy of elevation values (Frey, H. and Paul, F. 2012; Szabó, G. 2011; Szabó, G. *et al*. 2013). The proportion of aspect categories was approx. equal for the forested, low mountainous regions. However, as the land cover types representing bare surface occur over the piedmont area southern slopes are dominated, and because of the almost meridional valleys the eastern and western directions are also significant. *Figure 5* shows a slight fluctuation of the error values in different directions, thus the effect of the aspect is considered negligible. On the other hand, in the forested areas the fluctuation is more noticeable: the highest differences occur in the northern directions.

Error correction

The first step was to remove the outlier errors, which could degrade the results of the further corrections. Before any complex correction algorithm the r.fill.dir command was used to remove the depressions from the models. The afterwards implemented method[12] was published by Neteler, M. (2005) and adopted to the characteristics of the models. The mean and standard devia-

[12] MAP=ASTER GDEM/SRTM/EU-DEM g.region rast=$MAP – p r.neighbors $MAP out=$MAP.mean3 meth=average size=3 r.neighbors $MAP out=$MAP.mean5 meth=average size=3 r.neigbors $MAP out=$MAP.stddev3 meth=stddev size=3 r.neigbors $MAP out=$MAP.stddev5 meth=stddev size=3 r.mapcalc „$MAP.filt=if($MAP >= 280, if(abs($MAP – $MAP.mean3) > 1.5 * $MAP.stddev3, $MAP.mean3, $MAP), if(abs($MAP – $MAP.mean5) > 1.5 * $MAP.stddev5, $MAP.mean5, $MAP) (Neteler, M. 2005).

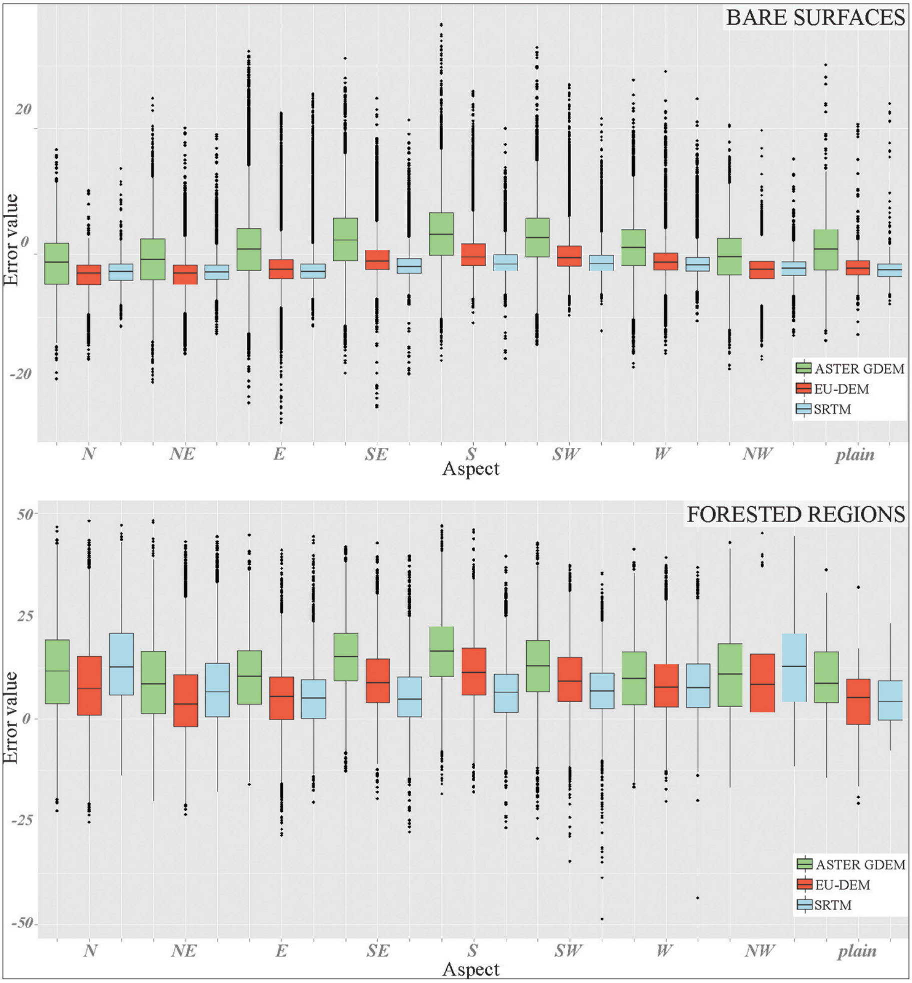

Fig. 5. The connection between the values of error and slope aspect over bare surfaces and forested regions

tion values were used to determine whether a cell deviates 'enough' to be considered as outlier, and, if so, the method replaces it with the mean value. Major changes in the original method were the use of lower standard deviation limit and different neighbourhood sizes based on the elevation. In the case of the ASTER GDEM ~22,500 cell values were involved in the correction, while less than 4,000 cells were modified on the other two models. However, removing the outliers affected the SRTM the most, as the ME, STDDEV, range of the errors and the difference between the normal and 3σ RMSE were also reduced.

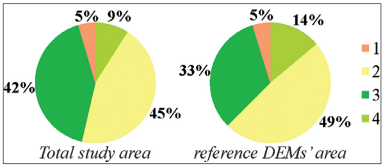

Fig. 6. Distribution of land cover categories. – 1 = urban and associated areas; 2 = areas considered as bare surface; 3 = forests; 4 = permanent crops, shrub, semi natural and agricultural area, dumpsites

To eliminate the effect of the land cover categories mean difference values, determined over the reference DEMs region, were subtracted from the DSMs. This was possible because the distribution of the different categories is almost identical for the total study area and the reference DEMs (*Figure* 6), so the values were considered representative. According to the previously stated correlation results the continuous forest areas, in regions with higher slope values, were subdivided based on aspect categories.

For smoothing the noises, residual errors on the models, Sun's denoising algorithm (Sun, X. *et al.* 2007; Stevenson, J.A. *et al.* 2010) was applied. The executable file runs from command line and manages the models out of GRASS GIS, as a 'xyz' dataset. Setting the parameters (threshold and number of iterations) give a good control over the method to produce an acceptable result. The parameter values (7 iterations and 0.98 threshold value) were determined based on the recommendations of the above mentioned studies. Although it should be mentioned, that tuning the values more precisely could lead to even better results. The 2.5D view of the DSMs shows a much smoother image. The most outstanding change was experienced on the ASTER GDEM.

As the last modification the models were smoothed with an average filter (by 3×3 neighbourhood matrix) in order to avoid steps at the border of the land cover categories.

Validation

The repeated visual assessments confirmed the reduction of errors, noise on the models. The shaded relief map of ASTER GDEM shows that the stronger smoothing algorithm affected the information content of the model. The subtraction maps also show a significant improvement (*Figure 7.* A, B). The ridges and valleys remained erroneous, as a result of the earlier mentioned characteristics of the models.

The RMSE (*Table 3*), MAE and ME values decreased the most in the case of the GDEM, while the STDDEV shows significantly lower values for the GDEM and SRTM. A notable change, related to the correction of outliers, is that the range of errors on the SRTM decreased by 25 percent. The cells with less than 1 m error are 41 percent on the SRTM, 37 percent on the EUDEM and only 27 percent on the ASTER GDEM.

The accuracy of slope and aspect as terrain derivatives was checked. The slope values were reclassified according to the agricultural suitability

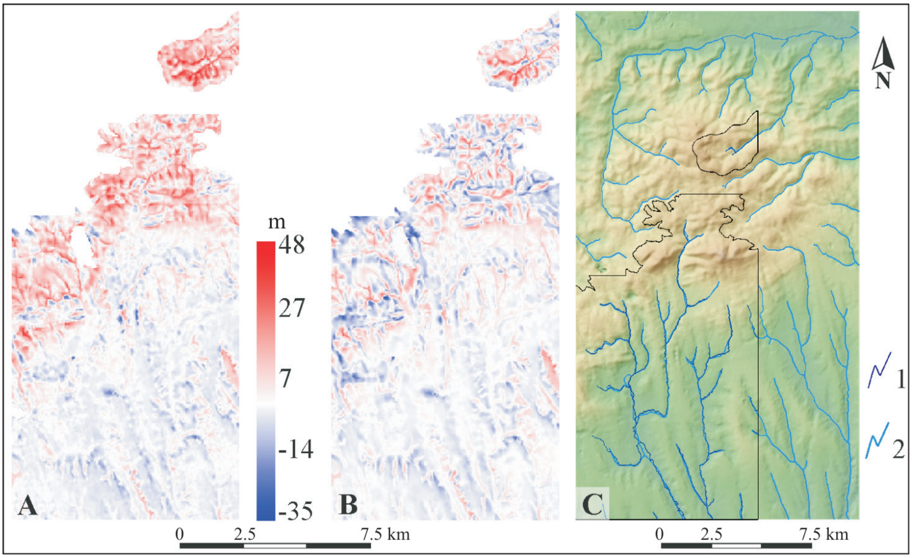

Fig. 7. The subtraction maps of the EU-DEM before (A) and after (B) the corrections and the derived stream network of the reference DEMs and the EU-DEM (C). – 1 = stream line on reference DEMs, 2 = stream line on EU-DEM

(Pécsi, M. 1985). Generally, all of the DSMs derivatives look similar to the ones created from the reference DEMs. The slope and aspect categories overlap best on the ASTER GDEM and EU-DEM, although the mean slope value of SRTM is closer to the reference DEMs'. The differences are partly related to the smoothing used at the production of the DSMs, and the original cell sizes.

As a validation step the stream network for at least 1 km^2 watersheds of the study site was computed with GRASS GIS (*Figure 7.* C). Although the length – based on the cell numbers – and location of the streams is almost identical, the correlation between the different stream networks is low. 77 percent of stream cells from SRTM stream lines, 71 percent from EU-DEM and 64 percent from GDEM stream line cells are within a 100 m buffer zone of the reference DEMs stream lines.

Geomorphometric map

The geomorphometric analysis had two purposes. First, it can be considered as a method to validate the corrected EU-DEM, but it also provides additional information for the geomorphological issues of the study area.

The geomorphometric map was generated by the TPI method, following the steps described by Weiss, A. (2001) and Jennes, J. (2006). This approach classifies the cells of the DEM based on the average elevation of their neighbourhood. It is calculated by subtracting the averaged models of different neighbouring cell matrices from the original. For the geomorphometric map two versions (averaged on 11×11 and 33×33 cells) of standardized TPI maps were combined, and the landforms were classified based on the standard deviation and slope values. The latter was set as 2.5 degrees, based on the findings of Pécsi, M. (1963). The map is generalized containing only 10 landform types, but it fits the resolution of the input elevation dataset.

Figure 8 shows the valley network, mountain top region and the piedmont-like surfaces to get a better view of these more important forms. The plain surfaces between 180–280 meters were selected as potential parts of the Eastern Mecsek Mountains' piedmont region. The elevation level was also defined according to the previous results of Pécsi, M. (1963).

The TPI-based landform classification verified the radial horst ranges surrounding the highest mountain top regions (Dobogó, Hármashegy and Zengő). The narrow, dense valley network of the central part of the study area fits the geological settings. The sharp bendings of the Völgységi Stream are clearly visible on the calculated landforms map, showing a strong correlation with the geological structures and tectonic lines.

The relict landforms of the Mecsekalja piedmont region were also found on the geomorphometric map. Stretching the patches of the piedmont-

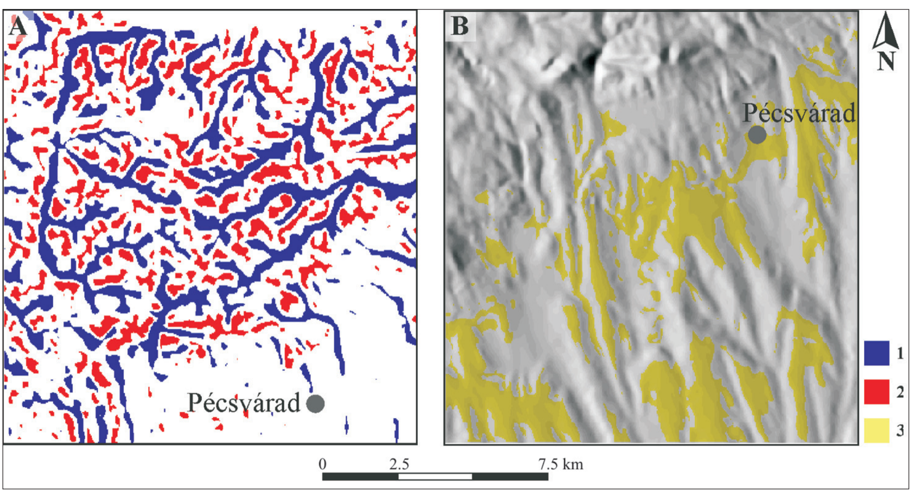

Fig. 8. The valley network and ridge lines of the Eastern Mecsek Mountains (A), and the piedmont-like surfaces stretched on the shaded relief map of EU-DEM (B) based on the TPI map. – 1= valleys; 2 = mountain tops, high ridges; 3 = piedmont-like surfaces

like surfaces on the shaded relief map it can be declared that these are in a good agreement with the former piedmont forms, that were fragmented into lower interfluves by the consequent streams. Evolution of the piedmont region can be also explained using the calculated landform map: basins and submountain depressions (Bogád, Ellend and Pécsvárad) affected by Mecsekalja dislocation zone and transversally dissected piedmont surfaces are also detected.

Conclusions

The EU-DEM and the two other satellite-based DSMs had different elevation error over the study area, so analysing the error statistics and distribution is recommended before applying. Then the horizontal misfit of the models was confirmed and corrected by comparing the location of peaks. The calculated effective resolution showed that the models horizontal spacing is over-estimated, resulting greater storage capacity requirements. The effective resolution, visual comparison and correlation between the elevation datasets suggest that the EU-DEM has more similarity to the SRTM, probably because of the smoothing used for the fusion method.

Lowering elevation data or uplifting the surface according to mean errors of the categories treated the height differences caused by the land cover. Based on the results, it seems to be a time-saving solution to alter a larger study area with values determined for smaller, but representative reference sites. The used denoising method also improved the models, and it is suggested even for just visualizing goals.

The visual and statistical validation process showed that there are still some errors that need to be corrected, and the parameterization of the denoising method could be more precise, but in all the models are suitable for geomorphologic studies. This was tested by creating the TPI-based geomorphometric map and analysing the results connected to the geomorphic issues of this particular area. Dissected piedmont-like surfaces and the radial horst ranges and the tectonic valley network were recognized.

Acknowledgements: This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP-4.2.4.A/ 2-11/1-2012-0001 'National Excellence Program'.

REFERENCES

Ádám, L., Marosi, S. and Szilárd, J. 1981. *A Dunántúli-dombság* (The Transdanubian Hills). Magyarország tájföldrajza 4. (Landscape Geography of Hungary 4). Budapest, Akadémiai Kiadó, 704 p.

Aguilar, F.J., Agüera, F. and Aguilar, M.A. 2007. A theoretical approach to modelling the accuracy assessment of digital elevation models. *Photogrammetric Engineering & Remote Sensing* 73. (12): 1367–1379.

ASTER GDEM database. http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html

ASTER GDEM Validation Team 2009. *ASTER global DEM validation summary report.* METI & NASA. 28. https://lpdaac.usgs.gov/sites/default/files/public/aster/docs/ASTER_GDEM_Validation_Summary_Report.pdf

ASTER GDEM Validation Team (Tachikawa, T., Kaku, M., Iwasaki, A., Gesch, D., Oimoen, M., Zhang, Z., Danielson, J., Krieger, T., Curtis, B., Hasse, J., Abrams, M., Crippen, R., Carabajal, C. and Meyer, D.) 2011. *ASTER Global Digital Elevation Model Version* 2 – Summary of Validation Results. 26. https://lpdaacaster.cr.usgs.gov/GDEM/Summary_GDEM2_validation_report_final.pdf

Bashfield, A. and Keim, A. 2011. *Continent-wide DEM Creation for the European Union. 34th International Symposium on Remote Sensing of Environment.* The GEOSS Era: Towards Operational Environmental Monitoring. Sydney, Australia 10–15 April 2011 http://www.isprs.org/proceedings/2011/isrse-34/211104015Final00143.pdf

Bivand, R. 2013. Package spgrass6: Interface between GRASS 6 and R. R package version 0.8–3. http://cran.r-project.org/web/packages/spgrass6/spgrass6.pdf

Bolch, T., Kamp, U. and Olsenholler, J. 2005. Using ASTER and SRTM DEMs for studying geomorphology and glaciation in high mountain areas. In *New Strategies for European Remote Sensing.* Ed. Oliuc, M. Proceedings, 24th Annual Symposium European Association of Remote Sensing Laboratories (EARSeL), 25–27 May 2004, Dubrovnik, Croatia. Rotterdam, Millpress, 119–127.

Borders of Hungarian micro regions. http://www.novenyzetiterkep.hu/?q=magyar/node/407

Borders of Natura 2000 areas. http://www.eea.europa.eu/data-and-maps/data/natura-4#tab-gis-data

Bubenzer, O. and Bolten, A. 2008. The use of new elevation data (SRTM/ASTER) for the detection and morphometric quantification of Pleistocene megadunes (draa) in the eastern Sahara and the southern Namib. *Geomorphology* 102. 221–231

Büttner, G., Kosztra, B., Maucha, G. and Pataki, R. 2012. I*mplementation and achievements of CLC2006*. 65. http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2/clc-final-report/clc-final-report/at_download/file

CLC2006 database. http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-2#tab-metadata

Drăguţ, L. and Eisank, C. 2011. Object representations at multiple scales from digital elevation models. – *Geomorphology* 129. 183–189.

Drăguţ, L. and Eisank, C. 2012. Automated object-based classification of topography from SRTM data. *Geomorphology* 141–142. 21–33.

Drăguţ, L., Eisank, C. and Strasser, T. 2011. Local variance for multi-scale analysis in geomorphometry. *Geomorphology* 130. 162–172.

Engler, P. and Mélykúti, G. 2000. *Az 1:10 000 méretarányú topográfiai térképek domborzatának ellenőrzése új mérési eredmények felhasználásával* (Control of the relief of topographic maps in scale 1:10,000 using results of new measurement). X. Országos Térinformatikai Konferencia, Szolnok.

EU-DEM dataset. http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/digital_elevation_model

EU-DEM Metadata. http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-metadata

Fábián, Sz.Á., Schweitzer, F. and Varga, G. 2005. A Pécsi-víz völgyének kialakulása és kora. In *A földrajz dimenziói: Tiszteletkötet a 65 éves Tóth Józsefnek*. Eds. Dövényi, Z. and Schweitzer, F. Budapest, MTA Földrajztudományi Kutatóintézet, 461–472.

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D. and Alsdorf, D. 2007. The Shuttle Radar Topography Mission. *Reviews in Geophysics* 45. 1–33.

Forkuor, G. and Maathuis, B. 2012. Comparison of SRTM and ASTER Derived Digital Elevation Models over Two Regions in Ghana – Implications for Hydrological and Environmental Modeling. In *Studies on Environmental and Applied Geomorphology*. Eds. Piacentini, T. and Miccadei, E., Rijeka, InTech, 219–240.

Frey, H. and Paul, F. 2012. On the suitability of the SRTM DEM and ASTER GDEM for the compilation of topographic parameters in glacier inventories. *International Journal of Applied Earth Observation and Geoinformation.* 18. 480–490.

Gichamo, T.Z., Popescu, I., Jonoski, A. and Solomatine, D. 2012. River cross-section extraction from the ASTER global DEM for flood modeling. *Environmental Modelling & Software* 31. 37–46.

Grohmann, C.H. and Sawakuchi, A.O. 2013. Influence of cell size on volume calculation using digital terrain models: a case of coastal dune fields. *Geomorphology* 180–181. 130–136.

Guth, P.L. 2010. *Geomorphometric comparison of ASTER GDEM and SRTM.* Special joint symposium of ISPRS Technical Commission IV & AutoCarto in conjunction with ASPRS/CaGIS 2010 Fall Specialty Conference, November 15–19, 2010 Orlando, Florida

Haas, J. 2012. Alpine evolution. In *Geology of Hungary*. Ed. Haas, J., Budapest, Eötvös University Press, 118–136.

Hengl, T. and Reuter, H. 2011. How accurate and usable is GDEM? A statistical assessment of GDEM using LiDAR data. In *Geomorphometry – Proceedings.* Eds. Hengl, T., Evans, S.I., Wilson, J.P. and Gould, M., CA, USA, 7–11 September 2011, Redlands, 45–48.

Hirano, A., Welch, R. and Lang, H. 2003. Mapping from ASTER stereo image data: DEM validation and accuracy assessment. *ISPRS Journal of Photogrammetry and Remote Sensing* 57. 356–370.

Hofton, M., Dubayah, R., Blair, J. B. and Rabine, D. 2006. Validation of SRTM elevations over vegetated and non-vegetated terrain using medium footprint Lidar. *Photogrammetric Engineering and Remote Sensing* 72. 279–285.

Jacobsen, K. and Passini, R. 2009. Analysis of ASTER GDEM Elevation Models. *International Archieves of the Photogrammetry, Remote Sensing and Spatial Sciences* 38. Calgary, 2010, 6 S.

Jenness, J. 2006. *Topographic Position Index* (TPI) v.1.2 http://www.jennessent.com/downloads/TPI_Documentation_online.pdf

Kääb, A. 2005. Combination of SRTM3 and repeat ASTER data for deriving alpine glacier flow velocities in the Bhutan Himalaya. *Remote Sensing of Environment* 94. 463–474

Karkee, M., Steward, B. and Aziz, S. 2008. Improving quality of public domain digital elevation models through data fusion. *Biosystems Engineering* 101. 293–305.

Kenyeres, A., Sacher, M., Ihde, J., Denker, H. and Marti, U. 2010. *EUVN Densification Action.* Final report. 19 p. http://www.bkg.bund.de/geodIS/EVRS/SharedDocs/Downloads/Publications/EUVN-DA__FinalReport,templateId=raw,property=publicationFile.pdf/EUVN-DA_FinalReport.pdf

Kovács, I.P., Bugya, T., Fábián, Sz.Á. and Schweitzer, F. 2013. Review on denudation levels of the Western Mecsek Mountains (SW Transdanubia, Hungary). *Studia Geomorphologica Carpatho Balcanica* 47.(1): 49–67.

Kovács, M. 2013. Egy Pécs közeli vízfolyás vizsgálata geomorfológiai módszerekkel (The analysis of a drainage basin near Pécs with geomorphic methods). In *A földtudományi kutatások új aspektusai*. Eds. Balogh, R. and Schmidt, P., Pécs, Publikon Kiadó, 27–32.

Li, P., Shi, C., Li, Z., Muller, J.-P., Drummond, J., Li, X., Li, T., Li, Y. and Liu, J. 2012. Evaluation of ASTER GEM Ver2 using GPS measurements and SRTM Ver4.1 in China. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* I-4. 181–186.

Lovász, Gy. (ed.) 1977. *Baranya megye természeti földrajza* (Physical geography of Baranya county). Pécs, Baranya Megyei Levéltár, 46–67, 163–188.

Magyar, I., Geary, D.H. and Muller, P. 1999. Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. *Palaeogeography Palaeoclimatology Palaeoecology* 147. (3–4): 151–167.

Mukherjee, S., Joshi, P.K., Ghosh, A., Garg, R.D. and Mukhopadhyay, A. 2013. Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). *International Journal of Applied Earth Observation and Geoinformation* 21. 205–217

Nagymarosy, A. and Hámor, G. 2012. Genesis and Evolution of the Pannonian Basin. In *Geology of Hungary.* Ed. Haas, J., Budapest, Eötvös University Press, 49–200.

Neteler, M. 2005. SRTM and VMAP0 data in OGR and GRASS. *GRASS Newsletter* 3. 2–6.

Paul, F. 2008. Calculation of glacier elevation changes with SRTM: is there an elevation dependent bias? *Journal of Glaciology* 54. (188.) 945–496.

Pécsi, M. 1963. Hegylábi (pediment) felszínek a magyarországi középhegységekben (Pediment surfaces in the Hungarian mountain ranges). *Földrajzi Közlemények* 87. (3): 195–212.

Pécsi, M. 1985. Domborzatminősítő térképek (Maps for qualification of relief). In *Mérnökgeomorfológiai térképezés* (Engineering geomorphological mapping). Eds. Ádám, L. and Pécsi, M., Budapest, MTA Földrajztudományi Kutatóintézet, 7–14.

Pécsi, M., Gerei, L., Schweitzer, F., Scheuer, Gy. and Márton, P. 1987. Loess and paleosol sequences in Hungary reflecting cyclic climatic deterioration in the Late Cenozoic. In *Pleistocene environment in Hungary.* Ed. Pécsi, M. Contribution of the INQUA Hungarian National Committee to the XIIth INQUA congress: Ottawa–Budapest, Geographical Research Institute, Hungarian Academy of Sciences, 42 p.

Pécsi, M., Gerei, L., Schweitzer, F., Scheuer, Gy. and Márton, P. 1988. Ciklikus éghajlatváltozás és rosszabbodás visszatükröződése a magyarországi löszök és eltemetett talajok sorozatában (The reflection of cyclic climate change and worsening from the Hungarian loess and buried paleosoil series). *Időjárás (Quarterly Journal of The Hungarian Meteorological Service)* 92. (2–3): 75–86.

Reuter, H.I., Nelson, A., Strobl, P., Mehl, W. and Jarvis, A. 2009. *A First Assessment of Aster Gdem Tiles for Absolute Accuracy, Relative Accuracy and Terrain Parameters*. IEEE International Geoscience and Remote Sensing Symposium. 240–243.

Robinson, N., Regetz, J. and Guralnick, R.P. 2014. EarthEnv-DEM90: A nearly-global, void-free, multi-scale smoothed, 90 m digital elevation model from fused ASTER and SRTM data. *ISPRS Journal of Photogrammetry and Remote Sensing* 87. 57–67.

Rodriguez, E., Morris, C.S., Belz, J.E., Chaplin, E.C., Martin, J.M., Daffer, W. and Hensley, S. 2005. *An Assessment of the SRTM Topographic Products*. Pasadena, CA USA, Jet Propulsion Laboratory, 143 p.

Saadat, H., Bonnell, R., Sharifi, F., Mehuys, G., Namdar, M. and Ale-Ebrahim, S. 2008. Landform classification from a digital elevation model and satellite imagery. *Geomorphology* 100. 453–464.

Sadeq, H., Drummond, J. and Li, Z. 2012. Evaluation of ASTER GDEM v.2 using GPS checkpoints, OSGB DEM values and photogrammetrically derived DEMs. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. I–4, XXIInd ISPRS Congress, 25 Aug.–1 Sept. 2012, Melbourne, Australia, 295–300.

Schweitzer, F. 1997. On late Miocene – early Pliocene desert climate in the Carpathian Basin. In *Geomorphology and changing environments in Central Europe*. Eds. Bremer, H. and Lóczy, D. IAG European Regional Geomorphological Conference, Hungary, April 1996. Stuttgart, Gebrüder Borntraeger, 37–43. (*Zeitschrift für Geomorphologie Supplementband* 110.)

Sebe, K., Csillag, G. and Konrád, Gy. 2008. The role of neotectonics in fluvial landscape development in the Western Mecsek Mountains and related foreland basin (SE Transdanubia, Hungary). *Geomorphology* 102. 55–67.

Seres, A. and Dobos, E. 2009. *Területhasználati térkép készítése műholdfelvételek alapján az SRTM magasságmodell pontosítására* (Preparation of landuse map based on satellite images to clarify SRTM elevation model), HunDEM2009, Konferencia és Kerekasztal Kiadv., Miskolc, University of Miskolc, 15 p.

Siart, C., Bubenzer, O. and Eitel, B. 2009. Combining digital elevation data (SRTM/ASTER), high resolution satellite imagery (Quickbird) and GIS for geomorphological mapping: A multi-component case study on Mediterranean karst in Central Crete. *Geomorphology* 112. 106–121.

SRTM 90 m Digital Elevation Database v4.1. http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

SRTM dataset. http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

Stevenson, J.A., Sun, X. and Mitchell, N.C. 2010. Despeckling SRTM and other topographic data with a denoising algorithm. *Geomorphology* 114. 238–252.

Sun, X., Rosin, P.L., Martin, R.R. and Langbein, F.C. 2007. Fast and Effective Feature-Preserving Mesh Denoising. *IEEE Transactions on Visualisation and Computer Graphics* 13. 925–938.

Suwandana, E., Kawamura, K., Sakuno, Y., Kustiyanto, E. and Raharjo, B. 2012. Evaluation of ASTER GDEM2 in Comparison with GDEM1, SRTM DEM and Topographic-Map-Derived DEM Using Inundation Area Analysis and RTK-dGPS Data. *Remote Sensing* 4. 2419–2431.

Szabó, G. 2011. Az ASTER GDEM adatbázis pontosságának vizsgálata egy hazai mintaterületen (Accuracy assesment of the ASTER GDEM dataset over a Hungarian study area). In *Az elmélet és a gyakorlat találkozása a térinformatikában II*. Ed. Lóki, J., Konferenciakötet. Debrecen, Kapitális Nyomdaipari Kft. 421–427.

Szabó, G. and Szabó, Sz. 2010. A Shuttle Radar Topography Mission (SRTM) során nyert adatbázis pontosságának vizsgálata hazai mintaterületeken (Checking the accuracy of the database collected during the Shuttle Radar Topography Mission [SRTM] in Hungarian sample areas). *Geodézia és Kartográfia* 62. 31–35.

Szabó, G., Mecser, N. and Karika, A. 2013. Assessing data quality of remotely-sensed DEMs in a Hungarian sample area. *Acta Geographica Debrecina Landscape and Environment* 7. 42–47.

Takeda, R. and Takeuchi, W. 2010. *Towards DTM generation from SRTM3 and ASTER GDEM in hilly terrain using wavelets.* 31st Asian conference on remote sensing (ACRS). Nov. 2 2010. Hanoi, Vietnam.

Urai, M., Tachikawa, T. and Fujisada, H. 2012. Data acquisition strategies for Aster Global DEM generation. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. I–4, XXIInd ISPRS Congress, 25 Aug.–1 Sept. 2012, Melbourne, Australia, 199–202.

Vágó, J. and Hegedűs, A. 2011. DEM based examination of pediment levels: a case study in Bükkaja, Hungary. *Hungarian Geographical Bulletin* 60. (1): 25–44.

Van Asselen, S. and Seijmonsbergen, A.C. 2006. Expert-driven semi-automated geomorphological mapping for a mountainous area using a laser DTM. *Geomorphology* 78. 309–320.

Weiss, A. 2001. *Topographic Position and Landforms Analysis.* A poster for the Conference. http://www.jennessent.com/downloads/tpi-poster-tnc_18x22.pdf

Winkler, P. 2007. Magyarország digitális ortofotó programjai és az 1:10 000 országos vektoros adatbázis (The digital ortophoto projects of Hungary and the 1:10,000 scale vector dataset). In *Földminősítés, földértékelés és földhasználati információ.* Eds. Tóth, T., Tóth, G., Németh, T. and Gaál, Z., Keszthely–Budapest, HAS CAR, 161–168.

Winkler, P., Iván, Gy., Kay, S., Spruyt, P. and Zielinski, R. 2006. Űrfelvételekből származtatott digitális felületmodell minőségének ellenőrzése a nagyfelbontású digitális domborzatmodell alapján (Quality checking of DSM derived from satellite data (SPOT and SRTM) on the base of Hungarian high resolution DEM). *Geodézia és Kartográfia* 61. 22–31.

Zhao, S., Cheng, W., Zhou, C., Chen, X., Zhang, S., Zhou, Z., Liu, H. and Chai, H. 2011. Accuracy assessment of the ASTER GDEM and SRTM3 DEM: an example in the Loess Plateau and North China Plain of China. *International Journal of Remote Sensing* 32. 8081-8093.

Hungarian Geographical Bulletin 63 (4) (2014) 425–436.
DOI: 10.15201/hungeobull.63.4.4

New opportunities for experiments in fluvial geomorphology: the flume PTETHYS

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Abstract

In recent decades both physical modelling and computer simulation of fluvial processes has undergone rapid progress. The paper summarizes the achievements of both international and Hungarian laboratory experiments in fluvial geomorphology. Then, the new automatically governed flume facility, called PTETHYS (Project for Tectonical and Hydrological Simulations) recently set up at the Faculty of Natural Sciences, University of Pécs, is presented. Finally, some of the new opportunities it offers for research in fluvial geomorphology are briefly demonstrated: the identification of geomorphological thresholds; modelling the generation of (flash) floods and its application for the reconstruction of the architectural elements and geomorphic evolution of floodplains. Some important channel parameters can be quantitatively investigated: channel cross-section change, amount of bedload influencing braiding, current velocity distribution etc. The novelty of the facility is the easy adjustment of channel slope and continuous experimenting (no need for interruption as in the case of laser-scanned experiments). The scaling necessary for quantitative analyses is also tackled.

Keywords: physical modelling, flume, channel patterns, flood generation, floodplain rehabilitation, scaling

Introduction

In recent decades monitoring has been launched in many instrumented catchments all over the world and numerous computer models have been elaborated for the explanation of some of the “eternal” questions of fluvial geomorphology. At the same time, the weaknesses of the first (a labour and

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time-consuming activity involving high expenses) and the second approach (e.g. magnification of errors springing from incorrect parametrisation or limited applicability to real-life situations) have also been recognized.

Observing the scaling rules, the small-scale physical models, long established in water engineering, seem to be capable to bridge the gap between the two approaches. If the results of experimentations could be quantified, physical modelling may also be helpful for the theoretical foundation of various water management tasks (including dam constructions, designing flood control alert and warning or river rehabilitation).

The aim of the project is to apply quantitative methods for the modelling of braided (and in the future meandering) channel evolution. Hopefully, the results can be used in designing river restoration, too. The experiment also helps students to combine their knowledge in laboratory studies, experimental geomorphology and remote sensing.

Previous flume experiments

Reaching back to the end of the 19th century, physical modelling has a long tradition in water management. It is particularly frequently applied in river channel studies for diverse purposes. The largest hydraulic model ever built in the world replicates the Mississippi River and its major tributaries (the Tennessee, Arkansas and Missouri Rivers) in ca 170 hectares' area near Clinton, Mississippi. Meant to aid flood control planning, it was built by 3,000 German and Italian prisoners of war for the US Army Corps of Engineers in 1944 (Foster, J.E. 1971). (It still exists now but in a neglected condition.)

In the United States smaller-scale laboratory studies on river channels began by the US Army Corps of Engineers in Vicksburg, Mississippi, in 1929. The first experiments, however, only modelled the origin of a meandering thalweg instead of a meandering channel (a famous example being Friedkin, J.F. 1945). A later recognition that pattern changes occur rather abruptly in rivers in the course of a punctuated evolution and are driven by channel gradient and the mode of sediment transport (Leopold, L.B. and Wolman, M.G. 1957; Schumm, S.A. and Khan, H.R. 1972; Miall, A.D. 1996). These led to experiments where gradient and sediment supply were changed, while water discharge was kept constant, and parameters like channel width/depth ratio, mean current velocity, bedload discharge and concentration, shear and Froude number were recorded (Schumm, S.A. 1973). The morphodynamics, particularly the depositional activity of braided rivers have been intensively studied in experiments (e.g. Ashworth, P.J. *et al.* 1994).

In fluvial geomorphology the second half of the 20th century was a period of identification of important thresholds. Such are the critical channel gradient values which separate straight, meandering and braided channel patterns – a major issue in fluvial geomorphology of the 1970s (Schumm, S.A. and Khan, H.R. 1972; Schumm, S.A. 1973; Brotherton, D.I. 1979).

The importance of bank strength was also recognised in determining channel pattern (Kleinhans, M.G. 2010), rivers with stronger (often vegetated) banks being narrower and deeper, and alternate bars common in their channel. Although it is widely accepted that bank-erosion rate and floodplain sedimentation, influenced by more complicated factors than just channel flow and sediment transport (Friedkin, J.F. 1945; Fraselle, Q. *et al.* 2010), are extremely difficult to scale (Ashworth, P.J. *et al.* 2004), it is also noted that even small-scale experiments adequately reproduce spatial patterns and the natural system dynamics (Paola, C. *et al.* 2009).

The importance of sediment transport was also recognised internationally (Ferguson, R.I. 1987) and in Hungary, too. In 1951 László Kádár began to set up a flume at the Kossuth Lajos University of Debrecen, Hungary, to study fluvial geomorphological processes and drew attention to the part sediment transport plays in the (trans)formation of channel patterns. On the basis of the visual observations made in the flume, he published papers (Kádár, L. 1954, 1955, 1969), where he presented a geomorphologically more consistent picture of meandering than it was usual at the time when the "theory of types of river reaches", borrowed from Germany, prevailed (Sipos, Gy. and Kiss, T. 2008).

In Hungarian water engineering model experiments started in 1928, when Sándor Rohringer installed a hydraulic laboratory of 670 m^2 area at the Department of Water Construction, Budapest Technical University. The aim of the first experiment was to investigate the hydraulics of the Danube channel at the artificial cut-off of Bogyiszló (Sárköz, South Hungary) (Fejér, L. 2001). In 1967 the Research Institute for Water Resources Management (VITUKI) established a hydrological model at the village Nick (Pannonhalmi, M. 2004). A flume of 40 × 6 m size supplemented with a glass channel 15 m long and 0.5 m wide was built to model a section of the Rába River. The experiments were conducted with the purpose of modelling meander shifts and the impacts of river regulation and served the basis for 48 river regulation proposals. However, the modelling of sediment transport was not satisfactory. After 2007 the facility was not used.

The largest physical model in Hungary served the checking of the rehabilitation plans for the Danube floodplain in the Szigetköz after the construction of the Bős (Gabčíkovo) Barrage and diversion of the main channel in 1992. The upper Szigetköz section of the Danube (from Dunakiliti to Dunaremete) was modelled at 1:500 scale, while the lower (from Dunaremete to Medve) at 1:700 scale in the Ecopark of Dunasziget. The impacts of river regulation are also reconstructed through the use of physical models (see e.g. Kornis-Akantisz, Zs. 1977).

Flume parameters

The new flume of the University of Pécs is intended both for educational and research purposes (*Photo 1*). It was designed by experts of the Department of Physical and Environmental Geography, Institute of Geography, and the Department of Mechanical Engineering, Pollack Mihály Faculty of Engineering and Informatics, University of Pécs, in 2012. The technical documentation, manufacturing and installation was the responsibility of the CsavarKONTROLL 2004 Ltd.

The versatility of the flume is demonstrated by its technical parameters, which are the following:

- size: 4.2 × 2.5 m;
- maximum fill weight: 2,500 kg (wet sediment in 150 mm depth);
- maximum tilting: around longitudinal axis: ±7.5, around transversal axis: +10;
- adjustable parts: 6 sections can be moved vertically ±120 mm at 10–200 mm per day speed;
- lateral deformation: possible through the displacement of 4 pushblades to the extent of 100 mm;
- closed equipment, water and sediment can only leave it through the sink.

Photo 1. View of the PTETHYS flume before installation

All motions in the flume are executed by computer-governed electro-engines. The speed of movements allows the modelling of both very slow and rather rapid changes. The rate of motions is checked by Leica Disto D3a BT laser meters (automatic feedback through Bluetooth).

Discharge is regulated through a 1-m-high water column, adjusted automatically to the position of the table. Water is recycled by a pump system.

The processes are detected through two devices. On the one hand, detailed picture information is collected and all physical parameters of the processes taking place in the flume are recorded by the use of eight Canon EOS 1100D cameras (*Photo 2*). The cameras are fixed on a system of cantilevers at 30 cm distance from each other and at 1.2 m height above bed. At 18 mm focal length the overlap between photographs is ca 80%, which allows 3D imaging. The cameras are connected to the PC and governed by a software of author's design.

In addition to the photographic cameras, a VarioScan 3021 ST type thermal camera is also used to establish the actual position of flowing water, the configuration of active channels, current velocity and the horizontal distribution of sediment fill saturation. The observation province of the thermal camera is between 8 and 12 μm and its thermal resolution is ±0.03 K.

Since the moisture content of the modelling medium (sediment) of the flume is of utmost importance from the point of view of fluvial processes, the moisture content is recorded at several depths by sensors of Decagon 10HS TDR system and the data are stored by Decagon EM50 data loggers.

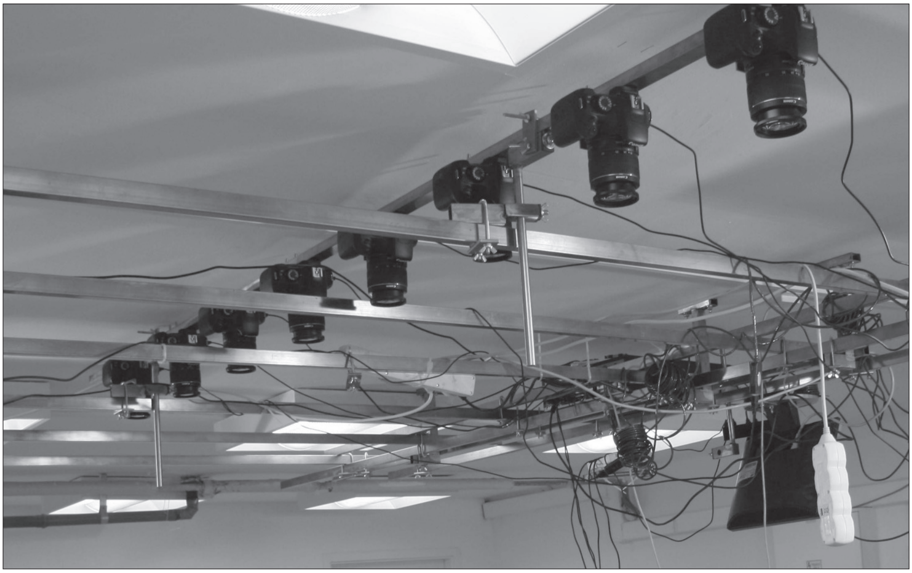

Photo 2. The cameras installed to record geomorphic processes

The material used for the sediment fill is also carefully designed and manufactured particularly for this purpose. The colours of grains indicate grain size and density: coarse grains (1.0 and 0.8 mm diameter) are ground basalt and andesite of grey and black colour, while the 0.6 mm diameter grains are of red marble and those of 0.2 mm diameter are of beige limestone.

The functions of governing flume position on the one hand and imaging and data logging on the other are shared between different computers. For imaging an Asus P9X79 PRO computer with Intel Core i7–3820 processor and nVidia GTX 660 Ti video card is applied. The operating system and processing is based on two Samsung 250 GB SATA3 2.5″ Basic (MZ–7TD250BW) SSDs, while data are stored by Seagate Barracuda 3 TB 64 MB 7,200 rpm SATA3 3.5″ (ST3000DM001) HDDs.

Image processing of stereo pairs and the representation of topography is performed by Agisoft StereoScan program. For the interpretation of the DEM and detection of processes ArcGIS 10.2.1 software is available.

Possible applications

The objective of the first experiment with the new flume was to find out how reliably the development of channel patterns can be modelled. The flume was filled with material of 8 cm depth and tilted at 5 degrees (~0.087). Imaging interval (both photographic and thermal) was set to 30 seconds.

Preliminary wetting was applied to reach 40 percent of the saturation moisture content all over the experiment area. In order to trigger and accelerate the process of channel incision a longitudinal groove of ca 2 cm depth was "burned" into the sediment surface. Previous observations showed that in lack of such an intervention, no collection of runoff into a channel would take place within an acceptable time span.

To identify active channel flow and current velocities, boiling water was conducted in pulses into the flume and its motion was detected by the thermal camera. The resulting channel cross-sections and sediment transport were studied in 3D images.

Braided channel evolution

Since Schumm, S.A. and Khan, H.R. (1972) found that channels above 0.016 gradient form a braided pattern, it was expected that such pattern will be the outcome from the first experiment (*Figure 1*).

In the non-cohesive material increasing discharge led to gradually broadening channels, providing space for more and more bifurcations

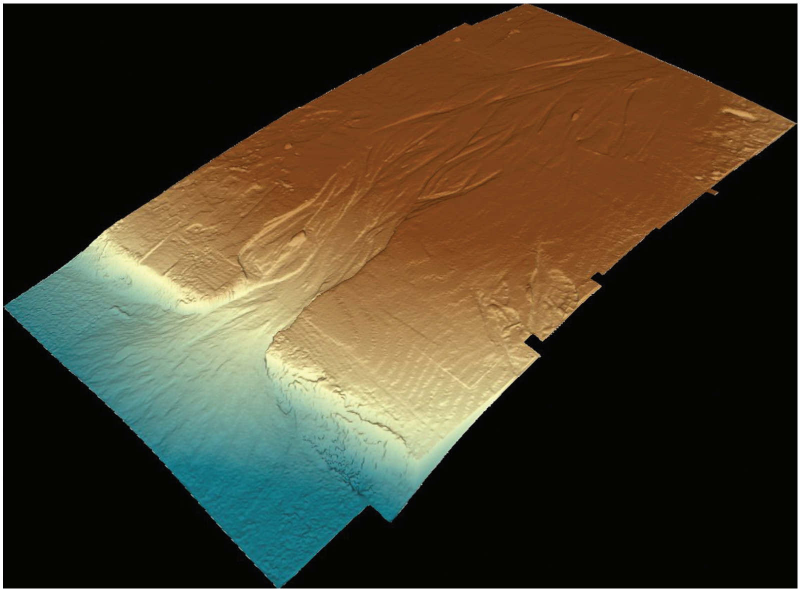

Fig. 1. The braided channel pattern generated in the first experiment

and the building of bars of various types. Thus, all the main morphological requirements for braiding were fulfilled. Since the banks are easily erodible, channel width remarkably fluctuates, but the width/depth ratio remains high throughout. During the experiment the following partial processes could be visually identified:

– channel widening through bank erosion;

– lateral bar accumulation;

– transverse bar accumulation and the resultant diversion of the thalweg;

– occasional reduction in the plan curvature of the thalweg, resulting in channel widening;

– emergence of bifurcations and mid-channel bars at regular distance from each other in broader channel sections;

– alternating cut and fill along the thalweg, which leads to a continuous displacement of braids, a dynamic rearrangement of pattern.

The observed channel evolution corresponds to the observations by Bertoldi, W. *et al.* (2001). The braided sections were locally replaced by anastomosing reaches, where the following partial processes were clearly visible:

– with widening channel and lowering water level, some bars rise above the general surface as more stable "islands";

– the distributary channels bordering islands are very shallow just downstream the bifurcation and only convey water at high water stages ("floods");

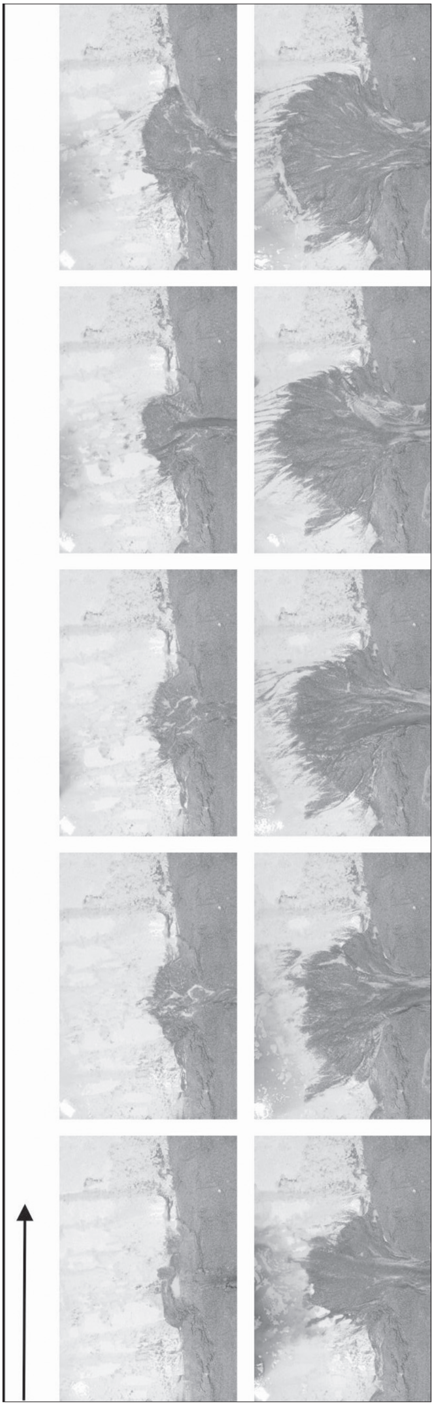

Photo 3. Stages of delta formation in the second experiment

– bifurcations are gradually replaced by avulsions (more permanent displacements of channel) where sediment accumulation is rapid, the distributary channels will acquire a slightly convex longitudinal profile;

– avulsions are concentrated where bank erosion is not particularly efficient since the banks are relatively stable but breach abruptly when reaching a threshold.

Comparing these observations with some descriptions of field studies (e.g. Miller, J.R. 1991), remarkable resemblances are seen. The development of avulsions is of great practical significance as far as flood hazard is concerned.

Due to the tilting function of the flume, the adjustable channel gradient allows the experimental establishment of further thresholds, e.g. between meandering and braided river behaviour (Parker, G. 1976; Püspöki, Z. *et al.* 2005). Its significance is underlined by recent papers, where the challenge of physical modelling of meandering river behaviour is pointed out (van Dijk, W.M. *et al.* 2012).

Delta formation

Another experiment proves that the equipment is suitable for the modelling of delta formation (*Photo 3*). Flume observations show that delta accumulation is composed of the following partial processes:

– the surface of the fan is continuously raised by accumulations by the main channel, which is continuously wandering and deposits large amounts of sediment;

– the main channel is affected by repeated avulsions and shifts to the lowest-lying zone of the delta fan;

– if water discharge increases, vertical accretion also raises the level of inter-channel surfaces.

Similar channelisation, avulsion and backward sedimentation processes on deltas of homogeneous material were found during experiments in the Netherlands (Van de Lageweg, W. 2013).

Flood modelling

In addition to in-channel geomorphic processes, overbank erosion and deposition can also be included among the objectives of physical modelling. This presupposes of creating an exact replica of the floodplain surface. The previously applied GIS-based modelling of flood hazard (e.g. Czigány, Sz. *et al.* 2011) can be supplemented by flume experiments locating the potential sites of dyke breaches and avulsions as well as the predictable extent of floodplain inundation. If the boundary conditions leading to river flooding are exactly defined during the experiment, first of all, local flood hazard (Lóczy, D. *et al.* 2009) can be precisely determined. The morphometric indices derived from the experiments are useful for estimating local flood hazard along channelized rivers and designing the necessary flood-control measures.

Floodplain rehabilitation planning

Through modelling channel migration and the related deposition processes, flume experiments are a potentially useful tool for reconstructing historical floodplain evolution under natural and human-induced conditions. Their advantages over field data are the opportunity to set both initial and boundary conditions and the much faster operation of processes. With appropriate monitoring technology, morphological changes and the resultant architectural elements can be recorded without intervention into the processes.

Channel evolution observations may be the starting point for the reconstruction of long-term floodplain evolution (Pizzuto, J.E. 1987; Bathurst, J.C. *et al.* 2002; Sellin, R.H.J. *et al.* 2003; Van Dijk, W.M. *et al.* 2013). In the flume the rate of sediment exchange between the main channel and distributaries can be measured and deposition patterns on the floodplain demonstrated. From data on natural floodplain evolution and human-influenced processes in the floodplain, the measures necessary to create conditions under which the ecosystem functions of floodplains are optimally fulfilled (i.e. floodplain rehabilitation) can be derived.

Similarity scaling

Until very recently physical models had been treated as analogue systems in comparison to real-world fluvial systems. Thus, the results of the experiments only allowed qualitative analyses of processes and the resultant landforms. Modern technology developed for the documentation of experimentation outcomes (e.g. DEM representation of high spatial resolution and digital photography of high temporal resolution) makes measurements and quantitative assessment possible.

A major problem in the quantitative interpretation of the processes recorded in flume experiments is seen in the spatial and temporal scaling. For scaling a set of rules have been established but not yet convincingly checked (Kleinhans, M.G. *et al.* 2010). The complexity of scaling to achieve similarity is addressed by numerous authors (see Paola, C. *et al.* 2009). Hydraulic scaling involves similarity in flow criticality (Froude number), current velocity, turbulence (Reynolds number), surface tension effects and bed roughness, while sediment-transport similarity refers to sediment mobility (Shields number), shear stress, particle size (Reynolds particle number) and suspended sediment (which is again the function of turbulence). We can also mention morphological similarity, i.e. the cumulative effect of width-to-depth ratio, channel bar dimensions and wavelength, transverse bed slope and other morphological parameters. Most of the above scaling factors have a temporal aspect, too, which also has to be considered.

A task of future research is to further develop the scaling rules in order to produce realistic and meaningful morphodynamics and stratigraphy (Van de Lageweg, W. 2013).

Acknowledgements: The project was partially financed from TÁMOP/SROP-4.2.2.C-11/1/KONV-2012-0005 (Well-being in the Information Society) and by the Hungarian National Scientific Research Fund (OTKA, contract number K 104552).

REFERENCES

Ashworth, P.J., Best, J.L. and Jones, M. 2004. Relationship between sediment supply and avulsion frequency in braided rivers. *Geology* 32. 21–24.

Ashworth, P.J., Best, J.L., Leddy, J.O. and Geehan, G.W. 1994. The physical modelling of braided rivers and deposition of fine-grained sediment. In *Process Models and Theoretical Geomorphology*. Ed. Kirkby, M.J., Chichester, Wiley, Chichester. 115–139.

Bathurst, J.C., Benson I.A., Valentine, E.M. and Nalluri, C. 2002. Overbank sediment deposition patterns for straight and meandering flume channels. *Earth Surface Processes and Landforms* 27. 659–665.

Bertoldi, W., Tubino, M. and Zolezzi, G. 2001. *Laboratory measurements on channel bifurcations.* Trento, University of Trento, Trento. 10 p. http://www.ing.unit.it/~bertoldiw_Laboratory_measurements_on_channel_bifurcations.pdf

Brotherton, D.I. 1979. On the origin and characteristics of river channel patterns. *Journal of Hydrology* 44. 211–230.

Czigány, Sz., Pirkhoffer, E., Nagyváradi, L., Hegedűs, P. and Geresdi, I. 2011. Rapid screening of flash-flood-affected watersheds in Hungary. *Zeitschrift für Geomorphologie* 55. Supplementary Issue 1. 1–13.

Fejér, L. 2001. *Vizeink krónikája* (Chronicle of our waters). Budapest, Vízügyi Múzeum, Levéltára, Budapest. 307 p. (in Hungarian)

Ferguson, R.I. 1987. Hydraulic and sedimentary controls of channel pattern. In *River channels: environment and process*. Ed. Richards, K.S. Oxford, Blackwell, Oxford. 125–158.

Forster, J.E. 1971. History and description of the Mississippi Basin Model. *MRM Report* 1–6. 115–126.

Fraselle, Q., Bousmar, D. and Zech, Y. 2010. Experimental investigation of sediment deposition on floodplains. In *River Flow 2010.* Eds. Dittrich, A., Koll, Ka., Aberle, J. and Geisenhainer, P. 8–10 September 2010, Braunschweig, Germany. Bundesanstalt für Wasserbau, Karlsruhe,. 823–830.

Friedkin, J.F. 1945. *A laboratory study of meandering of alluvial streams*. Vicksburg, MS., US Army Corps of Engineers Waterways Experiment Station, 40 p.

Kádár, L. 1954. Az eróziós folyamatok dialektikája (Dialectics of erosion processes). *Közlemények a Debreceni Kossuth Lajos Tudományegyetem Földrajzi Intézetéből* (Papers of the Institute of Geography, Kossuth Lajos University of Debrecen) 18. 1–20. (in Hungarian)

Kádár, L. 1955. Das Problems des Flussmäander. *Közlemények a Debreceni Kossuth Lajos Tudományegyetem Földrajzi Intézetéből* (Papers of the Institute of Geography, Kossuth Lajos University of Debrecen) 21. 1–24.

Kádár, L. 1969. Specific types of fluvial landforms related to the different manners of load-transport. *Acta Geographica Debrecina* 8–9. 115–178.

Kleinhans, M.G. 2010. Sorting out river channel patterns. *Progress in Physical Geography* 34. 287–326.

Kleinhans, M.G., Van Dijk, W.M., Van de Lageweg, W.I., Hoendervoogt, R., Markies, H. and Schuurman, F. 2010. From nature to lab: scaling self-formed meandering and braided rivers. In *River Flow 2010*. Eds. Dittrich, A., Koll, Ka., Aberle, J. and Geisenhainer, P. 8–10 September 2010, Braunschweig. Vol. 2. Karlsruhe, Bundesanstalt für Wasserbau, Karlsruhe. 1001–1010.

Kornis A.-né Akantisz, Zs. 1977. Mozgó medrű folyószabályozási kisminta-kísérletek (Model experiments for river regulation with moveable bed). *Hidrológiai Közlöny* 12. 546–553. (in Hungarian)

Leopold, L.B. and Wolman, M.G. 1957. River channel patterns: braided, meandering, and straight. *US Geological Survey Professional Paper 282-B*. Washington, D.C.

Lóczy, D., Kis, É. and Schweitzer, F. 2009. Local flood hazards assessed from channel morphometry along the Tisza River in Hungary. *Geomorphology* 113. 200–209.

Miall, A.D. 1996. *The geology of fluvial deposits: sedimentary facies, basin analysis, and petroleum geology*. New York, Springer, 582 p.

Miller, J.R. 1991. Development of anastomosing channels in south-central Indiana. *Geomorphology* 4. 221-229

Pannonhalmi, M. 2004. A nicki kisminta kísérleti telep története, jelenlegi állapota. (History and presend-day state of the hydraulic model at Nick). Presentation at the Annual Meeting of the Hungarian Hydrological Society, Győr, 18 May 2004. (in Hungarian)

Paola, C., Straub, K.M., Mohrig, D.C. and Reinhardt, L. 2009. The "unreasonable effectiveness" of stratigraphic and geomorphic experiments. *Earth-Science Reviews* 97. 1–43.

Parker, G. 1976. On the cause and characteristic scales of meandering and braiding in rivers. *Journal of Fluid Mechanics* 76. (3): 457–480.

Pizzuto, J.E. 1987. Sediment diffusion during overbank flows. *Sedimentology* 34. 301–317.

Püspöki, Z., Szabó, Sz., Demeter, G., Szalai, K., McIntosh, R.W., Vincze, I., Németh, G. and Kovács, I. 2005. The statistical relationship between unconfined compressive strengths and the frequency distributions of slope gradients: A case study in northern Hungary. *Geomorphology* 71. (3–4): 424–436.

Schumm, S.A. 1973. Geomorphic threshold and complex response of drainage systems. In: *Fluvial geomorphology.* Ed. Morisawa, M. Binghampton Publications in Geomorphology 3. 299–310.

Schumm, S.A. and Khan, H.R. 1972. Experimental study of channel patterns. *Geological Society of America Bulletin* 83. 1755–1770.

Sellin, R.H.J., Bryant, T.B. and Loveless, J.H. 2003. An improved method for roughening floodplains on physical river models. *Journal of Hydraulic Research* 41. (1): 3–14.

Sipos, Gy. and Kiss, T. 2008. A medermintázatok értelmezése Kádár László kutatásainak fényében (Explanations of channel patterns in the light of László Kádár's investigations). In *Geographia generalis et specialis*. Eds. Szabó, J. and Demeter, G. Debrecen, Kossuth Egyetemi Kiadó. 49–54. (in Hungarian)

SZITE 2007. *Javaslat a Szigetköz–Csallóközi hullámtéri mellékágrendszer többcélú rehabilitációjára* (Proposal for the multi-purpose rehabilitation of the Szigetköz–Csallóköz by-channel system in the active floodplain). Szigetközi Természetvédelmi Egyesület (Szigetköz Association for Nature Conservation), 28 p. (in Hungarian) http://www.szite.hu/hun/duna_rehabilitacio.html

van de Lageweg, W. 2013. *Morphodynamics and sedimentary architecture of meandering rivers*. PhD Thesis. Utrecht, Utrecht University, Faculty of Geosciences, Department of Physical Geography, Utrecht. 159 p. http://about.me/wietsevandelageweg

van Dijk, W.M., van de Lageweg, W.I. and Kleinhans, M.G. 2012. Experimental meandering river with chute cutoffs. *Journal of Geophysical Research* 117. F03023, doi:10.1029/2011JF002314.

van Dijk, W.M., van de Lageweg, W. and Kleinhans, M.G. 2013. Formation of a cohesive floodplain in a dynamic experimental meandering river. *Earth Surface Processes and Landforms* 38. (13): 1550–1565.

Hungarian Geographical Bulletin 63 (4) (2014) 437–456.
DOI: 10.15201/hungeobull.63.4.5

The rehabilitation of former Soviet military sites in Hungary

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Abstract

This paper focuses on the current status and future possibilities of the regeneration of former Soviet military sites in Hungary. As part of our research a nationwide survey was conducted in order to determine the location, size and present function of such military sites. In addition, empirical research was carried out in six selected medium size cities (county seats). After the introduction of our methodology, the paper briefly presents the state-of-the-art of research on brownfield sites in Hungary, subsequently, the results of our survey are introduced. On the basis of the analysis, we discuss the following aspects: factors of successful rehabilitation and factors that – against the expectations – did not contribute to the quick and successful renewal of these urban sites.

Keywords: brownfield regeneration, rehabilitation of military sites, Soviet military sites, functional conversion, Hungary

Introduction

Similarly to other post-socialist countries, after the change of regime, industrial and military sites have become excessively underused in Hungary (Woodward, R. 2004; Spyra, W. and Katzsch, M. 2007). This was caused by various reasons e.g. by the fall in industrial production, the restructuring of the military system and the withdrawal of the Soviet troops. These areas have often become brownfields, and only a few of them have been converted to permanent use until most recently. Even though the Hungarian Academy of Sciences has already conducted general brownfield researches in Hungary, little information has been made available so far regarding the civil use, the new functions and the rehabilitation of Soviet military sites.

In the last twenty years, the transformation of military sites in Hungary remained limited, not least because the rehabilitation of these sites did not

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have high priority in urban regeneration policies. This can be partly explained by the fact that EU and Hungarian policy documents for regional and urban development apply a relatively narrow interpretation of brownfield territories. The category of *brownfield* includes mainly urban areas previously utilised for industrial and mining purposes, whereas former military sites and areas abandoned by traffic are generally not included. The EU has supported the utilisation of former industrial (mining) and military brownfields by various initiatives and programs (Ferber, U. *et al.* 2006; Grimski, D. and Ferber, U. 2001; Kádár, K. 2009; Kälberer, A. 2005). However, Hungary could not essentially receive funds from the sources for the conversion of military areas.

In this study the conversion of Soviet military sites in Hungary and its obstacles are discussed. First we briefly introduce our research methodology and the problems related to brownfields. Then the history of the occupation of Hungary by Soviet troops and their withdrawal is summarised. In the analytical part the typical types of the former Soviet military sites and the results of our empirical research conducted in six Hungarian county seats are presented. On the basis of empirical research we want to highlight the new functions that the former military sites gained after the withdrawal of Soviet troops and their underpinning factors.

Research methodology

Information on military sites is difficult to acquire even today as there was no systematic data collection in the field and authorities possessing such information are difficult to approach. Therefore, a significant number of former Soviet military sites have been omitted from Hungarian documents aiming at mapping brownfields and analysing their utilisation. Similarly, documents of urban development (e.g. ICDS – Integrated City Development Strategy, economic development programs, e.g. Euró-Régió 2008. – HHP Contact, 2008) list only some of the former Soviet and Hungarian military sites.

The information about the exact location and size of former Soviet sites in scientific publications or internet websites is also quite poor. Either incomplete information or only data on special segments of the problem are available (e.g. Nagy, Á. 2003; IUCN 1996). Therefore, during our research first we had to perform own data collection through fieldwork, interviews and analysis of secondary data derived from archives and scientific literature (Altman, J. *et al.* 1998; Barta, Gy. 2007; Csapody, T. 2000; Csendes, L. 1998a,b; Győri, R. 2006; Nagy, Á. 2003; Ránki, Gy. 1976; Sági, J. 2006). After the careful analysis of available publications we carried out empirical research in the county seats using different types of questionnaires. In addition we made interviews at the local government offices with the senior architect or his/her fellow-workers. Through questionnaire survey we could collect information about the rehabilitation of military barracks in the Hungarian county seats.

Due to the lack of necessary information some sites were assessed through on-site surveys. Based on the acquired data a map was prepared illustrating the locations of the Soviet garrisons all over the country. We also assessed the changes in the use and functions of the former Soviet sites, which is the first comprehensive analysis of all former Soviet military sites in Hungary. As a part of our research, another type of questionnaire was sent out to all concerned local municipalities. The questionnaire survey revealed that information is available only for about 55 percent of all the sites. It is not surprising that different institutions and organisations lack relevant information in Hungary since the location, the capacity and the functions of Soviet (and also Hungarian) military sites were top secret before the change of regime.

Challenges of brownfield areas in Hungary

Due to deindustrialisation a significant amount of brownfield lands have been produced in Europe since the 1960s and 1970s. After the collapse of communism deindustrialisation also speeded up considerably in post-socialist cities as part of economic restructuring (*Photo 1*). Problems of brownfield areas have

Photo 1. Brownfield area in the Hajógyár Island, Budapest. *Source*: internet

been aggravated by former military and transport properties becoming empty both in Western and Eastern Europe (Oliver, L. *et al.* 2005; Lux, G. 2009; Barta, Gy. 2002; Erdősi, F. 2009; Kádár, K. 2011a).

The Centre for Regional Studies of the Hungarian Academy of Sciences defined in a seminal volume that brownfields are ex-industrial areas that are not used efficiently (underutilised) and are occasionally vacant (Barta, Gy. 2004). Also the under-utilised or abandoned railway areas and the vacated military sites fall under this definition. Brownfield areas have negative effects on their environment, the surrounding communities, and their utilisation is also difficult. Their successful rehabilitation may contribute to increasing urban competitiveness, the improvement of the quality of urban life and it can decrease the crowding of cities (Barta, Gy. 2003; Janin, C. and Andres, L. 2008).

The EU does not have exact data on the size of brownfield areas inside the European Union, basically due to the lack of consistent terminology. The Eurostat has not either published any information concerning the topic (until the end of 2010), although several programmes have been initiated in the last decades to handle the problem. Even though we do not have exact data, the survey of Ferber, U. *et al.* (2006) has revealed that approximately 1 million hectares of brownfield lands are to be found in 11 EU countries.

Since the change of regime new enterprises in Hungary have primarily preferred greenfield investments, meaning that the investments were mostly realised on vacant areas withdrawn from agricultural production (Győri, R. 2006). This is due to the fact that greenfield investments have been more cost-effective in Hungary than brownfield investments, since in the latter case some surveying, environmental release, demolition, cleaning and renovation or preservation of the existing buildings (e.g. having industrial historical significance) are necessary.

Successful brownfield regenerations of the last twenty years have been concentrated mainly in inner city areas in Hungary (Barta, Gy. 2002). The demand for land has been lower in the countryside, in former industrial or suburban areas. The analysis of greenfield and brownfield investments in regional centres shows that the possibilities of brownfield area development were not at all exploited by cities mainly due to the nearly unlimited amount of greenfield lands (Győri, R. 2006). However, in order to promote sustainable development, reutilisation of brownfields must be coupled with incentives, land-use policies and regulations that encourage investors to choose brownfield areas over greenfield locations. The goal is to maintain compact city land-use by enhancing the recycling of run-down and unused areas within cities and retaining green spaces that prevent settlements from urban sprawl. The unregulated development of greenfield sites decrease the share of green areas and other recreational functions and may decrease the ratio of areas that can be utilised in the future.

Former Soviet military sites in Hungary

The aim of this study is to present the state of the art of rehabilitation of the former Soviet military areas in Hungary, as special segments of brownfield areas. The main difference between military brownfield areas and others is that their functional change does not stem from economic reasons or structural changes, but from political reasons. After the Cold War large scale military areas became evacuated and abandoned both in the countries of the NATO and the Warsaw Pact, as a consequence of the change in the global geopolitical system, and the subsequent the withdrawal of the American and Soviet troops. The evacuation was not only the consequence of consolidation and arms reductions: in some countries also the accession to the NATO resulted in the closure of several military and strategic facilities used previously by the national armies (Altman, J. *et al.* 1998). Some of them were passed into the ownership of local municipalities; others became the propriety of public institutions or churches, and the remaining part, whose renovation was the fastest, got into private ownership.

The rehabilitation of unused military areas caused a problem not only in countries of the former communist bloc, struggling with the lack of finances, but also in the wealthier Western European states. That is why more initiatives were launched in the EU in the last decade focusing especially on the rehabilitation and functional change of brownfield territories including military areas.

In the literature and internet sources we mainly find information about the conversion of former military sites of NATO member states. Information regarding the transformation of Soviet military sites in former state-socialist countries is scarce. Rare exceptions are the Soviet military sites in the former GDR, and especially in Brandenburg region, which was severely affected by the occupation of the Soviet army. After the withdrawal of Russian troops Brandenburg had to deal with the rehabilitation of several hundreds of polluted and abandoned sites (Kádár, K. 2009; Ganser, R. and Williams, K. 2007; Vogt, R. 2006; Millar, K. 2003; Kälberer, A. 2005).

The geographical distribution of Soviet troops in Hungary before 1991

Soviet troops invaded Hungary during World War II in autumn 1944 (*Photo 2*) and they left the country after 47 years in June 1991. Very little information is available about the military and political reasons for placing Soviet military sites into certain cities in Hungary. Data are mostly available about the Hungarian army and its restructuring, and these are to be found in the Institute and Archives of Military History.

Photo 2. Soviet troops crossing the Tisza river in 1944. *Source*: internet

In the first phase of withdrawal the Soviet Army withdrew 22 troops from Hungary: an armoured troop, a descent storming battalion, a chemical protection battalion, a military officer training school and other units (Homor, Gy. 2009; Horváth, M. 2003; Kádár, K. 2011b). The number of soldiers stationed in Hungary was decreased by 10,000 soldiers and 4,000 civilians also left the country.

After this first step 11 garrisons and several accommodation buildings got into Hungarian ownership. According to the information by colonel-general Burlakov, the accommodation buildings measured 950 hectares overall. Besides this, there were 850–900 flats, 19 military quarters, 13 canteens, 200 vegetable stores, depositories and other areas. 400 sites out of these had been built by the Southern Group of the Red Army (Veszprém Megyei Napló, 1989).

On *Figure 1* we indicated the settlements where Soviet military sites were operating between 1945 and 1990 according to the available documents. Every settlement is indicated by a point independently from the number of sites and the size of the garrison. The number of garrisons whose activity had been ceased before 1990 is 30. Altogether there are at least 108 known settlements in the country where Soviet soldiers have stationed up to the change of regime (Homor Gy. 2009; Institute and Archives of Military History 2006)[2].

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[2] If we take into account neighbouring settlements where the boundaries of Soviet garrisons expanded, 13 more settlements can be added to the list.

Fig. 1. Soviet military presence in Hungary, 1945–1991. Ed. by the author. Cartographic design: Szám-tér-kép Bt.

The map clearly shows that the presence of Soviet military forces affected most intensively Central Transdanubia and Central Hungary (Budapest and Pest county) and it was least dominant in Southeast Hungary. The border zones with former Czechoslovakia and the Soviet Union (Ukraine) in Northern Hungary, with Romania in Eastern Hungary, and with Yugoslavia in the South were also sparsely settled by the Soviet Army. However, higher concentration of Soviet military sites could be recorded around Debrecen. In Southeast Hungary the Soviets troops stationed only in four cities, in Kecskemét, Szolnok, Békéscsaba and Szeged. Other large areas like the *Jászság* or the region around the Lake Tisza remained vacant.

The occurrence of Soviet garrisons and sites is surprisingly dense in other areas of Hungary, for example in the area of Balaton Highlands and Székesfehérvár and its surroundings, around the middle part of the Danube (e.g. Dunaföldvár, Paks and Kalocsa), the Western part of Pest county and the environs of Gerecse and Vértes mountains (e.g. Komárom, Tata, Tatabánya, Oroszlány etc.) The Soviet forces appeared in several settlements along the Danube, whereas their presence concerned far fewer settlements in the Eastern part of the country, i.e. the region between the Danube-Tisza Interfluves than in Transdanubia.

The surveying and the estimation of environmental damages left behind by the Soviet troops had started before the complete withdrawal of all Soviet troops (Nagy, Á. 2005). Experts considered soil and water pollution by carbon-hydrogen the most severe. Furthermore, the amount of communal, operational and constructional waste stored up in accommodation buildings could be regarded significant. More surveys and environmental tests of former Soviet properties have been conducted since 1990 (IUCN 1996, VITUKI 2005). For the sake of damage elimination and the installation of the planned monitoring systems, a list of liabilities for environmental remediation was made regarding the properties belonging to State Privatization and Holding Company (ÁPV Rt.).

Based on government decrees, the environmental status surveys of former Soviet sites were conducted by the state. Within the scope of a midterm programme for eliminating the caused environmental damages, the most significant damages had to be prevented. As a result of the ÁPV Rt. launched "Former Soviet Real Estate Programme" as part of the National Environmental Remediation Programme, there were examinations on 9 sites and there was technical intervention on 25 sites, while 3 sites were subject to monitoring (Almássy, E. 2002). Summarising the damage caused by the Soviets, the environmental and natural damage amounted to HUF 66 billion. 171 garrisons with 6,000 buildings, occupying 46,000 hectares of land in 340 settlements were claimed to be contaminated (*Photo 3*).

Different sources provide different statistics about the evacuated Soviet sites. According to Csapody (2000) the Soviet Army was stationing with

Photo 3. Former Soviet military flats in Szolnok (Photo: Kádár, K.)

around 55,000 soldiers and approximately 10,000 civilians on 288 sites, in 104 settlements of Hungary. Based on the research of the National Environmental Remediation Programme made by VITUKI Kht. (Nagy, Á. 2005) 171 former Soviet sites were found in the country. Homor (2009) mentions in his book that 100,380 Soviet citizens left the country, including 44,668 soldiers, leaving 94 garrisons vacant. In these garrisons 328 properties were used by the Soviets.

Based on our research it can be stated that the Soviet army used at least 342 sites during their stay between 1945 and 1990, in at least 108 settlements. 13 more settlements can be added to the list, which are smaller settlements neighbouring the core settlements of the garrisons, like Somogydöröcske near Igal, or Fertőendréd near Fertőd etc. Thus, the number of settlements where Soviet Army stationed may reach 121, which exceeds the data published so far.

The reutilisation of former Soviet properties

In 1990 new directives for utilisation of Soviet properties becoming vacant were worked out in Hungary, which was sent out to the presidents of the councils in each concerned settlement. Later in this year the committee supervising the withdrawal of Soviet troops and the committee coordinating the distribution of sites were contracted, and the new committee started the utilisation project according to the recommendations of the councils. Decision was made that those properties which were no subject of demand could be reutilised by the state. In these cases the Ministry of Interior negotiated with the Ministry of Welfare and the Ministry of Environmental Protection about the way of utilisation. In March 1991 the government announced that the reutilisation of the former Soviet properties would start in 14 settlements and the properties would be transferred to local the municipalities free of charge (Homor, Gy. 2009).

Utilisation was regulated by a government decree in 1992, which stated that utilisation became the responsibility of the Hungarian Property Management Organisation. The form of utilisation included the sale, the handing over free of charge, the leasing, the hypothecation and the passing over of the real estate to a company on the basis of the regulation. In the case of selling or leasing, the local municipality had the right of pre-emption or pre-leasing, however, the law stipulated that in the case of properties utilised by the Hungarian Property Management Organisation, the new owner was liable for environmental remediation, reutilisation and mapping. The properties could be utilised through an application or as a handing over free of charge. Plans for utilisation usually concerned the building of flats. This could be easily realised in the case of properties occupied by the Soviets but built by the Hungarians, however, properties built by the Soviets could be sold only following the signing of an intergovernmental agreement. Approximately 5 percent of Soviet sites got into the ownership and use of the Hungarian Army, and another part of them got into private ownership shortly after the evacuation – these were, on the one hand, buildings in adequate conditions that could be easily sold and cost-efficiently occupied, and on the other hand, areas that could be easily utilised for economic purposes. Based on their original functions the Soviet military sites could be divided into three groups (*Table 1).*

First the concerned settlements were contacted with a questionnaire in autumn 2011 in order to find out reuse of former Soviet site(s). Local municipalities could potentially give three answers concerning utilisation:

1. utilisation has already been finished,
2. it has partly been implemented,
3. it has not started yet.

The survey provided the following results: 61 local municipalities returned the sheet out of the 108 (56%). Based on the answers we could obtain information about 188 sites out of the 342. The answers partly showed that some of the municipalities did not even know about the fact that once a Soviet site was located on their territory. The reuse was already finished in 32 percent of the 188 sites; it was partly finished in 26 percent and was not started in 18 percent of them. Local authorities had no information about 24 percent of the sites. The latter included mostly training areas, bomber shooting fields, airfields and secret sites (e.g. bomb depositories).

Summarising the results, only about half of the municipalities taking part in the survey was able to handle properly the issue of reusing the former Soviet sites, in one way or another e.g. using them for public purposes, or selling them/handing them over to companies that could develop new functions for the sites. Large part of the former Soviet military sites did not go through any reutilisation, and the local municipality did not have among its priorities the functional change of these areas (*Photo 4*). However, it should also be noted that the latter category included mostly smaller settlements (villages or smaller towns) with excessive greenfield areas for new developments and limited financial resources for urban regeneration.

Table 1. Types of former Soviet military sites according to their previous functions

Features	Types		
	1. Residential buildings, offices, service facilities	2. Training, technical and storage edifices	3. Shooting fields, exercise areas, airfields
Public utilities	Yes	Depending on former functions	None
Chemical contamination or construction debris	No	Yes, but to a limited extent. Contamination is known.	Mainly yes and there can be undiscovered contamination.
Guarding	Yes	Yes	None
Communal waste	In traces	In traces	Illegal disposal – in large quantity
Location	Central or within city limits	Within city limits	Peripheral
Infrastructural facilities*	Good	Good, sufficient	Moderate
Extent of disorder and dereliction	Average	Average	Great
Opportunities for investment and utilisation	Average	Limited	Insignificant
Costs of investment**	Average	Average	Low*** or high****

*Pavements, roads, public lightening. **In the case of renovation and reconstruction compared to other properties on (non-brownfield) areas. ***No costs of demolition and renovation, the area can be obtained at pushed down price. ****In some cases the costs are increased by public utilities, installation of infrastructure and cleansing. *Source*: Compiled by the author.

Photo 4. The ruins of a former Soviet kindergarten in Székesfehérvár (Photo: Kádár, K.)

The estimated overall territory of the former Soviet military sites

On the basis of available information regarding the size of the former Soviet properties, we made estimations on their overall territory. Our results show that the overall territory of the 342 sites was approximately 27,000 hectares (some of these sites were divided into more parts with different functions) (*Table 2*).

Based on the data collected from local municipalities, 32 percent of all sites had been reused until 2011. Multiplying this data with the mean size (45.5 hectares) of the Soviet military sites calculated on the basis of the surveyed 122 sites, we can conclude that a total area of 5,551 hectares has been rehabilitated in the past 22 years. We identified 96 properties in Budapest and the county seats, which mean 30 percent of all sites. Most of them are located in Budapest (25), whereas Eger, Tatabánya, Kaposvár, Békéscsaba and Salgótarján had no Soviet military properties, while in Pécs, Miskolc and Szekszárd the former Soviet sites were transferred to Hungarian use at the time of the withdrawal of Soviet troops

According to available data and our estimations, around 30 percent (95–100) of the former Soviet military sites are located in the county seats in

Table 2. Number and size of former Soviet military sites in Hungary

Type	Number	Average size, hectare	Overall size, hectare	Ratio based on the number of sites, %
Firing positions	7	10.0	70.0	1.8
Camps	14	1.0	14.0	3.7
Accommodation buildings	98	20.0	1,960.0	25.9
Exercise areas	48	250.0	12,000.0	12.7
Elutriator stations	4	0.5	2.0	1.1
Shooting fields	24	250.0	6,000.0	6.3
Airports	22	150.0	3,300.0	5.8
Residential areas	19	18.0	342.0	5.0
Hostels, accommodation buildings	7	0.5	3.5	1.8
Radio-technical broadcasting stations	44	3.0	132.0	11.6
Schools, kindergartens	7	0.5	3.5	1.8
Magazines	39	73.0	2,847.0	10.3
Depositories	11	2.0	22.0	2.9
Hospitals	5	2.0	10.0	1.3
Offices	3	1.0	3.0	0.8
Fuel stations	8	28.0	224.0	2.1
Clubs	4	0.5	2.0	1.1
Other*	15	10.0	150.0	4.0
Total	379	45.5	27,085.0	100.0

*Beaches, plots, outdoor gym areas, holiday resorts, military roads, railways, etc. *Source:* Author's calculation.

Hungary. Half of these sites (47) are located in the county seats that were selected for further investigation (Szeged, Székesfehérvár, Debrecen, Szolnok, Győr and Kecskemét). The reasons for selecting these county seats are related to the dynamics of their development, the presence of complex urban development programmes, competences and – ideally – financial resources for urban regeneration programmes (Kádár, K. and Kozma, G. 2011). All types of Soviet military sites summarised in *Table 1* occur on their territory and a great number of new functions (institutional, cultural, commercial, residential, etc.) has appeared as an outcome of regeneration. This provided an excellent basis for a comparative analysis of several factors contributing to rehabilitation e.g. economic, social, architectural, and functional.

Factors determining the success of rehabilitation

Urban brownfield policy and its influence on regeneration

The question comes to the fore if the regeneration of Soviet military sites in the selected cities was influenced by the cities' brownfield policies after 1990. Three out of the six investigated cities (Szolnok, Szeged and Debrecen) have a strategy for decreasing the weight of greenfield investments and increasing the role of brownfield regeneration. However, the commitment to regeneration did not start immediately after the withdrawal of Soviet troops, but many years later, usually in the period of the elaboration of integrated urban development strategies. Therefore, it is utterly difficult to define how strong the influence of brownfield strategies on urban development policy was in the earlier period. Every city – independently from its brownfield policy – sold the major part of former Soviet military areas on favourable prices or supported the functional changes by other tools which finally led to the renewal of these areas. However, in the majority of cases re-investment was not resulted by the intervention of the local government, but by the favourable location of the area or the existing infrastructure.

Chances of residential and non-residential utilisation

In this section we focus on the residential and other, non-business utilisation of Soviet military sites. 18 percent of the Soviet military sites located in the six investigates cities have been reused for residential purposes. The question can be raised if these areas were transformed into residential function because of the growing population figures and new demand for accommodation, or due to other aspects related to economic and social reasons. The average population number of the six analysed cities was 131,887 in 1990, and 133,221 in 2011. Thus, the number of population did not change significantly in these cities during the last 21 years. The population number of Szeged, Kecskemét, Győr and Debrecen grew by a few thousands (mainly in Kecskemét, where the number of residents increased by 11,000, which means a 10% of growth). The population of Szolnok and Székesfehérvár decreased by a couple of thousands: in Székesfehérvár the population figure dropped by 5.4 percent and in Szolnok by 4.9 percent.

In the light of these figures it is strange enough, that the greatest amount of sites used for residential purposes (40%) is located in Szolnok, which is followed by Győr (35%). The changes in the number of population, therefore, does not seem to be related to the intensity of residential regeneration, which was more influenced by the growing demand for cheaper apartments for rent, flats with small floorspace (i.e. for young couples), and the suburban locations (e.g. in Szolnok, Debrecen, Kecskemét).

The demand for upmarket flats has grown since 2000, consequently some part of the old, tarnished buildings previously used for Hungarian military purposes have been converted to luxury flats in or close to the city centre locations (e.g. in Győr, which has the highest income per capita among the county seats). The area of demolished sites often proved to be suitable for new single family homes or villas (e.g. in Szolnok or Kecskemét) and subdivisions (e.g. in Győr) provided the area was not located far from the centre of the city. In Debrecen, the second largest city in Hungary, only 5 percent of the former sites were converted to housing, mostly some apartments located in the centre of the city. This could be the result of the fact that Debrecen has the greatest size of Soviet military areas and the largest part of it is the former Soviet military airport.

Besides entrepreneurial (commercial and manufacturing) and residential functions, the role of educational, recreational, administrative or public services in the regeneration of Soviet sites was also analysed. Considering the average value of the cities, 13 percent of the total area was converted to educational (cultural) functions and 21 percent to administrative-institutional functions. The educational-cultural function reached its peak in Kecskemét (16% of the sites) and the administrative-institutional function in Debrecen (30.7%).

Based on these findings we can draw the conclusion that the ratio of public institutions and educational-cultural functions on former military estates is high especially in those cities where the interest of private sector is low (Kecskemét and Debrecen). Secondly, in these cities there is a huge amount of other (non-brownfield) investment opportunities with lower investments costs. Thirdly, the intervention of private capital was also hampered by the fact that the sites of these cities comprised mainly large building complexes some of them with monument status which limited the possibilities of reuse and renovation.

Economic performance as factor of regeneration

According to economic indicators (e.g. foreign capital inflow, GDP per capita, number of economic organisations etc.) we set the following rank order among the six selected cities: 1. Győr, 2. Székesfehérvár, 3. Debrecen, 4. Szeged, 5. Kecskemét and 6. Szolnok. Based on our list one would presume that cities with stronger economic performance and more developed industry achieved better results regarding the regeneration of former Soviet military sites, and the utilisation of these sites for economic purposes is also more frequent.

In Győr and Székesfehérvár, the two most developed cities, the share of re-utilised sites is indeed high (100% and 90% respectively), however, in the latter case the share of the areas rehabilitated by the local government reaches 33.5 percent, which is only 4.8 percent in Győr and 18.2 percent in Debrecen. The major part of the rehabilitation projects was implemented during the initial period (between 1990 and 1995) only in Székesfehérvár, the majority of successful functional changes was realised in Győr in the beginning of 2000s and in Debrecen in the middle of the 1990s.

Out of the new functions the ratio of commercial, industrial and entrepreneurial functions reaches the highest ratio in Debrecen (62%), while in Győr and Székesfehérvár this ratio is lower (35% and 50%). Győr's good economic performance and favourable location in the country makes the city a favourable destination of international and domestic migration, contributing to a higher level of residential utilisation of former Soviet sites. On the other hand, the ratio of areas utilised for economic purposes is significant in Szolnok and Kecskemét (40% and 41%), which nearly reaches the figures of Székesfehérvár and Debrecen. In these two cities commercial utilisation plays a more important role (new functions as department stores, shopping malls and retail stores) than the reuse for industrial goals. Therefore, it has not been justified that the success of rehabilitation is mainly determined by the economic power.

The effects of EU funds obtained for urban rehabilitation and brownfield development between 2004 and 2011

All selected cities in our study received financial resources for urban rehabilitation from the EU during the previous and the present budget period, however, none of them received EU funds for the functional change of brownfield areas. Thus, considering the ratio of reutilising Soviet sites and the differences among the cities we could not take it in account as an advantage. EU funds for rehabilitation of Soviet sites either stem from an earlier period (e.g. in Szolnok and Debrecen funds from the PHARE program), or from other EU resources, e.g. from the European Social Fund. Accordingly, we draw the conclusion that EU resources for brownfield rehabilitation have not contributed to the renewal of any of the sites: firstly because the sites did not meet the conditions of application[3] secondly, the country could not even apply for monetary instruments for the rehabilitation of military sites[4].

Location within the city

According to our hypothesis sites with the best regeneration possibilities are located in the centre of the city and they are successfully reused. This is the

[3] In the Regional Operative Program 2.2. (2004–2006) the minimum size of territory for the application should have attained 40 hectares.

[4] Hungary could not apply for EU funds aiming at the conversion of military areas (CONVER, PERIFRA)

consequence of the increasing demand for both residential and business space in the inner neighbourhoods of larger cities. At the same time sites categorised as Type 1 and Type 2 in our *Table 1* are relatively easy to regenerate without significant previous cleaning and arrangement of the area (or demolition of the buildings located there). We suppose that the farther the territory is located from the centre of the city, the less intense its utilisation could be. These sites are hard to regenerate not only due to their location but also their maleficent and poor infrastructure, inadequate condition of buildings.

Available data confirm our initial hypothesis, as unutilised sites situated within the city borders makes up on average only 11 percent of the total territory of Soviet military sites. In three of the cities (Győr, Szolnok, Szeged) there are no unutilised sites, in the other cities their share is between 15 and 20 percent. Altogether 20 sites are located in the suburbs or outside the city limits and the intensity of their reuse varies greatly among the cities (0% in Szolnok, 15% in Szeged, 45% in Debrecen, 76% in Kecskemét and 75% in Székesfehérvár). (Győr does not have such sites.) The high value is striking in Kecskemét and Székesfehérvár as a great number of former Soviet sites are situated in the suburbs (8 and 4), which makes their utilisation more difficult according to our initial hypothesis – if there are other green- and brownfield investment possibilities within the city limits.

Based on our findings we can confirm that the utilisation of sites in the centre of the city was enhanced by their location, while the location did not hamper the utilisation of sites situated in the suburbs or outside the city limits. In the case of the latter not the favourable location, but other factors (such as sufficient infrastructural features, adequate condition of the buildings, the opportunity to start a profitable business enterprise) determined their transformation.

Conclusions

Former military sites of the Soviet Army became abandoned in large number in Hungary after 1991. As our study demonstrated a number of factors determine the success of rehabilitation of such sites and the role of these factors varies greatly in space and time. According to *economic aspects,* Győr and Székesfehérvár the two economically most successful cities in Western Hungary are leading the list while the lowest values were found for Szolnok and Kecskemét. But if we handle separately the factors used for analysing economic performance, some of them prove to be able to affect the success of rehabilitations (e.g. the number of functioning enterprises in the city, or the volume of investment in the given region). Differences and similarities in *brownfield policy of cities* are not relevant.

Greenfield protection policy is only present in the development documents of Szolnok, Szeged and Debrecen. Based on our analysis, *the increase or decrease in population* did not influence the ratio of reuse of former Soviet premises for residential function (e.g. Szolnok has the highest ratio of reuse for residential purposes with the greatest decrease of population). In connection with *sites used for other than commercial or residential purposes,* it has to be highlighted that the ratio of such utilisation (e.g. for public institutions, foundations and cultural purposes) had the highest value in Kecskemét and Debrecen, where private investors showed little interest in utilising these sites. Our survey also revealed that *geographical aspects* played a greater role in determining the success of rehabilitation. The *location within the city or in the inner city* was strongly determining the success of regeneration; however *EU funds* did not contribute considerably to the success of the process.

REFERENCES

Almássy, E. 2002. *Országos Környezeti Kármentesítési Program. Tájékoztató* (The National Environmental Remediation Program. Information). Budapest, KVM. http://www.kvvm.hu/szakmai/karmentes/kiadvanyok/okkptajekoztato2002/okkptajek2002.htm

Altman, J., Liebert, W., Neuneck, G. and Scheffran, J. 1998. Dual use and Conversion of Military Related R&D in Germany. In *Conversion of Military R&D.* Eds. Reppy, J., Rotblat, J., Holdren, J. and Avduyevsky, V., London–New York, Palgrave Macmillan, 163–182.

Barta, Gy. 2002. *A magyar ipar területi folyamatai 1945–2000* (Territorial processes of the Hungarian industry 1945–2000). Budapest–Pécs, Dialóg Campus Kiadó, 272 p.

Barta, Gy. (ed.) 2003. *Rehabilitációs megoldások az európai nagyvárosok rozsdaövezetében* (Keys for rehabilitation in the rust belts of some European towns). Pécs–Budapest, MTA Regionális Kutatások Központja, 34 p.

Barta, Gy. 2004. *A budapesti barnaövezet megújulási esélyei* (Chances of renewal for the brownfield zone in Budapest). Magyarország az ezredfordulón sorozat. Stratégiai tanulmányok a Magyar Tudományos Akadémián. Budapest, MTA Társadalomkutató Központ, 347 p.

Barta, Gy. (ed.) 2007. *Regionális Fejlesztési Operatív Program (ROP 2.2.): A városi területek rehabilitációját célzó intézkedések értékelése* (Operational program for Regional Development [ROP 2.2.]: Evaluation of the measures taken to rehabilitate urban territories). Zárótanulmány. Pécs–Budapest, MTA Regionális Kutatások Központja, 151 p.

CABERNET 2004. Scale of Brownfields. http://www.cabernet.org.uk/index.asp?c=1315

Csapody, T. 2000. *A gyalogsági aknák Magyarországon. Országjelentés a Landmine Monitor részére* (Landmines in Hungary. Country report for Landmine Monitor). Budapest, MTA Politikai Tudományok Intézete, 53 p.

Csendes, L. 1998a. Hadseregtörténet 1989–1990. (History of Army 1989–1990). *Új Honvédségi Szemle* 3. 51–55.

Csendes, L. 1998b. Hadseregtörténet 1990–1991. (History of Army 1990–1991). *Új Honvédségi Szemle* 4. 42–52.

Erdősi, F. 2009. Összeomlás vagy reneszánsz? A hagyományos vasúti közlekedés állapota és kilátásai Kelet-Európában (Collapse or renaissance? The state and chances of the traditional railway transport in Eastern Europe). *Tér és Társadalom* 23. (2): 1–23.

Euro-Régió Ház Kft. 2008. *Debrecen Megyei Jogú Város Integrált Városfejlesztési Stratégiája* (Urban development plan of Debrecen, county seat). Debrecen, Városi Önkormányzat, 220 p.

Ferber, U., Grimski, D., Millar, K. and Nathanail, P. (eds.) 2006. *Sustainable Brownfield Regeneration: CABERNET Network Report*. Nottingham, University of Nottingham, 132 p.

Ganser, R. and Williams, K. 2007. Brownfield Development: Are we using the right targets? Evidence from England and Germany. *European Planning Studies* 15. (5): 603–622.

Grimski, D. and Ferber, U. 2001. Urban brownfields in Europe. *Land Contamination and Reclamation* 9. (1): 143–148. http:// eppdocs.books.officelive.comDocuments 09-1-14.pdf.

Győri, R. (ed.). 2006. *Zöldmezős és barnamezős beruházások a magyar nagyvárosokban* (Greenfield and brownfield investments in Hungarian county seats). Budapest, MTA Regionális Kutatások Központja, Kézirat.

Hadtörténelmi Levéltár 2006. *A dolgozó népet szolgálom! Forráskiadvány a Magyar Néphadsereg Hadtörténelmi Levéltárban őrzött irataiból, 1957–1972* (I am serving the working people! Issue of the documents of the Hungarian Army safekeeped by the Archives of Military Histrory, 1957–1972). Budapest, TONYO-GRÁF Nyomdai és Grafikai Stúdió, 306 p.

HHP Contact Tanácsadó Kft (ed.) 2008. *Győr Megyei Jogú Város Középtávú Integrált Fejlesztési Stratégiája* (Integrated Mid-term City Development Plan of Győr). http://www.gyor.hu/adatok/ivs_kgy_valt_080221.doc

Homor, Gy. 2009. *Szovjet csapatkivonás térségünkből* (Withdrawal of Soviet troops of our region). Pápa, Jókai Mór Városi Könyvtár Kötészeti és Sokszorosító Műhelye, 336 p.

Horváth, M. 2003. *1956 hadikrónikája* (Military chronicle of 1956). Budapest, Akadémiai Kiadó, 482 p.

IUCN 1996. *Tanks and Thyme – Biodiversity in Former Soviet Military Areas in Central Europe.* Gland, CH – Cambridge, UK. IUCN, 202 p.

Janin, C. and Andres, L. 2008. Les friches: espaces en marge ou marges de maneouvres pour l'aménagement des territoires? *Annales de Géographie* 5. (63): 62–8.

Kádár, K. 2009. Barnamezős rehabilitáció Nagy-Britanniában és Németországban (Brownfield rehabilitation in Great Britain and Germany). In *Regionális Politikai és Gazdaságtani Doktori Iskola Évkönyve 2009*. Eds. Buday-Sántha, A., Erdős, K. and Komlósi, É., Pécs, PTE KTK, 120–129.

Kádár, K. 2011a. Barnamezők Magyarországon (Brownfields in Hungary). *DETUROPE Central European Journal of Regional Development and Tourism* 3. (2): 122–143. http://www2.zf.jcu.cz/public/projects/cejrdt/img/upload/volumes_22753418.pdf2011

Kádár, K. 2011b. A szovjet katonai objektumok kialakítása, elhagyása és újrahasznosítása hazánkban (Building up, giving up and reutilisation of Soviet military sites in Hungary). *Sereg Szemle* 2. 133–147.

Kádár, K. and Kozma, G. 2011. Az egykori szovjet katonai területek funkcióváltása Debrecenben (Functional changes in use of the former Soviet military sites in Debrecen). *Tér és Társadalom* 25. (2): 164–179.

Kälberer, A. (ed.) 2005. *The Future lies on Brownfields. Reactivation of Urban Land Reserves. Redevelopment Potentials and Practical*. Kempten, Umwelt-Bundesamt, 40 p.

Lux, G. 2009. Az ipar hagyományos terei: a régi ipari térségek (The traditional spaces of industry: old industrial sites). *Tér és Társadalom* 23. (4): 45–60.

Millar, K. (coord.). 2003. *CABERNET: State of the Art – Country Profile Germany*. 1st Edition. Nottingham, University of Nottingham. www.cabernet.org.uk

N.N. 1989. Megkezdődött a csapatkivonások gyakorlati előkészítése (The preparation for the withdrawal of troops has been started). *Veszprém Megyei Napló* 45. 27. p.

Nagy, Á. (ed.) 2003. *Az EU strukturális alapok keretében barnamezős rehabilitációra kiírandó pályázatok szakmai megalapozása* (Professional support of applications to be submitted for brownfield rehabilitations stemming form the Structural Funds of the EU). Budapest, VÁTI Kht. 44 p.

Oliver, L., Ferber, U., Grimski, D., Millar, K. and Nathanail, P. 2005. *The Scale and Nature of European Brownfields.* Nottingham, University of Nottingham, http://www.cabernet.org.uk/resourcefs/417.pdf

Ránki, Gy. 1976. *A második világháború története* (The History of the World War II.) 2. kiadás. Budapest, Gondolat Kiadó, 651 p.

Sági, J. 2006. *A logisztikai támogatás keretében megvalósuló ingatlangazdálkodás a honvédelmi szerveknél* (Maintenance of real estates with logistic support by the institutions of the Ministry of Defence). Szakdolgozat. Budapest. Zrínyi Miklós Nemzetvédelmi Egyetem, 71 p.

Spyra, W. and Katzsch, M. (eds.) 2007. *Environmental Security and Public Safety*. Dordrecht, NATO Springer, 192 p.

Székesfehérvár Megyei Jogú Város Integrált Városfejlesztési Stratégiája 2008. (Urban development plan of Székesfehérvár, county seat, 2008). Székesfehérvár, Városi Önkormányzat, www.szekesfehervar.hu

T.T.T. Bt. 2007. *Szeged Megyei Jogú Város Fejlesztési Koncepciója*. (Urban Development Conception of Szeged, county seat). Szeged, Városi Önkormányzat, 81 p.

VITUKI Kht. 2005. *Az Országos Környezeti Kármentesítési Program Alprogramjai. Tájékoztató összefoglalás az 1997 és 2004. között elvégzett feladatokról* (Subprograms of the National Environmental Remediation Program. Information about the task fulfilled between 1997 and 2004). http://www.kvvm.hu/szakmai/karmentes/alprogram/alprogramok.pdf

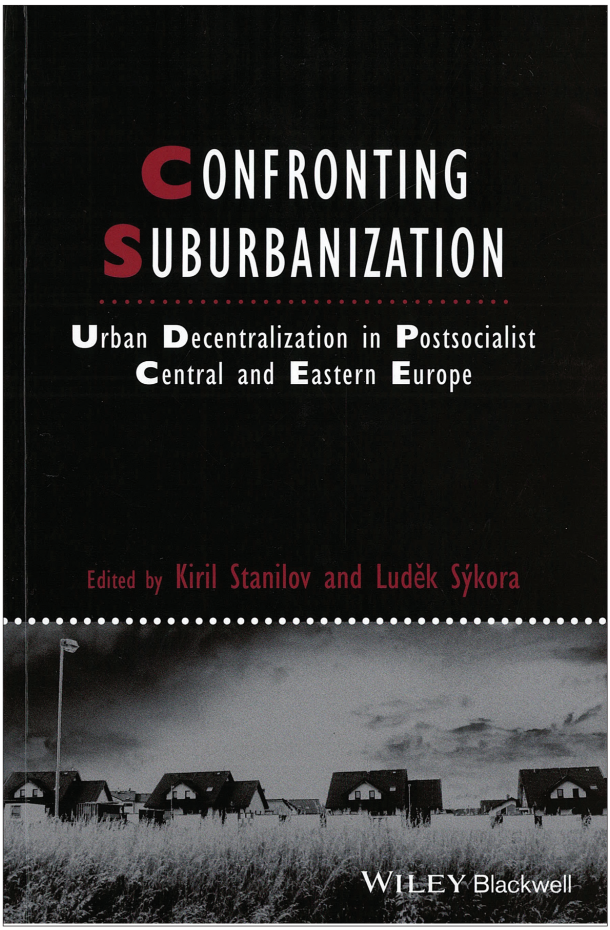
Vogt, R. (ed.). 2006. *The Baltic Sea Region: from a highly militarised area to conversion area.* Conversion Handbook for the Baltic Sea Region, Brandenburg. www.conver.net

Woodward, R. 2004. *Military Geographies.* Malden, USA, – Oxford, UK, – Carlton, AU. John Wiley & Sons, 212 p.

Hungarian Geographical Bulletin 63 (4) (2014) pp. 457–464.

Stanilov, K. and Sýkora, L. (eds.): Confronting Suburbanization. Urban Decentralization in Postsocialist Central and Eastern Europe. Wiley Blackwell, Chichester, 360 p.

The book focuses on the process of suburbanization that has been perhaps the most spectacular spatial phenomenon of urban restructuring in post-socialist countries. It provides a detailed overview about the migration from core cities to suburbs, the reasons and consequences of suburbanization, and the common features and distinctive characteristics of the process in the post-socialist cities. In addition, it explores the impact of the globalization, the EU-enlargement, the financial crisis and the role of local authorities, investors, and inhabitants. Although single papers have been excessively published on suburbanization in individual cities in post-socialist Central and Eastern Europe, however, this is the first attempt to evaluate suburbanization from a comparative perspective in the region.



The structure of the book follows the traditions: an introductory and two summarizing chapters were written by the two editors, Kiril Stanilov and Ludek Sýkora. In between the reader finds seven case studies about the capital cities of Central and Eastern Europe. The introductory chapter argues that the main factors of rapid suburbanization were the privatization of state assets, the deregulation of economic activities, and the decentralization. These reforms (implemented right after the change of regime) created favourable conditions for the rapid sprawl of population, services, and commerce.

The concluding chapters and the case studies equally emphasize the importance of national policies (e.g. privatization) and local authorities. In the early phase of transition suburbanization was triggered by the mass provision of land by suburban municipalities causing substantial population loss in big cities. The EU-enlargement brought about significant changes because the countries had to establish their regional authorities and environmental policies and regulations had to be developed in line with EU standards. The effects of the urban sprawl, however, did not always reach an alert line on behalf of public authorities; therefore, policy responses were either late or completely missing. The authors claim that if suburbanization is lessening, it is mainly due to market forces, like the financial crisis or the urban rehabilitation programs that increased the supply of high quality inner-city dwelling stock.

The case studies were prepared according to a common methodology. The authors first put the suburbanization in its historical context, summarizing the pre-socialist and state socialist periods. This is followed by an introduction of the post-socialist processes. Not only the suburbanization of population, but of trade, services and other functions are analyzed. The role of the different actors like public authorities, urban developers, planners and the market is also explored. The common structure makes the individual chapters very transparent and comparable.

The case example of Ljubljana presented by Pichler-Milanović, N. demonstrates that the deregulation, the lack of coherent strategy, and the inadequate cooperation of local governments have a lot of negative effects. Despite the negative consequences of the urban sprawl, suburbanization has proved to be sustainable in Ljubljana. This is explained by the dispersed pattern of the settlement system, the spread of energy-efficient construction, and the improvements in sewage facilities.

The metropolitan area of Prague is highly fragmented (more than 200 settlements) which would require greater cooperation among the suburban localities. However, during the transition period, a competition began among the local governments for attracting new jobs and residents. The lack of competence at higher administrative levels resulted in negative consequences as far as the authors of the case study, Ludek Sýkora and Ondrej Mulíček claim. The priorities in Prague's metropolitan region were the improvement of transport connections and the construction of roads, while the environmental issues were completely neglected.

The heterogeneity of the agglomeration zone is one of the main characteristics of the Sofia Metropolitan Area. According to the authors, Kiril Stanilov and Sonia Hirt, the attractive natural environment of the Vitosha Mountain close to the southern border of the city determines the direction of suburban migration.

The mobile middle class people tend to move to this southern area, while the northern suburbia has remained a deteriorated industrial zone inhabited mainly by lower class people. The process of suburbanization started around Sofia in the 2000s and dramatically slowed down after the financial crisis; the price of newly built houses has decreased by 40 percent since 2008.

The Budapest Metropolitan Area is similarly divided but the heterogeneity of the zone is explained not only by its physical geographical features but also by the direction of the main roads, and the characteristics and functions of the suburban settlements. The authors of the chapter – Zoltán Kovács and Iván Tosics – have identified three economic growth poles around Budapest each having logistics, commerce or industry as a driving force behind. Authors also point out that in the mid-2000s the outflow of population lessened, while the city itself started to grow again. This was partly the consequence of the urban rehabilitation programs that resulted in a steady growth of newly constructed dwellings inside the city boundaries. Budapest was the first case among post-socialist cities where national legislation intervened and prevented limitless land conversion in the suburban belt by a law in 2005.

The main characteristic of the Estonian capital is that in Tallinn suburbanization was driven by the cheaper housing due to an oversupply of flats in the periphery. This supply was partly created by the Russian-speaking residents who left Estonia after the country became independent, thus their apartments and summer homes became vacant at a relatively low price level. The authors (Leetmaa, K., Kährik, A., Nuga, M. and Tammaru, T.) claim that the main period of suburbanization in Tallinn was also in the early 2000s like in all other postsocialist countries.

Warsaw is the only large capital city in Central and Eastern Europe which has continuously increased its population during the last 25 years, while the suburban periphery also experienced increasing population growth rates. Authors (Lisowski, A., Mantey, D. and Wilk, W.) pay special attention to the conflicts between the old and new residents of the suburban settlements caused by their different lifestyles, attitudes and development preferences.

Moscow is the most special case among the analyzed cities, not only because of its size, but also because the very nature of urban development is different. The major sources of metropolitan growth are not suburbanizing residents arriving from the core city, but the newcomers from other parts of the country and from Post-Soviet states. Despite the large scale housing constructions over the last two decades the agglomeration of Moscow is still very heterogeneous; it maintains a strong agricultural character. The authors (Brade, I., Makhrova, A. and Nefedova, T.) claim that the proportion of unregistered inhabitants and informal economic activity is extremely high.

The editors' conclusion is that the conditions of suburbanization were set by the new capitalist system implemented after 1990, and its ideological platform, the neoliberal state. After the crisis this doctrine must be revised because the uncoordinated urban sprawl contradicts to the principles of sustainable development. This is a very readable book and a successful trial to set the suburbanization of post-socialist cities in a global context.

Balázs Szabó

Lozovanu, D., Delinschi, A., Kahl, T. and Prishchepov, A. (eds.): Gagauziya (Gagauz Yeri) Avtonom Bölgesi Atlasi / Atlas of ATU Gagauzia (Gagauz Yeri). Editura PROART, Chişinău, 2014, 72 p.

The atlas of Gagauzia (or formally Autonomous Territorial Unit of Gagauzia) is an attempt to present the general characteristics of this relatively small autonomous region of the Republic of Moldova established 20 years ago. Gagauzia covers only 1848 km^2, where 156 thousand people lived in 2004, whose majority was Gagauzian. Gagauzians are Orthodox Christians who speak Gagauzian which belongs to the Turkic language group.

According to the authors' introduction, this is the first thematic atlas about Gagauzia (and also the first in the broader region), which serves as "a model of the regional Atlases in Republic of Moldova and abroad" (p. 9). Moreover, based on the outfit of high standard, the diverse content and the involvement of governmental institutions in the preparation of the atlas, this collection of maps looks more a national atlas of Gagauzia than a "simple" regional atlas. Naturally, labeling the atlas of an autonomous territory as 'national' would lead to political conflicts particularly in a country which still faces territorial conflicts with the *de facto* sovereign Transnistrian state.

The atlas is addressed not only to scholars but everyone who is interested in Gagauzia's geography, economics, ecology, history and ethnography. The authors intend this issue on the one hand as a scientific basis for development programs, and on the other as a source of information about Gagauzia. Contrary to the above mentioned specific target, the reason for creating this atlas sounds rather vague, as it is "due to the spirit of times, perception of something new …" (p. 9).

Looking into the atlas one can find 77 maps on 72 pages. The maps do not accompanied and explained by texts (only by short additional information in some cases), except the introductory words and dedications by the managing editor, the governor of Gagauzia and the main sponsor. Both the texts and the legends are available in four languages (Gagauzian, Moldavian, Russian and English) to reach not only local and Moldovan readers but also the outside world. Place-names are written in Moldovan, Gagauzian and Russian in the autonomous territory and without Gagauzian names outside Gagauzia. Regarding the place-names, two inconsequences can be found on page 14 and 15 where Gagauzian names are missing.

The autonomous territory's current conditions are depicted in 14 topics. Out of the 77 maps, only 47 are limited to Gagauzia itself. The weight of the topics does not reflect the general structure of the international traditions in atlas cartography. Some issues are underrepresented or even missing, which is probably due to the hard-to-access statistical data, while some topics are overrepresented, which reports on the local importance of these issues (e.g. ethnic structure). Analyzing the structure of the atlas, we identified only one map which does not meet the logic chain of the atlas at all: this is the map of the central part of Comrat, the seat of Gagauzia (p. 52). But overall, except this case, the atlas' structure satisfies the criteria of a regional atlas.

The number of maps by categories clearly shows the topics with high local interest. Among demographic maps, ethnicity is presented in four maps and two diagrams, while only one map is dedicated to natural increase and migration which strongly affect the country's demographic, economical and social circumstances. Similarly, 17 maps focus on issues related to the agriculture, while other parts of economy presented only in 5 maps. Most of the topics representing the Gagauzian society (e.g. education, culture, health care, religion, sport, tourism) are approached from an infrastructural perspective: for instance education maps concentrate on the number of the institutions rather than the educational attainment of the population.

The last two maps before the historical maps depict the distribution of Gagauzians in the broader region based on official and estimated data. Since the title of the book refers that the atlas' content is about Gagauzia and not about Gagauzians, involving this issue reports on inconsistency. This highlights the mingled nation concepts (territorial or cultural) characterizing the whole region. Similarly, the historical maps are probably involved to the atlas in order to strengthen local/regional/ethnic (Gagauzian) identity, otherwise their inclusion is meaningless. Both phenomena underpin that the book serves as a national atlas and thereby it is a cartographic tool for Gagauzian nation building (as all of the national atlases).

The design of the maps is generally harmonious. The maps reflect a consistent editorial work with predetermined scale series. The symbols are easy-to-read and easily interpreted. The cartographic elements (title, scale bar, legend) are aesthetic. At the same time, the symbols of the map legend appear to be overcolored, which resulted in too vivid outlook. Colors with less saturation, precisely elaborated symbols would have eventuated in clear-out, more readable maps.

Concerning the territory of Gagauzia, it is a striking phenomenon that the thematic content appears as a so-called "island-like map" (a map on which only a selected area is mapped fully) in most cases. Presenting such a small area it would have been a worth using contiguous thematics to fill in the emptiness among the isolated territories of Gagauzia (like on page 21). A positive but single example is found on page 30, where this deficiency is compensated by the overview map of Moldova. But generally the "island-like map" phenomenon, especially spectacular in case of the physical geographical part of the atlas, reduces readability.

From cartographic point of view, the lack of the geographical grid is considered to be a fault, and, although scale bar is part of the maps, scale in numeric format should also be written on maps. Another problem is the crowding of the maps originated from applying too many diagrams and the multilingual legends, which makes map interpretation difficult (e.g. on page 46).

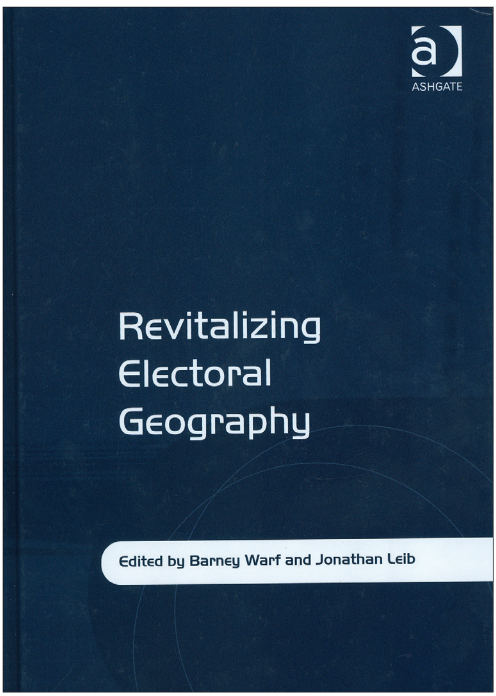
More minor cartographic errors can be found throughout the atlas, but they are not decreasing the value of enjoyment of maps. Just to name some of the problems: map on geology, climate and soils does not contain border of communes, therefore the localization of some phenomena challenges the reader. In addition, the soil map legend is constituted by eight categories but the summarizing cake chart includes only six ones. In several maps, contrary to the initial practice, the outlines of the settlements are missing. In case of the maps with landscape orientation in the historical-administrative section, it would have been better to orient them in the same direction.

On the whole, we conclude, that despite the minor cartographic problems, the Atlas of ATU Gagauzia is a well-designed work of high quality, which is recommended for everyone who would like to be acquainted in depth with this region and its cartographic representation.

Zsombor Nemerkényi and Patrik Tátrai

Warf, B. and Leib, J. (ed.): Revitalizing Electoral Geography. Burlington, Ashgate Publishing Company, 2011. 238 p.

Electoral geography has a long and complex history and once possessed a distinguished status within the discipline of political geography. This dominance decreased after 1980 and the thematic coverage of electoral geography became partially obsolete. While social geography began to deal with more conceptual questions, electoral geography became utterly positivist and sank into its own 'moribund backwater'. Electoral geographers had to face the challenges of renewal, and this book is an important trial to revitalize electoral geography.



The book consists of three major parts and contains altogether twelve chapters. The first part of the book sets the conceptual background. Barney Warf and Jonathan Leib, who are the editors of the volume, describe the need for revitalisation and summarise the messages of the studies included in the book. The editors emphasize that the overall goal of these chapters is to show some conceptual, theoretical and methodological perspectives for electoral geographers.

In the second chapter Jonathan Leib and Nicolas Quinton discuss the current trends in electoral geography. Authors analyse 224 articles published mainly in English language journals (e.g. Political geology, climate and soils does not contain border of communes, therefore the localization of some phenomena challenges the reader. In addition, the soil map legend is constituted by eight categories but the summarizing cake chart includes only six ones. In several maps, contrary to the initial practice, the outlines of the settlements are missing. In case of the maps with landscape orientation in the historical-administrative section, it would have been better to orient them in the same direction.

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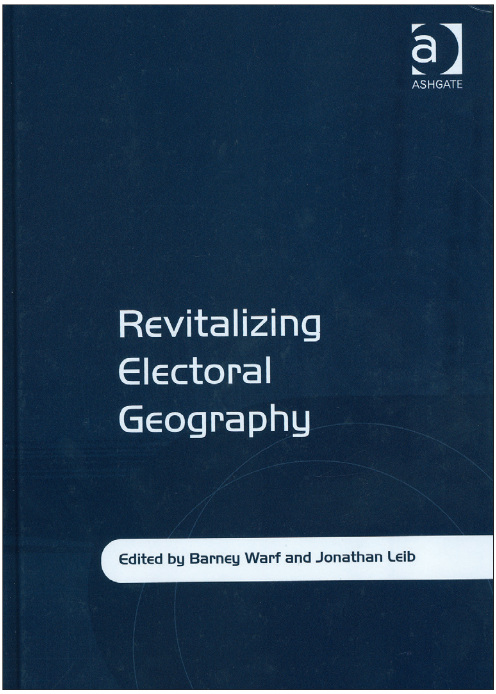

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Geography, Regional Studies and Professional Geographer) after 1990. They come to the conclusion that 39 percent of the articles deal with the United States, 20 percent with the United Kingdom, in addition to the Anglo-Saxon dominance a lot of studies focus on the electoral processes of the Post-Soviet states. The bulk of the literature concentrates on the analysis of voting patterns, electoral systems, redistricting or pedagogic issues. Some of the major theoretical perspectives, e.g. spatial analysis, political economy, and post-structuralist interpretations also appear in the articles. As a reader, I found this chapter very informative and the comprehensive analysis of electoral geography publications provided a solid foundation for the book.

In the second part of the book case studies from the UK, Italy, Spain, Taiwan and Puerto Rico can be found. In the third chapter, Ron Johnston and Charles Pattie use the United Kingdom as a case study to describe the strengths and weaknesses of the wide varieties of electoral systems. They think that the geography is the core of most systems which use elect legislators to represent territorially-defined constituencies. There are no perfect systems but for the sake of social justice, it is necessary to examine the balance between advantages and drawbacks in electoral systems and geography plays a key role here.

The fourth chapter presents how geographic information systems and spatial regression methods can be used for electoral geography. Michael Shin and John Agnew focus on the objectivity of research methods in modern geography. Their case study is on the Lega Nord (North League) in Lombardy. Authors examine the differences between the statistical methods (territorial autocorrelation and geographical weighted regression) and the role of the scale. The anti-immigration and regional party has both positive (around Brescia and Sordio) and negative (east side of Milano) correlation with the rate of unemployment. This chapter can be perceived as a great methodological innovation regarding how spatial regression can be used to point out local differences behind the global correlations and regressions results.

Erinn P. Nicley focuses on the cultural political economy perspective of elections. He points out that the Bloque Nacionalista Galego regional political party first rose and then fell between 1985 and 2005. Initially, the author restricts the terminology as the impact of the capitalist regulation on the identity of voters. The influences of the global political and economic shifts on voting behaviour are analysed, at the same time the effects of local cultural and ideological differences on political patterns are emphasised. In my view, this article provides a new perspective for electoral studies because it contains critical parts behind the main analyses of the results.

Although English language publications focus predominantly on the elections of North America and Europe, Daniel McGowin provides a unique chapter because his case study is Taiwan. Analysing the historical, identical factors of voting behaviour author comes to the conclusion that in the past, the main differentiating factor of voting behaviour was the progeny of people (Chinese or native). Nowadays, the main cleavages between the Kuomintang and the Democratic Progressive Party are not so much based on ethnic issues but more on the attitudes towards mainland China.

In the seventh chapter, Luis D. Sánches-Ayala describes the problems and dilemmas of the extension of the voting rights in Puerto Rico. Could the electoral universe for a future referendum be limited only for those who have lived on the island or for those who were born on the island? These questions are hot because more Puerto Ricans live in the United States than in Puerto Rico. In recent decades, there have been three referendums and the voters were very much divided each time. The main cleavages in the Puerto Rican society are the attitude towards the United States, the differences between nationality and statehood and furthermore, the differing identities between the migrants and the islanders.

The third part of the book focuses on the United States. Barney Warf, in the eights chapter, describes the impacts of class, ethnicity and religion on the presidential elections in 2008. The general stereotype about American voters is that working class people vote for the Democrats and the white and wealthier groups support Republicans. Author uses geographically weighted regression and shows why this class-stereotype is not applicable nowadays. Moreover, he notes that religion and ethnicity are more determining factors of voters' behaviour. I found this chapter highly informative because the author also highlights the main political impacts of neoliberalism after 1970. For instance, lots of Democrats became Republican voters because the Democratic Party overemphasized liberal and multicultural values. Toby Moore, in his chapter, analyses the spatial dimensions of American voting in the 2008 elections, in the light of voter identification laws and voting technologies. The way how voters cast their ballots shows enormous differences across the United States. For example some states allow voters to register and cast their ballots on the same day. In another states, many people cast their ballots through e-mail. These kinds of regional differences also influence the electoral results.

In the next chapter, Fred M. Shelley and Heather Hollen examine the geographical aspects of pre-elections, which is rather new topic in electoral geography. Authors use the presidential primaries in 2008 as a case study and emphasize the cleavages within one party throughout the United States. On the one hand, Obama attract strong support in metropolitan areas, among ethnic minorities and highly qualified people. On the other hand, Hilary Clinton is more popular among elderly, lower-class people and in rural areas. Republican candidates also create their own cleavages; Romney is popular in urban areas while McCain in rural areas. In the next chapter, Nicholas Quinton and Gerald R. Webster try to make connections between conceptual approaches and quantitative methods. They use spatial autocorrelations and factor-analysis and compute the data of the Local Indicators of Spatial Association, presidential elections and electoral outcomes of referendums. As they found North Alabama has a white, conservative, republican voting behaviour pattern and the 'black belt' has a liberal, multicultural pattern with democratic dominance. This study is an excellent demonstration how quantitative methods can successfully be applied in post-structuralism paradigm.

Finally, Thomas Chapman analyses the geographical features of the referendum about the same-sex marriage in Florida. This topic divided very much the population and finally the majority rejected it. However, there were several areas where the same-sex marriage got strong support, for example, in the neighbourhoods of the universities. The author describes the spatial patterns of this referendum through the lens of cultural politics of sexuality.

To sum up, I found the twelve chapters of this book highly informative and thought-provoking. I recommend this book for all those academics and researchers who are interested in electoral studies and would like to know more about the modern straits of electoral geography.

György Vida

Hungarian Geographical Bulletin 63 (4) (2014) pp. 465–471.

Report on the 2014 Annual International Conference of the Royal Geographical Society (with the Institute of British Geographers)

London, August 27–29, 2014

The Annual International Conference of the Royal Geographical Society (RGS) was held at the London headquarters of the RGS and the nearby Imperial College in Kensington this year. The conference theme was 'Geographies of co-production'. The title refers to the challenges that emerged in research and teaching activities as a result of a range of new encounters, such as commercialisation, engaged arts, open innovation, participatory social science and public engagement. The conference provided opportunities to analyse the challenges of multi-disciplinarity and the opportunities of creating new understandings by using different perspectives.

Interior from the London headquarters of the Royal geographical Society

The main panel session brought together leading scholars, among others Katherine Gibson, Uma Kothari, Patricia Noxolo, Nik Theodore, Wendy Larner, Keri Facer and Jane Wills to discuss what co-operation means for universities, academics and knowledge itself. The covered topics included the political economy of co-production; co-production and the politics of post-colonialism, feminism and anti-racism; issues of success, quality and legacy. The chair's plenary lecture was given by Vinay Gidwani (one of the most prominent Marxist geographers working on issues like work, poverty, agrarian change in India) on the topic of 'Value struggles: ethno-geographic notes on waste work in urban India'. He analysed the importance of emerging informal need economies to urban livelihoods and urban living and he examined the poverty, injustice and struggle in neoliberal urban India.

These were only a selection of highlights - this year almost 1,800 participants contributed to over 380 panels and sessions. Several topics were discussed in these sessions, among others, issues of international development, climate change, transnational education, urban political ecology, the different perspectives of (urban) sustainability, geopolitics, social and environmental justice and many more.

One of the most inspiring presentations at the conference was given by Uma Kothari who analysed the new actors in the changing environment of international development. These included celebrities, armed forces, philanthropists and international volunteers. Her research especially focused on how these volunteer actors form and forge new global connections and alliances.

Many of the sessions reflected the issues related to the current economic crisis, such as the session called 'Geographies of forced eviction'. The session raised the attention to a 'crisis' urbanism in the Global North characterized by new forms of social inequality, increased housing insecurity and violent displacement. It also aimed at considering what geographers can offer to inform understanding of, and action against this foremost human-rights violation.

The RGS publishes its own book series and organizes 'author meets interlocutors' sessions at the conference. This year one of the most interesting books was Marisa Wilson's 'Everyday moral economies: food, politics and scale in Cuba'. The panel session was held by the author and the reviewers of the book (with human geography and Latin American studies backgrounds). 'Everyday moral economies' is a fascinating combination of human geography and anthropology. Using a geographical understanding of politics of scale with anthropological sensitivity of daily life, Marisa Wilson reveals in her study how contradictions between food-as-commodity (within the globalized neoliberal markets) and food-as-entitlement (within a planned economy) are resolved in everyday social practice.

Prior to the first day of the conference, a conference training symposium had been hosted by the RGS Postgraduate Forum and it provided training and networking opportunities for postgraduate students attending the conference. The workshop also helped postgraduates to meet other delegates and get to know the venue before the start of the conference. The first part of the workshop was led by Nicola Thomas and it focused on the ways in which postgraduates can develop strategies, ideas and actions for making the most out of the conference in terms of professional career development (e.g. networking strategies). The second part of the symposium focused on strategies for engaging with critical reading, writing and self-editing processes. The workshop was organised and led by Gavin Bridge.

Every year more and more Hungarian delegates attend the RGS Annual International Conference but this year there were only two participants from Hungary. Márton Lendvay, who obtained his Master's degree in geography at Eötvös Loránd University, currently a PhD student at Aberystwyth University (Wales) analysed how a resilient economy is created in a Hungarian agricultural community. Using empirical research, he argued that small farming community members are moving away from the institutions and services provided by the state and seek alternative and local solutions of adaptations instead. The other Hungarian presenter was Noémi Gonda who is pursuing her PhD degree in Environmental Science and Policy at the Central European University. Using a feminist political ecology framework, she examined farmers' gendered experiences of climate change in two rural communities in Nicaragua. She argued that gender roles and relations are not static and they are significantly changing under the effects of climate change in Nicaragua. These changes are linked to climate-related migrations, modifications in the production systems and development interventions.

To conclude, the conference provided an intellectually very stimulating environment for geographers and other social scientists as well, thanks to the many thought-provoking panel and paper sessions and the interdisciplinary and international character of the conference. The next Annual International Conference of the RGS will be held at the University of Exeter from 2 to 4 September 2015, where hopefully several Hungarian delegates will take part as presenters, chairs, convenors or discussants.

László Cseke

Report on the 3rd Romanian-Bulgarian-Hungarian-Serbian conference

Srebrno jezero (Veliko Gradište), Serbia, 18–21 September, 2014

The roots of the conference go back to the year 2010, when the first regional conference on the "Geographical environment and cross-border cooperation within the Danube lower basin", was organized by the University of Craiova (Romania) gathering geographers and other researchers from European countries who shared their experiences, knowledge and research results about all aspects of geography. The first conference took place in Craiova and it was organized by the Geography Departments of the University of Craiova and the University of Timisoara. The second conference was held in Eger, and it was organised by the Department of Economic and Social Geography of the University of Szeged in 2012. The third conference was initiated by the Faculty of Geography (University of Belgrade) and Faculty of Sciences, Department of Geography, Tourism and Hotel Management (University of Novi Sad).

The conference theme was 'Geographical Research and Cross-Border Cooperation in the Lower Basin of the Danube'. One of the main goals of the conference was to bring geographers and institutions together from the countries lying at the lower basin of the Danube and establish a working group to promote sustainable measures for the sake of cross-border cooperations. As participants, we can confirm the importance of personal meetings in the building of real and operating cross-border networks or communities of researchers.

Location of the conference – Hotel Danubia Park in Srebrno jezero (Veliko Gradište, Serbia)
(Photo: Ernő Molnár)

The venue of the conference was in the Eastern Serbian Srebrno jezero (part of Veliko Gradište) near the Danube and close to the Iron Gates. This developing recreation zone is located next to a spectacular artificial bay of the river. The presentations took place in the Hotel Danubia Park.

On the first day the programme of the conference was opened by the representatives of the universities and national bodies (e.g. head of the office responsible for EU integration affairs) that was followed by plenary presentations. Seven sessions with approximately 100 presentations and more than 40 posters were planned (however considerable part of the previously registered participants did not show up). Apart from this fact a broad range of topics covered almost every field of geography and earth sciences.

Evidently, presentations relating to the European Union's Danube Strategy had high relevance among the topics presented. Considerable part of the presentations was in connection with hydrology e.g. from the aspects of floods or sedimentology. Research topics of weather and climate change were also represented through the results on urban heat islands, local climate zones, extreme weather events or evidences and forecasts of climate change. Topics of geomorphology and landscape ecology were primarily analysed by GIS methods which reflected the differences between countries in their approaches, in their most relevant issues and in their research methods.

Demographic issues represented important part of the presentations, mainly in the context of migration. Some debates were generated about the one way migration from Central and Eastern Europe towards the West European countries and about its effect on

The audience of the plenary session (Photo by the organizers)

Participants of the conference and field trip above the Danube and the Iron Gates at Kapetan Misin Breg (Photo by the organizers)

local demographic, social and economic situation. Ethnic issues were subordinated and focused primarily on international tourism. In the light of the presentations, tourism seemed to be one of the key elements in the building of cross-border cooperation.

The programme of the conference was supplemented by presentations about the situation and possible development of geography teaching (e.g. through out-of classroom lessons) in different countries.

Floods, water pollution, monitoring systems and tourism developments might provide possibility for countries to cooperate. Besides of these, some common socio-economic processes – e.g. international migration, transforming post-socialist spatial structure or tourism development – also give the chance to find ground to think together.

After the sessions a boat trip was organized on the Danube with guiding on board, concluding remarks of the sessions and a specific presentation about GIS techniques and devices.

A one-day bus trip was organized on Saturday (20 September) that contained several stops with geographic and historic relevance. Our first destination was the monumental Golubac Fortress that was under revitalization at the time of the conference (funded by the European Union). The location of the fortress provides a strategic position that was demonstrated by the Roman stronghold as historic background of the current structures. Lepenski Vir (next stop of the trip) is a Mesolithic archaeological site that was excavated during the creation of the Iron Gate gorges. The museum provides the possibility to study the transition from the Mesolithic to the New Stone Age.

The visit at Boljetin was a spectacular programme because flash floods caused massive damages there only few days before the conference. Participants could see the cleaning and reconstruction works nearby the fascinating geologic formations. Traditional local lunch was served at Kapetan Misin Breg with beautiful scenery. The next stop was at Lajko's cave which is one of the most spectacular caves especially after torrential rains where quite humid conditions were waiting for the visitors. Majdanpek town was the last stop in the programme which is an important copper mining and metallurgy area in Serbia (Hungarian participants associated to Salgótarján seeing Majdanpek).

The organizers summarized some potential fields of international cooperation:

– Intensification of collaboration between the participating institutions (with signing a cooperation agreement);

– Intensification of the exchange of teachers and students among our institutions (e.g. in the form of summer schools and camps, what was organized by colleagues from Romania last summer)

– Preparation of scientific projects between geographical institutions from the region (establishment of a commission with 2 members from each country)

Some project ideas were also proposed:

– Vulnerability map of Natural Hazards for this region (Hungary, Serbia, Romania, Bulgaria);

– Soil erosion map with assessment of changes in the intensity of soil erosion caused by demographic changes and changes in land use (in the given region);

– Assessment of soil loss caused by bank erosion in the southern part of the Pannonian basin;

– Preparation of a Global Change atlas.

A declared objective was to follow the traditions by the continuing the organization of similar conferences in the near future, next time in Bulgaria.

János Pénzes