HUNGARIAN GEOGRAPHICAL BULLETIN

FÖLDRAJZI ÉRTESÍTŐ

Special issue on
Renewable energies, GIS and Climatology

Edited by
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Volume 63 Number 1 2014

HAS
Research Centre
for Astronomy and
Earth Sciences
GEOGRAPHICAL
INSTITUTE

HUNGARIAN GEOGRAPHICAL BULLETIN

Quarterly Journal of
GEOGRAPHICAL INSTITUTE
RESEARCH CENTRE FOR ASTRONOMY AND EARTH SCIENCES
HUNGARIAN ACADEMY OF SCIENCES

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This publication was supported by Hungarian Academy of Sciences

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Guest editorial address

This special issue of the Hungarian Geographical Bulletin is devoted to the international conference on "Changing world, changing society, changing knowledge acquisition, the role of renewable energies in regional development", held in Eger in the central building of the Eszterházy Károly College, 10–12 October 2013. The conference was organised within the framework of the TÁMOP-4.2.2.A-11/1/KONV-2012-0016 project.

The project title is as follows: "Complex analysis of the potential applicability of renewable natural resources in the mirror of climate change, in order to develop a sustainable model region, under German Hungarian Cooperation".

The special issue contains seven selected papers reflecting the broad spectrum of the conference where altogether 55 papers were presented on the following topics:

1. Global and regional environmental challenges;
2. Renewable energies and regional planning;
3. Regional studies;
4. Challenges of earth sciences in public and higher education.

This is the second conference on "Changing world, changing society, changing knowledge acquisition" at the Eszterházy Károly College organised by the Department of Geography. The first conference took place in 2009 when the Department of Geography celebrated its sixtieth anniversary.

During the last decade the Department of Geography has widened its research and education activities. As a result of this, the Agria Innoregion Knowledge Centre was established in 2011. The Department of Geography organised several conferences recently. In 2010 the annual meeting of the Hungarian Meteorological Society was held in Eger. In 2012 the Department of Geography and the Hungarian Geological Society set up the IGCP 572 Closing Conference. The XI. HUNGEO Conference, the meeting of Hungarian earth scientists took place also in the city in 2012.

After the opening of the conference by the rector of the college, Professor Kálmán Liptai and by Zsolt V. Németh, Minister of State for Rural Development, seven papers were presented at the plenary session. Ilona Pajtók-Tari, vice rector of the College gave a talk on the Eger model-region focusing on sustainability, followed by the keynote speech of Gabriele Gorzka (Universität Kassel) about the role of the East–West co-operation in technology transfer. Professor Ulf Hahne (Kassel University) gave an interesting paper about the resilience of regions and about solving spatial problems for the post-fossil society. Professor Jürgen Aring (Dortmund Technical University) focused on the Eger region introducing the concept and action plan for the development of the Eger region.

Three panel presentations are included in this issue. Judit Bartholy *et al.* gave an overview on the expected characteristics of climate change in Hungary. Maria Szabó, M. and Ádám Kiss reported on the effects of renewable energies on the landscape and on regional development. Methodical aspects, i.e. the application of GIS technology were dealt with in the paper of János Unger *et al.* The papers published in this issue are grouped according to the topics of the last three keynote speeches. The first day was finished by a fantastic concert and a gala dinner.

Three sessions were organised in the morning of the second day. The first session focused on global and environmental challenges, the second, parallel session on renewable energies and regional planning and the third, parallel session on the challenges of earth sciences in public and higher education. After lunch the papers were given in three parallel sessions (global and regional environmental challenges, renewable energies and regional development, regional studies).

A half-day scientific excursion was organised on the third day of the conference to the Bükkalja Region, in the vicinity of Eger. Interesting natural features like a fossil tundra soil profile, thermal springs and a thermal spa as well as travertine terraces, beehive stones (rhyolite cones, formed by selective erosion) and cliff dwellings were shown during the excursion.

Ádám KERTÉSZ

Hungarian Geographical Bulletin 63 (1) (2014) 5–16.
DOI: 10.15201/hungeobull.63.1.1

Effects of renewable energy resources on the landscape

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Abstract

One of the most important prerequisites of the sustenance of modern societies is the safe energy supply. An energy supply system, which is currently based mainly on fossil energy resources cannot be maintained even in the medium-term, at least not longer than for a few decades. Therefore, the application of renewable energy resources will play a significant role in forming our energy future. Most of them except geothermal and tide energies, use directly or indirectly solar energy. In this paper, the direct use of solar energy, wind energy, biomass and hydropower will be discussed. It will be shown that the widespread application and the broad expansion of any of the renewable energy resources and the large-scale production of renewable energies are always connected with serious environmental impacts, whichever of the resources is used. They all require a relatively large area for use in the case of producing a significant amount of energy. Renewable energy production methods will be an important factor of landscape change, and will have a strong influence on landscape management. In this study, particularly, hydropower will be investigated. In the typical case of the Gabčikovo (Bős) Hydropower Station on the Danube the influences on the landscape structure and functions will be demonstrated. It will be shown that intensive human use and alteration (river engineering, the constructions of dams and hydroelectric power plants) of riverine landscapes have led to enormous degradation.

Keywords: energy utilization, solar energy, wind energy, biomass, hydropower, landscape impacts

Introduction – the significance of the safe energy supply

The continuous and reliable energy supply is perhaps the most significant prerequisite for the organization of modern societies. Everything which is necessary for a larger community, e.g. the food, water industry, appropriate homes, heating and lighting, traffic, waste deposition etc. needs energy (e.g. Boeker,

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E. and van Grondelle, R. 1999). The needed energy sums up to a high amount in our complicated and interconnected world. Even a short disruption, caused by technical failures or natural catastrophes can create dangerous situations and sometimes great social tensions. By now, it is clear that the sustainability of human societies requires a safe and smooth-running energy supply.

Since the first energy crisis in the early 1970's, every decision maker knew that energy supply is a vulnerable and sensitive issue and energy consumption should not grow. However, in spite of all the considerations, energy consumption has steadily increased from approximately by 300 EJ/year in 1980 to about 550 EJ/year today (*Figure 1*).

The analysis showed that there was a strong correlation between population and energy consumption. In *Figure 2*, per capita consumptions for the period of 1980–2010 are shown. Consumption per capita is about 73 GJ/year and it reveals only a slight (~10%) increase in the last three decades. Of course, there are big differences among the regions of the world.

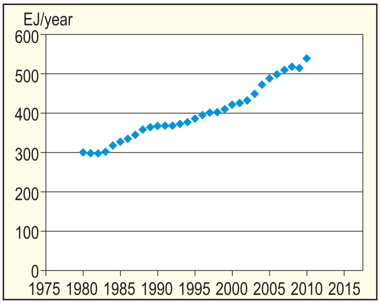

Fig. 1. Yearly energy consumption of the world in the period of 1980–2010. *Source*: Compiled by the authors based on EIA data, 2013

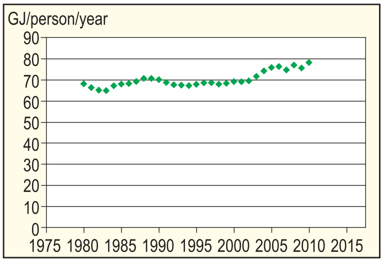

Fig. 2. Per capita yearly energy consumption of the world in the period of 1980–2010. *Source*: Compiled by the authors based on EIA data, 2013

The almost stationary nature of per capita energy consumption suggests that the energy consumption will grow at least proportionally with population growth. We should be prepared for an increasing need of energy in the medium term, as the world population is estimated to grow from 7.1 billion (2012) to at least 9 billion by 2050.

The present energy consumption is assured by up to more than 80% by fossil fuels, and besides the small contribution of nuclear energy (2.7%), the share of renewable energy resources is only 16–17% (EIA, 2013). In the future, the extensive use of fossil fuels will be limited partly by the restricted resources, by unacceptable effects on the environment and by their contribution to climate change. The effectiveness of energy saving projects seems to be limited (Vajda, Gy. 2009) and the extension of nuclear energy is debated, so the introduction of renewable energy resources is inevitable in the near future.

The present work assumes the necessity of the widespread expansion of the most important renewable energy resources. We shall outline the environmental effects of these alternative energy production methods, with special emphasis on the landscapes. After some general remarks, a case study of landscape degradation caused by the Gabčikovo (Bős) Hydropower Station will be presented, and the consequences of renewable energy production will be shown, as well.

Survey of environmental aspects of renewable energy production

The most important renewable energy production methods are the following: solar energy, wind energy, biomass energy and hydropower[3] (hereafter the expression "renewable energy resources" will be used). It is proved that all of them are able to generate a considerable amount of energy for human use.

Many illusions are connected with the widespread usage of renewable energy resources. The main reason of making them desirable is the low emission of harmful byproducts. It is true even for the application of biomass which is neutral to carbon dioxide emission in regard to the whole production cycle.

The major problem of renewable energy resources is that all of them occupy huge areas when the objective is to generate a great amount of energy. The facilities for solar energy, such as photovoltaic elements or mirrors cover large areas, wind turbines need many wind power stations, the production of biomass needs huge arable fields and the hydropower stations have big reservoirs. The areas with any of the above mentioned facilities for energy production can hardly be used for anything else. The use of renewable resources changes the whole surrounding environment. In the case of solar energy and wind power, there are serious difficulties caused by the considerable fluctuations in production rates. There are no technologies to store surplus energy. Even the power coming from a hydropower station and the production of biomass depend on the meteorological circumstances, but they can be planned for a longer period. Biomass is the only renewable energy resource which has a storage capacity.

The comparison of the energy sources, from the point of view of the environmental effects, is a hard task. In the cases of the renewable energy resources, the capacity of a facility is always much bigger than the actual amount of the produced energy. The basic starting point is that the comparison must be made for the same amount of produced energy.

Characteristics of renewable energy resources

Renewable energy resources represent very different energy production methods. The scientific, physical and biological backgrounds are completely differ-

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[3] Wave, tidal and geothermal energy are also renewable energy sources, however, their importance is less and therefore we did not analyze them.

ent and even the principles are not the same. Therefore, the survey of the most important characteristics of renewable energy sources should be performed individually.

There are two ways to use *solar energy*. It is possible to produce electric energy by the irradiation of photovoltaic (PV) elements and it is feasible to use the heat which is generated by solar irradiations.

PV technology is one of the most rapidly developing branches of the materials science (Wagemann, H-G. and Eschrich, H. 2007). The most informative parameter is radiation efficiency. The efficiency of the PV elements nowadays is about 7–10% in mass production (in laboratory it is up to 40%). There is a big development potential in commercial PV elements. There is about 12 GW installed capacity (2012) in the world and it is growing very fast, by 40–50% a year. However, today the contribution of the PV energy supply to the produced electric energy is very low; it is below 0.1% (EIA, 2013).

The other possibility to use solar energy is to apply it as a heat source. It is feasible to build solar farms for electric energy generation. Using mirrors in order to concentrate radiation, and electric generators can be driven by the generated heat.

Large areas covered by PV elements and mirrors are needed for the utilization of the solar energy. An estimate for the power density of the achieved average power is about 7–10 W/m^2 (Szarka, L. and Ádám, J. 2009). It means that areas up to 100 km^2 should be covered by a facility with a potential of 1 GW$_{el}$ on the average. Such a facility is a dominant element of the landscape.

Wind energy (Kaldellism, J.K. and Zafirakis, D. 2011) has a significant potential close to the sea. However, its ability to produce energy decreases with the distance from the seashore. In the central parts of the continents, the average wind-velocity is significantly lower. Therefore, the availability of wind power stations is close to 50% at the seashore and it is difficult to find places for about 25% availability in a continental country like Hungary. The total installed wind power capacity was well over 250 GW in 2012 and it is growing very fast, first of all, in Europe, North America and China.

The major difficulty of applying wind energy is the big fluctuations of its distribution in time. This problem can be solved by coupled hydropower systems or by spinning on gas turbines.

The height of a modern wind power station is close to 100 meters and its nominal capacity is about 1.5 to 2 MW. Its average power is about 100 kW in a country without a seashore. To have an energy system which produces 1 GW$_{el}$ power on the average about 1,000–2,000 wind power stations are needed. According to Szarka, L. and Ádám, J. 2009, the average power density of wind energy is 1.2 W/m^2. In the case of major wind power use landscape would be dominated by wind turbines.

There are many controversies about *biomass energy*. On the one hand, it is an important agricultural activity creating jobs for people. On the other hand, it can take away large areas from food production. The basic problem with biomass is energy low efficiency photosynthesis.

The areal density of biomass energy use is about 0.4 W/m^2 for electric power production (Szarka, L. and Ádám, J. 2009). It means that about 4,000 km^2 should be covered by appropriate energy plants for 1 GW$_{el}$ average electric power. The produced energy grasses or woods decrease biodiversity, creating monocultures of sublimated plants of the same age (like locus-tree, hybrid poplars, willow species etc.) leading to landscape degradation.

Hydropower has been used by human society for several thousands of years. Today we have well-known, reliable and proved technologies. Hydropower has a significant share in the electric energy production of the world (~17%).

Hydropower has many advantages. There is no fuel cost and the working costs are low. It emits no harmful materials. Dams are a good tool against flood and support shipping on the rivers. On the other hand, the construction of a hydropower station is time-consuming and costly. In the case of big hydropower stations, big areas are generally flooded. The power stations are non-native landscape elements, sometimes huge constructions.

Hydropower stations have an estimated average areal power density of about 14 W/m^2 (Szarka, L. and Ádám, J. 2009). A reservoir of about 70 km^2 area created for a hydropower station produces 1 GW$_{el}$ power on the average. Such an artificial lake is a determining element of the landscape changing almost all characteristics of it.

There are several serious analyses which dealing with the environmental effects of the renewable energy sources (e.g. Community Research, 2003). The studies do not deal with the landscapes and landscape details. A thorough analysis is only possible if each individual case is discussed separately (Owen, A.D. 2004, and Hemiak, J., 2011).

In the following part of the paper, as an example, a case study will be presented to show the effects of the Gabčikovo (Bős) Hydropower Station (GHPS). The GHPS was built on the Danube, at the border between Slovakia and Hungary *(Photos 1–2)*. The power station is a dam-on-the-river type facility. The installed electric power capacity is 749 MW$_{el}$. According to official data of the Slovak Republic, the average of produced electricity of GHPS in 15 years is ~259 MW$_{el}$ (see e.g. Bödők, Zs. 2008).

80% of the Danube water was diverted through the dammed lake at Čunovo (Dunacsún) into the artificial service channel for energy production. The diversion of the Danube was a fundamental turning point in the ecological functioning of the riverine wetland system.

Photo 1–2. The Gabčikovo (Bős) Hydropower Station (Photos: Kɪss, Á.)

Landscape effects: the Gabčikovo (Bős) Hydropower Station case study

The complex ecosystem of large floodplain rivers with their enormous variety of diverse habitats in a relatively small area contributes to the natural biodiversity of an ecoregion considerably. However, with river regulation and the increasing use of floodplains, a significant proportion of the natural functions of the ecoregions was lost.

Covering almost 36,500 hectares, Szigetköz in Hungary is the largest semi-natural floodplain area in the Danube Valley of Eastern Central Europe (*Figure 3*). Its wetland habitats are of outstanding importance. Due to the geological, geomorphological, climatic, hydrological and soil properties of the region, a great habitat diversity developed. The sites of highest natural value are protected by law as parts of the Szigetköz Landscape Protection Area (1987).

The highly varied topography of the region, plains, sand dunes, bars, islands of various sizes and a peculiar hydrographical system with oxbow lakes and various types of aquatic habitats, sustains a wide range of biotopes from dry terrestrial to aquatic biotopes (*Photo 3*). Vegetation, flora and fauna are remarkably diverse, including aquatic, marsh, swamp and meadow communities, willow-poplar (softwood) and oak-ash-elm (hardwood) forests, oakwoods and the forest-steppe vegetation of the sand ridges were all preserved in an almost natural state until diversion of the Danube (Sɪᴍᴏɴ, T. *et al.* 1993; Gᴇʀɢᴇʟʏ, A. *et al.* 2001).

River-floodplain systems have a special mosaic-like landscape structure. Intensive human use and the alteration of riverine landscapes have led to enormous degradation, especially in highly industrialized countries (Dʏɴᴇsɪᴜs, M. and Nɪʟssᴏɴ, C. 1994; Sᴄʜɪᴇᴍᴇʀ, F. 1999; Hᴏʜᴇɴsɪɴɴᴇʀ, S. *et al.* 2005). The

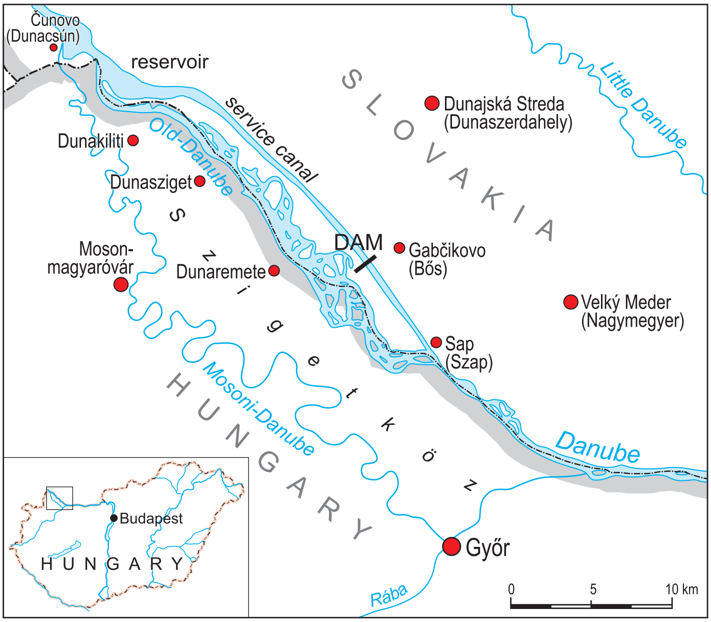

Fig. 3. Szigetköz at the border between Hungary and Slovakia

Photo 3. Dunasziget side-branch system (Photo: Szabó, M.)

related problems are recognized by the society and by the governments. Their interest to restore ecosystem functions of regulated and dammed rivers is very significant. That recognition is also emphasized in the EU Water Framework Directive (WFD, 2000).

The determining ecological factor of floodplains is the cycle of flooding and drying. The hydro-, morpho-, pedo- and biodynamic processes of natural floodplain areas determine the variety of landscape structures and their functions.

Landscape changes caused by the Gabčikovo (Bős) Hydropower Station

The hydrological regime and the hydro-morphological processes are the most important landscape-forming factors playing an essential role in landscape evolution in Szigetköz. The most important driving forces of river geomorphology are the volume and the temporal distribution of water supplied from upstream, the sediment volume and character. Local climate (particularly the occurrence of a freezing in winter and an extended dry season) as well as the nature of the riparian ecosystems are also important.

The first significant water management interventions directly forming the Szigetköz water system were water regulations in the 19th century. As a consequence of this river engineering, the area of floodplain habitats considerably decreased (Szabó, M. 2011). The second large effect was the construction of Gabčikovo/Bős–Nagymaros Dam in the frame of the Czechoslovakian–Hungarian joint project at the beginning of 1980's. In 1989, due to the increasing awareness of the environmental and ecological aspects and the protest against the dam system, the Hungarian Government suspended the project.

In October 1992, the Czechoslovak government dammed the Danube at river-km 1,851.75 and diverted it into a 29 km-long canal. Thereafter, Hungary had no influence on discharge into the main Danube channel. As a consequence, the water level of the river reaching Szigetköz between Čunovo (Dunacsún) and Sap (Szap) dropped by 2–3 m within a few days and several side channels of Danube dried out. In the following two years, the flow of water practically stopped on the active floodplain branches cut off from the main riverbed. At the same time, the surface of point bars emerged in the river bed (*Figure 4).*

Groundwater level and the capillary moisture conditions are essential factors of wetland ecology, and also for agriculture. Groundwater levels markedly decreased after the diversion and remained so even after the construction of the underwater weir in 1995. They stayed under the mean level even after the subsidence of the water level of the Danube and the groundwater level by 2.5–3.0 meters in less than a week (*Figure 5*). The wells in the figure are between Dunakiliti and Dunaremete, close to the main Danube channel.

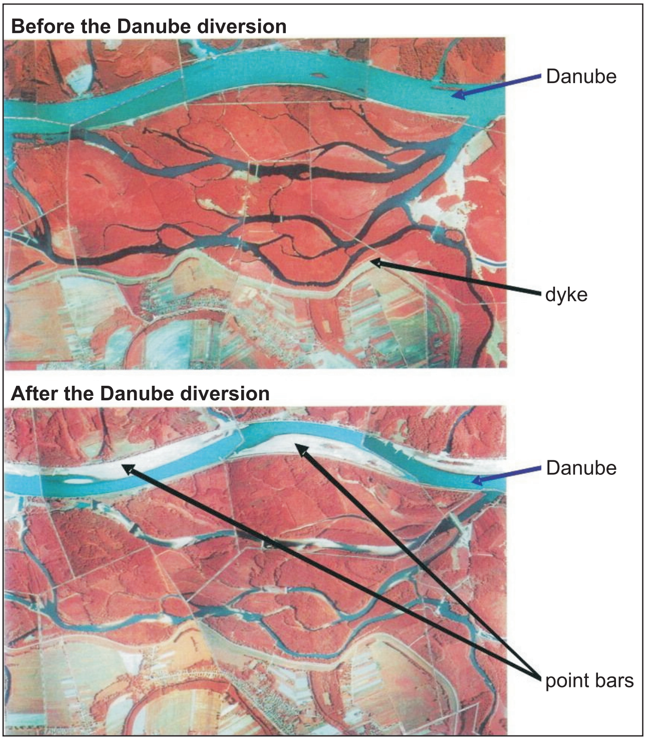

Fig. 4. Infrared image of the Danube branch system. 12 June 1990, before the Danube diversion (upper image); 8 September 1993, after the diversion (lower image). Aerial colour infrared photos taken at altitude 2,500 m a.s.l. Processed by ARGOS Studio, Budapest

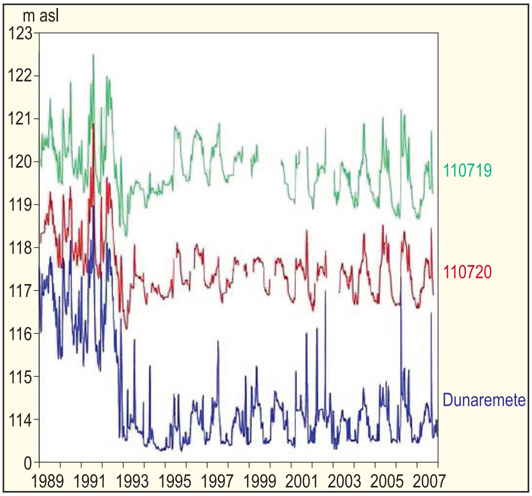

Fig 5. Two weekly means of surface (Dunaremete) and groundwater levels, wells No. 110719 and No. 110720. Blue line: gauge at Dunaremete; red and green lines: groundwater levels in wells No. 110719 and 110720, respectively. *Source*: Hungarian Hydrological Database

This abrupt change had a severe impact on the ecosystems in Szigetköz, especially on fish and other aquatic biota, as well as on alluvial forests in the active floodplain and on several habitats of the former floodplain. The area of wetlands and the diversity of ecosystems decreased. In line with that, the area of the degraded, characterless dry grasslands and woodlands increased (Fitzmaurice, J. 1996; Gergely, A. *et al.* 2001; Jansky, L. *et al.* 2004; Szabó, M. 2007).

Aquatic habitat quality deteriorated considerably at the same time. *Figure 6* shows the decline of sand and gravel bars of different succession stages. During the implementation of the Gabčikovo (Bős) Hydropower Station, the remaining point bars in the main channel were turned into permanent softwood stands.

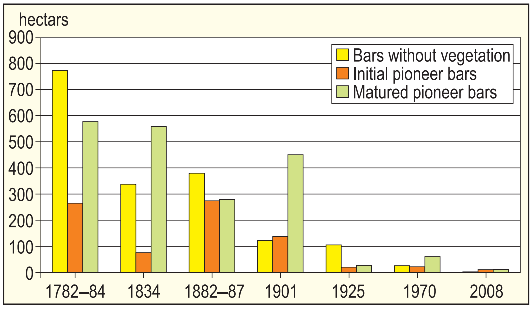

Fig. 6. Change of the total area of unvegetated and vegetated sand and gravel bars in hectares. *Source*: Ijjas, I. *et al.* 2010

Summarising the above statements, construction of Gabčikovo (Bős) Hydropower Station had the following consequences:

- Reduced or disconnected riverine – floodplain interactions.
- Alteration of hydromorphological dynamics of the Danube: reduction of bed load transport by upstream dams.
- Changes of landscape structure and function.
- Changes of biodiversity because of the extinction of aquatic and wetland species and because of the habitat's drying.
- A number of native wetland species became threatened.
- Spreading of several non-native invasive species in dry habitats.
- These are all irreversible landscape changes.

Conclusions

The investigation on the effects of the Gabčikovo (Bős) Hydropower Station was only an example for the complex influence of a large energy generating facility on the environment and landscape. In similar cases, the environmental effects of power stations should be accompanied by have similar discussions.

However, the present energy supply system using fossil fuels up to 80% cannot be maintained not even for the coming decades. Renewable energy sources should have a major role in the future. The methods of renewable energy resources for the production of large amount of energy have grave effects on the environment.

The effects of these types of power stations on the landscape and on the environment are significant. There will be landscape structure and function changes by using renewable energies causing the degradation of habitats and ecosystems. These prospects must have a strong influence on general energy policy and on regional development plans.

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Hungarian Geographical Bulletin 63 (1) (2014) 17–27.
DOI: 10.15201/hungeobull.63.1.2

Solar and wind energy resources of the Eger Region

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Ilona PAJTÓK-TARI[1]

Abstract

The spatial interpolation and mapping of renewable energy resources is an important task of potential estimation of atmospheric renewable energy sources. First the global radiation on horizontal surfaces and near-surface wind speed at 10 m height above the surface (not at 60–120 m, which is the height of contemporary wind turbines) is measured. Based on standard meteorological observations, the experts of the Hungarian Meteorological Service elaborated a series of digital maps with 0.1°×0.1° resolution. The grid-point values are based on homogenised data using MASH theory and software. The study tackles solar and wind energy from four aspects. Firstly, a trial for validation of the gridded data is provided by a comparison between a single station, Eger and the very closely located grid-point values. Secondly, the annual cycles of the areal-mean global radiation and wind speed are presented, based on the gridded data of a selected area of 50×50 km. Both the averages and the standard deviations of the diurnal mean values are presented for the 1981–2010 reference period. Presenting the maps of the distribution within the area is the third issue with average and standard deviation values. Finally, the point-wise trends are drawn for both energy sources in the single grid-point used in the aspect one in 1981–2010 and also in the nearby located stations for comparison. The trend of solar energy is positive, whereas the trend for wind energy (speed cube) is negative in the given 30 year period. Since, mainly warming characterised those three decades in the Northern Hemisphere, the trends might also be interpreted as responses to the large-scale forcing, though the observed behaviour does not necessarily mean causal relationship with the global tendencies.

Keywords: global radiation, wind energy, Eger Region, annual cycle, climate change

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Introduction

The development of society and economy is often determined by climate, topography and water availability. This relationship is in the focus of our present research on renewable energy sources and energy efficiency in the Eger Energy Region, NE Hungary. Natural conditions for the utilisation of the resources and the associated societal conditions will be discussed in the paper. The Eger Energy Region consists of 23 settlements including the county seat, Eger. The area of the region is 718 km^2; its population was 92,483 inhabitants in 2009.

The present study deals with solar and wind energy. Results of spatial and temporal analyses of global radiation and wind speed data will be presented below. Gridded data values will be compared with those of one single station located very close to one of the grid-points. The annual cycle of the area-mean values and the standard deviations of the diurnal means as well as distributions will be presented. Finally, the point-wise linear trends of annual and seasonal solar radiation and wind cube values will be given for the grid-points.

Data and methods

In the meteorological practice, solar energy is observed on a horizontal surface. Wind energy is related to 10-metre height above the ground. None of them is considered as maximum available energy since the optimally directed and tilted solar cells as well as the higher-elevated wind turbines will provide more energy. Nevertheless, the smooth spatial distribution of both energy sources provide a first insight into the availability of the energy, since direction and tilt modify the energy independently of the spatial coordinates, except in the case of extreme topographical conditions. The logarithmic dependence of wind speed from the height does not explicitly vary with horizontal coordinates, either.

The presented results are mainly based on grid-point data in a ca. 50×50 km area containing the Eger Energy Region (*Figure 1*). More exactly, the gridded data are characterised by their geographic limits of are 47.6° and 48.1° Northern latitudes and 20.0° and 20.7° Eastern longitudes. The gridded data obtained by the experts of the Hungarian Meteorological Service are also available on the Internet (www.carpatclim-eu.org). The interpolation was performed for the whole country also involving some near-border stations of the neighbouring countries. Hence it is difficult to assess how many stations were involved in the interpolation. From the meta-data, one can establish that allowing 0.6°–0.6° wider areas than the rectangle, the area contains 7 stations for wind speed but only two stations for sunshine duration. The data series is available for 1961–2010, but we use the data of the 1981–2010 period which coincides with a more or less even warming period in the Northern hemisphere which is also confirmed by the recent IPCC AR5 Report (IPCC, 2013).

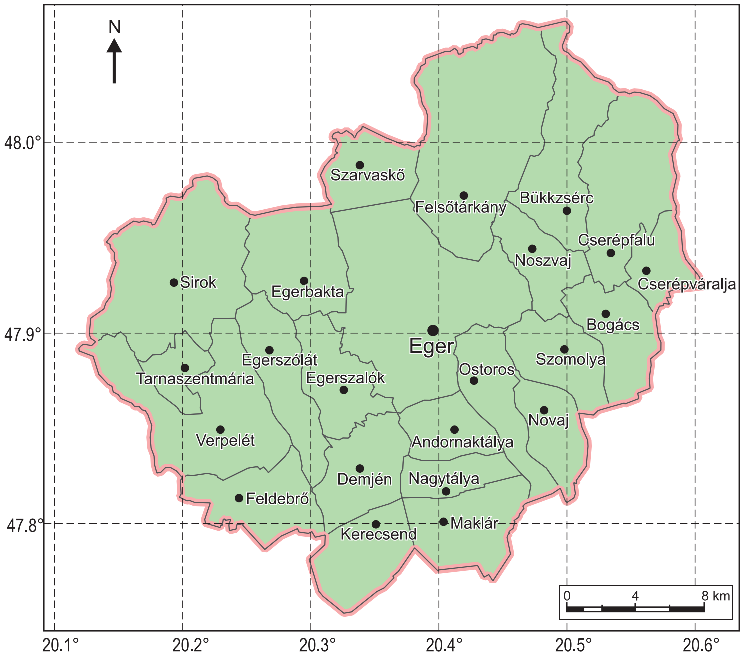

Fig. 1. The Eger Energy Region in the 0.1°×0.1° geographical network with the single station called Eger. The other lines represent the administrative areas of the 23 settlements of the region

The area of computations is characterised by variable topography, though the majority of the highest hills of the investigated rectangle are not included in the region. The average height of the rectangle is 205 m, the standard deviation of the elevation of the 48 grid-points is 150 m. The highest located grid-point is at 866 m a.s.l., whereas the lowest point is at 86 m a.s.l.. There are 12 grid-points below 100 m a.s.l. and again 12 grid-points above 300 m a.s.l.. For these features are considered by the interpolation methodology is applied.

The input data of the stations underwent on a homogenisation process ("MASH" by Szentimrey, T. 1999) to avoid non-realistic fluctuations and to obtain a statistically optimal interpolation ("MISH" by Szentimrey, T. and Bihari, Z. 2006). The latter does not only use the spatial correlation of the elements but also the temporal correlation which is not known in any other spatial interpolation methodology. Both statistical processes are described by the authors at http://www.carpatclim-eu.org/docs/mashmish/mashmish.pdf.

In the given database wind data are derived from direct measurements, but solar radiation data are estimated from sunshine duration applying the method of Angström, A. (1924) modified by Prescott, J.A. (1940).

For comparison, the point-wise observed data measured by the standard meteorological station of Eger (47.90° N, 20.39° E, 225 m a.s.l.) are also used for much shorter periods, namely the data of 2001–2010 for global radiation and those of 1996–2010 for wind speed. The point-wise values are compared with the grid-point data at the point of 47.90° N latitude and 20.40° E longitude. One must note that the station Eger was not involved in the grid-point value derivation due to the sparse data availability in 1961–2010.

The statistical calculations applied below are fairly simple: averaging is based on the diurnal values. Standard deviations are also computed for the diurnal values to represent diurnal variability of the available energy. The trends are determined by the method of least squares. The significance of the trends is not estimated, the correlation coefficients are added for orientation.

The validations of the gridded data both for global radiation and wind speed cube for Eger are presented in the next part of the paper. The validation is crucial from the point of view of feasibility to apply the gridded data in the evaluation of energy potential in the region.

The annual cycles of the gridded global radiation and wind speed data based on the area mean values will also be presented. Not only the annual cycle of the means but also the standard deviations are in the scope of the evaluations to describe the stability of the available potential.

The estimated spatial differences for the climatic means and standard deviations of January and July months will be detailed too. Geographical distribution around the mean values is also mapped exhibiting interesting spatial patterns despite the small size of the investigated rectangle.

Finally, we return to the point-wise values of Eger to explore the long-term tendencies in the time variations of global radiation and wind cube at 10-m height.

Validation of the grid-point data

The first important question concerning the grid-point data is whether they reflect the real values correctly, especially under the circumstances of complex topography. We could make this comparison only between the meteorological station of Eger and the nearby grid-point. The horizontal distance between them is less than 1 km. Note that the station was always involved in the interpolation.

Global radiation

Table 1 represents a fair agreement between the global radiation of grid-point (R_{cc}) and the observation by the station (R_{obs}). The difference between the

Table 1. Basic statistics for global radiation in Eger and in the nearest grid-point

MJ/m^2/day	R_{cc}	R_{cc}	R_{obs}
Period	1981–2010	2001–2010	
Mean	12.00	12.27	12.06
Median	10.67	11.00	10.61
Standard deviation	7.59	8.36	8.44
Minimum	2.09	0.39	0.00
Maximum	29.46	31.25	
No of days	10,957	3,652	

means of the 30-year period and the means of the 10-year period is rather significant though in case of comparing the shorter station data series with the identical gridded data, the difference is increasing. That statement also refers to the medians. The standard deviation values taken from the identical ten-year periods, however, are closer to each other. The maxima and the minima are fairly close to each other, as well. So, the grid-point values can be considered as a fair approximation for global radiation with no considerable biases.

Wind speed

Unfortunately the grid-point values of wind speed cubes (F_{cc}), i.e. the first approaches of the available wind energy (*Table 2*) do not perform so well. The 30-year climate estimate is 50% larger than values observed at the station (F_{obs}) during a 15-year period. About half of the difference disappears if we compare the identical time periods. The remaining difference is still 25%, i.e. the gridded values overestimate the wind cubes by that value. The medians are also a bit overestimated.

Table 2. Basic statistics for wind-cube in Eger and in the nearest grid-point

(m/s)^3	F_{cc}	F_{cc}	F_{obs}
Period	1981–2010	1996–2010	
Mean	30.07	25.07	19.94
Median	10.65	10.22	9.26
Standard deviation	69.29	52.18	34.38
Minimum	0.02	0.06	0.00
Maximum	1,702.21	1,401.17	614.13
No of days	10,957	5,479	

The standard deviation of daily values differs even more significantly. The difference between the 30 years grid-point values and the 15 years station values is above 100%, roughly the half of which remains when comparing the identical periods but different data. This strong overestimation peaks in case of maxima with almost threefold difference between the 30-year gridded and 15 years local data. Due to the difference, the statistics of wind will be mapped only for its first power (instead of its cube).

We would like to emphasise again that the Eger station was not involved in the grid-point value derivation, since the observations were performed at different sites during the basic 1961–2010 interpolation period. The above validation is a good example for any point of the Eger region, because the grid-point data are completely independent from the station-data.

Areal-mean daily statistics

Averages of global radiation and wind speed

Figure 2 illustrates the annual cycle of global radiation and wind speed by the areal mean values based on the gridded data, also indicating the highest and the smallest values of the 30 years average values of monthly total radiation and monthly mean wind speed. The July maximum of global radiation is slightly over the June value explained by the annual minimum of cloudiness in July.

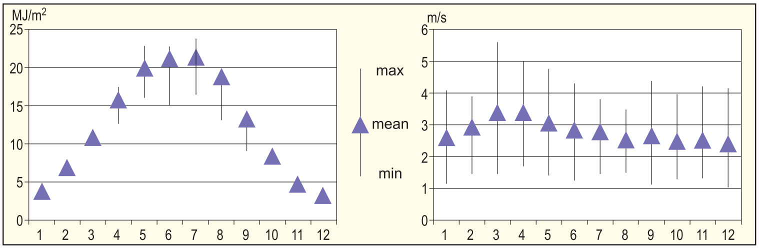

Fig. 2. Annual cycle of global radiation (MJ/m^2) (left) and the mean wind speed (m/s) (right) by the areal mean values with the lowest and highest point-wise averages in 1981–2010

Standard deviations of the diurnal values

The climatic mean values provide first insights into the available energy resources. The knowledge of diurnal variability around these values is also important. *Figure 3* presents the standard deviations for the daily sums of global radiation and the daily mean wind speed which, certainly, reflect the strong annual cycle of global radiation, but they behave differently from the annual cycle of wind speed (*Figure 2*).

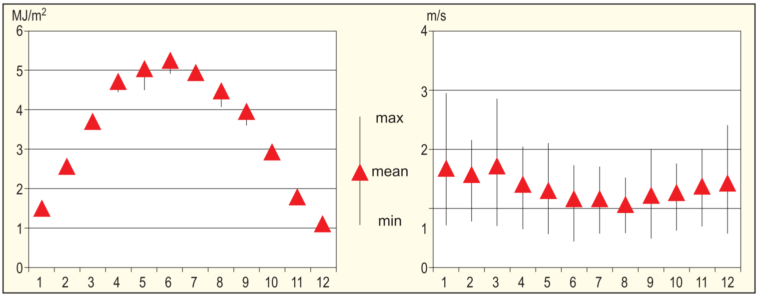

Fig. 3. Annual cycle of standard deviation for diurnal global radiation (M J/m²) and that of wind speed by the areal average values with maxima and minima of the region (1981–2010)

Mapping diurnal means and standard deviations

Global radiation

Figure 4 illustrates the spatial distribution of global radiation in January and in July. The data represent the diurnal mean values. The maps were created by the ArcGIS software. The annual cycle of global radiation is mainly determined by the astronomical differences at the given latitude, i.e. the early summer maximum of the zenith angle, the length of daylight and by the annual cycle of cloudiness which is the lowest in July.

The standard deviation maps of the diurnal data can be seen in *Figure 5*. Here, again, the fair estimation of standard deviation by the single grid-point value near Eger in the above validation allows for considering the above maps confirming the estimates of the real standard deviations. Only the peak value of standard deviation in the 47.9° N 20.0° E grid-point is influenced by the mountainous station of Kékestető located almost there, nearly 1,000 m a.s.l.. Here, cloudiness may cause strong time variations in radiation. That effect is present only in July, but not in January when there are clouds at any elevation.

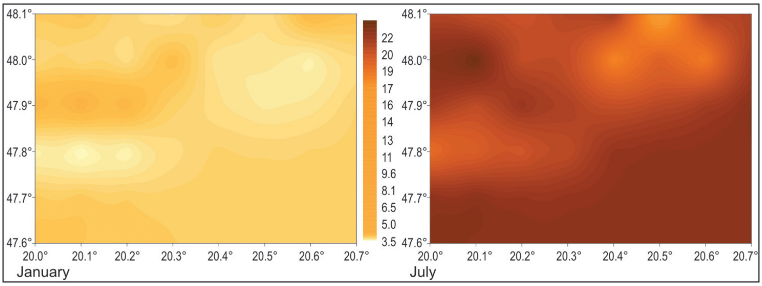

Fig. 4. Average global radiation fields diurnal global radiation at a horizontal plain by the gridded data. Units: MJ/m²

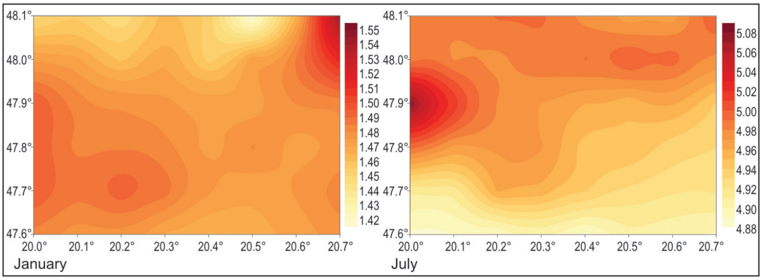

Fig. 5. Standard deviation of diurnal global radiation at a horizontal plain according to the gridded data. Units: MJ/m^2

Wind speed

Figure 6 presents similar values of wind speed at the 10 meters observation level. The maps indicate even larger relative differences within the area possibly as a consequence of over-interpretation of the topography. The maxima around a few single grid-points are not convincing, either.

The standard deviation values of the diurnal mean values of wind speed can be seen in *Figure 7*. Their structure also contains some surprising local extremities which are hardly real consequences of the real topography. Hence, even if the maps represent the linear wind speed estimates, the spatial patterns of both the averages and the standard deviation are rather uncertain.

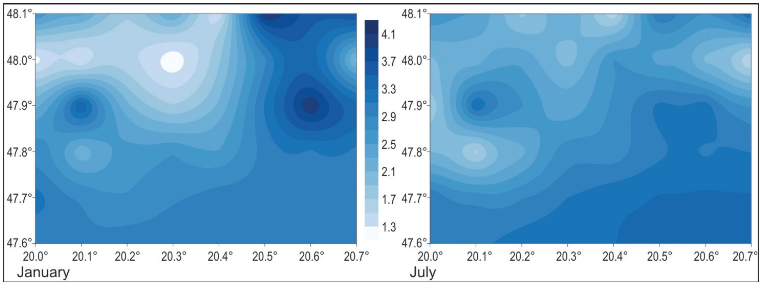

Fig. 6. Average fields of diurnal mean wind speed according to the gridded data. Units: m/s

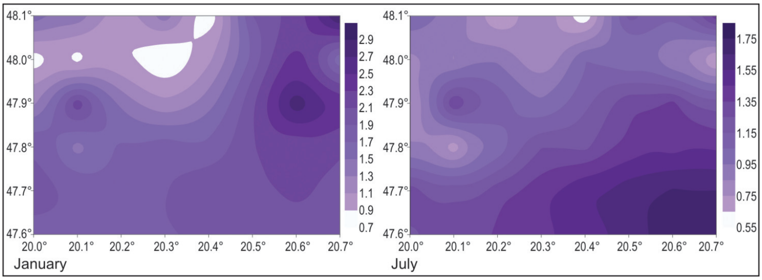

Fig. 7. Standard deviation of diurnal mean wind speed at 10 m above the ground level according to the gridded data

Observations

Global radiation

The long-term trends are presented in a single grid-point located at the shortest distance (ca. 1 km) from Eger. The CC series are based on the derived values from sunshine duration (see above). It is fairly convincing that in the last 10 years with frequent observations, the inter-annual fluctuation occurred parallel in the two series (*Figure 8).*

The annual totals of global radiation exhibit unequivocal moderate trend of 5.31 MJ/m^{2}year. Comparing it with the average value of the 30-year period, it can be establish that it is the only 1% per decade. It means that the future development of solar energy industry will hardly depend on the direct effect of climate change.

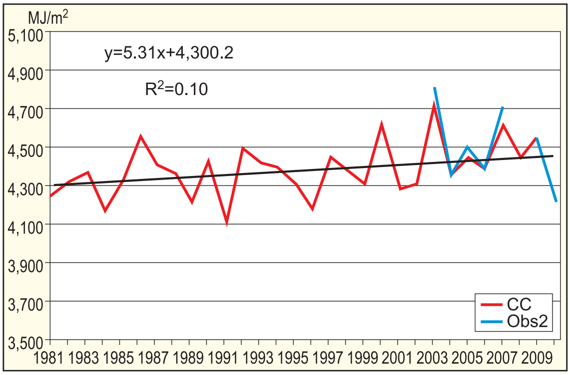

Fig. 8. Trends of annual global radiation (MJ/m^2) in the near-Eger grid-point (CC: 1981–2010) and the local observation in Eger (Obs2)

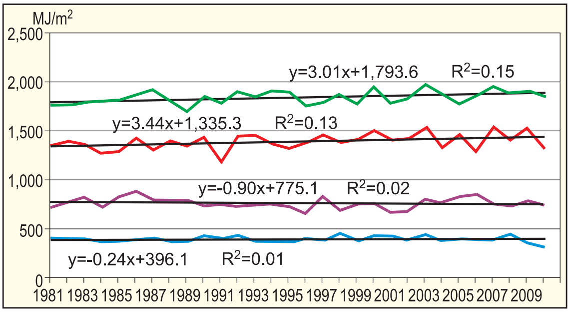

Fig. 9. Seasonal trend lines in the CC series of global radiation with the linear trend and the explained variance (square of correlation coefficient) by the given trends

According to *Figure 9* the two seasons with the highest absolute values, i.e. summer and spring exhibit increasing trends, whereas the two other seasons are characterised by decreasing trends. Both the absolute difference and the differences of steepness of the trends support the positive trend of annual global radiation presented in *Figure 8.* Since the observed 1981–2010 period coincided with a global warming period. The trends can also be interpreted as a result of a monotonically warming period of 30 years.

Wind energy

The same analysis is performed for wind cube data and their annual means shown in *Figure 10*. The diagram indicates a considerably decreasing trend in 1981–

2010. As stated previously, the differences between the gridded and the point-wise data are rather big. However, the strong biases may have been constant during the 30-year period.

The wind speed trends of seasonal means are presented in *Figure 11*. They equally demonstrate the decreasing tendency which makes the reality of the trend in the annual mean even more convincing.

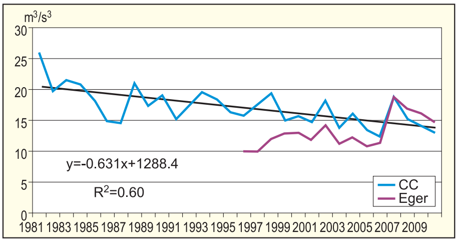

Fig. 10. Trends of the annual mean value of daily mean wind-cube (m^3/s^3) in the grid-point nearest to Eger and in the point-wise measurement in Eger

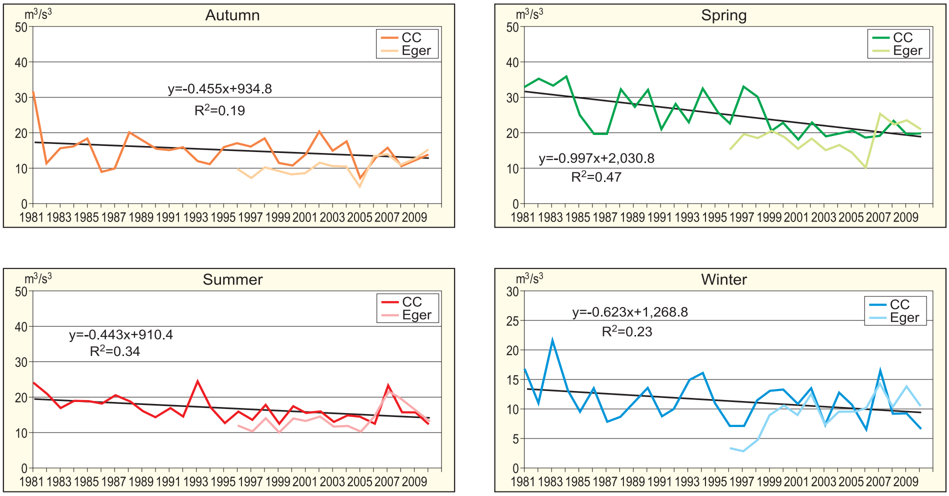

Fig. 11. Trends of the seasonal mean values of daily mean wind-cube (m^3/s^3) in the grid-point nearest to Eger and in the point-wise measurement in Eger

Discussion

The gridded global radiation data may be considered as fairly good approaches but this is not the case for wind data. In both cases, data compared with the data of Eger station were not involved in the interpolation. Hence, both experiences can be considered to be based on the comparison of independent data.

The presented mapping is based on the probably best available statistical interpolation using input data from the whole country and for some stations near the border. In principle, it promises a better estimation of real values than any other interpolation using a smaller dataset. MISH does not only use spatial but also temporal correlations, which may also improve the interpolation. Furthermore, the statistical homogenisation of the data allows avoiding the biggest errors of initial observations.

The spatial structure of the wind speed is derived without the finest spatial structure of the region. Of course, at higher altitudes where the wind turbines are generally operated, the wind field is smoother. Nevertheless, the real wind turbines would need site-specific dynamical modelling as generally requested in the feasibility studies.

The observed trends are convincing both for the increasing global radiation and for the decreasing wind speed. The positive experience of the validation for global radiation supports the established trends, which cannot be repeated for wind speed cubes. Moreover, the trends do not necessarily mean that they continue in the future if the global warming continues.

Acknowledgements: The study was supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0016 Project in Hungary. The gridded data are downloaded from Open Access data base derived by the CarpatClim Project (http://www.carpatclim-eu.org/pages/home/).

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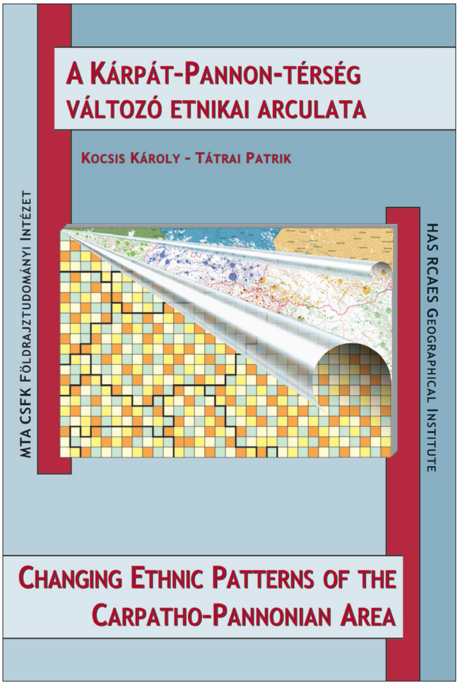
Changing Ethnic Patterns of the Carpatho–Pannonian Area from the Late 15th until the Early 21st Century

Edited by: Károly KOCSIS and Patrik TÁTRAI

Hungarian Academy of Sciences, Research Centre for Astronomy and Earth Sciences
Budapest, 2013.



This is a collection of maps that visually introduces the changing ethnic patterns of the ethnically, religiously, culturally unique and diverse Carpathian Basin and its neighbourhood, the Carpatho-Pannonian area.

The Hungarian and English volume consist of three structural units. On the main map, pie charts depict the ethnic structure of the settlements in proportion to the population based on census data et the millennium. In the supplementary maps, changes of the ethnic structure can be seen at nine dates (in 1495, 1784, 1880, 1910, 1930, 1941, 1960, 1990 and 2001). The third unit of the work is the accompanying text, which outlines the ethnic trends of the past five hundred years in the studied area.

The antecedent of this publication is the „series of ethnic maps" published by the Geographical Research Institute of the Hungarian Academy of Sciences from the middle of the 1990's, which displayed each of the regions of the Carpathian Basin (in order of publication: Transylvania, Slovakia, Transcarpathia, Pannonian Croatia, Vojvodina, Transmura Region, Burgenland, Hungary). This work represents, on the one hand, the updated and revised version of these areas, and, on the other hand, regions beyond the Carpathian Basin not included on previous maps. Thus, the reader can browse ethnic data of some thirty thousand settlements in different maps.

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Hungarian Geographical Bulletin 63 (1) (2014) 29–41.
DOI: 10.15201/hungeobull.63.1.3

Local Climate Zone mapping using GIS methods in Szeged

János UNGER[1], Enikő LELOVICS[1] and Tamás GÁL[1]

Abstract

Owing to anthropogenic activity, local climate develops in the area of built-up zones. The characteristics of built-up zones can be quantified by different methods. One of the methods is the Local Climate Zones (LCZ) classification system which describes the physical conditions of a local-scale environment of a measuring site from the viewpoint of the generated local climate. It is applicable worldwide universally and relatively easily based on objective geometric, radiative and thermal properties of the surface. The objectives of this study are to develop GIS methods in order to calculate several parameters describing the LCZs for any part of the study area using different databases and to identify and delineate the LCZ types which occur in and around the city of Szeged (Hungary) using the developed methods. As a result, six built LCZ types were distinguished and mapped in the studied urban area: "compact mid-rise", "compact low-rise", "open mid-rise", "open low-rise", "large low-rise" and "sparsely built". The developed method can be used in any urban area if the necessary input databases are available.

Keywords: climate mapping, Local Climate Zones, surface parameters, lot area polygons, GIS, Szeged

Introduction

Nowadays about half of the human population is affected by the burdens of urban environments, therefore studies dealing with the urban impact on climate are particularly important. By definition, the urban climate is a local climate which is modified by the interactions between the built-up area and the regional climate (WMO, 1983). Among the parameters of the urban atmosphere, the near-surface (screen-height) air temperature shows the most obvious modification compared to the rural area. Urban warming is commonly referred to as the urban heat island (UHI) and its magnitude is the UHI inten-

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sity (Oke, T.R. 1987). Traditionally, UHI intensity is interpreted and calculated as the difference between the temperature values of a central urban site and those of a nearby rural site.

In the literature of heat island, the terms "urban" and "rural" have no single, objective meaning as the areas around the measuring sites can be very different. For example, an "urban" site can be in a park, college ground, street canyon, housing estate, etc., while "rural" sites are placed e.g. at airports, farmlands, fields or in the suburb areas depending on the investigated cities. It makes difficult to compare the results obtained in the different settlements of the world (Stewart, I.D. 2011).

To improve the characterization of the surrounding environment of the measurement sites based on their ability to influence the local thermal and dynamic conditions of the near-surface atmosphere, Stewart, I.D. and Oke, T.R. (2012) developed a classification system. Their Local Climate Zones (LCZ) system is based on the earlier works of Auer, A.H. (1978), Ellefsen, R. (1991), Oke, T.R. (2004), and Stewart, I.D. and Oke, T.R. (2009) as well as a personal worldwide survey of heat island measurement sites and their local environments (Stewart, I.D. 2011).

The objectives of this paper are

– to develop GIS methods in order to calculate some geometric, surface cover and radiative parameters describing the LCZs for any part of the study area using different databases which are available or created for that purpose,

– to identify and delineate the LCZ types which occur in and around the city of Szeged using the calculated surface parameters by the developed methods.

Short introduction of the LCZ system and the study area

The main purpose of the LCZ system is to facilitate the characterization of the local environment around a temperature measuring site with a screen-height sensor in terms of its ability to influence the local thermal climate. To this end, the number of types is not too large and the separation is based on objective, measurable parameters. LCZs are defined as "regions of uniform surface cover, structure, material, and human activity that span hundreds of metres to several kilometres on horizontal scale" (Stewart, I.D. and Oke, T.R. 2012). The spatial extension of the zones is local because an upwind fetch of typically 200–500 metres is required for the air at screen-height to become fully adjusted to the underlying, relatively homogeneous surface (Oke, T.R. 2004). The main characteristics of the LCZ types are reflected in their names (*Table 1*).

LCZ types can be distinguished by typical value ranges of measurable physical properties which characterize the surface geometry and cover, the thermal, radiative and anthropogenic energy features of the surface (*Table 2*).

Table 1. Names and codes of the LCZ types

Built types		Land cover types	
LCZ 1	compact high-rise	LCZ A	dense trees
LCZ 2	compact mid-rise	LCZ B	scattered trees
LCZ 3	compact low-rise	LCZ C	bush, scrub
LCZ 4	open high-rise	LCZ D	low plants
LCZ 5	open mid-rise	LCZ E	bare rock / paved
LCZ 6	open low-rise	LCZ F	bare soil / sand
LCZ 7	lightweight low-rise	LCZ G	water
LCZ 8	large low-rise		
LCZ 9	sparsely built		
LCZ 10	heavy industry		

Source: Stewart, I.D. and Oke, T.R. 2012.

Table 2. Physical properties characterizing the elements of the LCZ system

Types of properties	
Geometric, surface cover	Thermal, radiative, metabolic
sky view factor	surface admittance
aspect ratio	surface albedo
building surface fraction	anthropogenic heat output
pervious surface fraction	
impervious surface fraction	
height of roughness elements	
terrain roughness class	

Source: Stewart, I.D. and Oke, T.R. 2012.

The LCZ classification system was not designed specifically for mapping but to standardize the classification of urban heat island observation sites, either urban or rural. Nevertheless, the spatial mapping of the urban terrain is a justifiable use of the system to determine the areas which are relatively homogeneous in surface properties and human activities.

In the context of the new LCZ classification system, the inter-urban UHI intensity is not an "urban-rural" temperature difference, but a temperature difference between the pairs of LCZ types (Stewart, I.D. *et al.* 2013). In this way, the application of the LCZ system gives an opportunity to compare the thermal reactions of different areas within a city and between cities (intra-urban and inter-urban comparisons) objectively.

Szeged as a study area is located in the South-Eastern part of Hungary (46°N, 20°E) at 79 metres above sea level on a flat terrain with a population of 160,000 within an urbanized area of about 40 km^2. The area is in Köppen's climatic region Cfb with an annual mean temperature of 10.4 °C and an amount of yearly precipitation of 497 mm. The study area covers a 10 km × 8 km rectangle in and around Szeged (*Figure 1*).

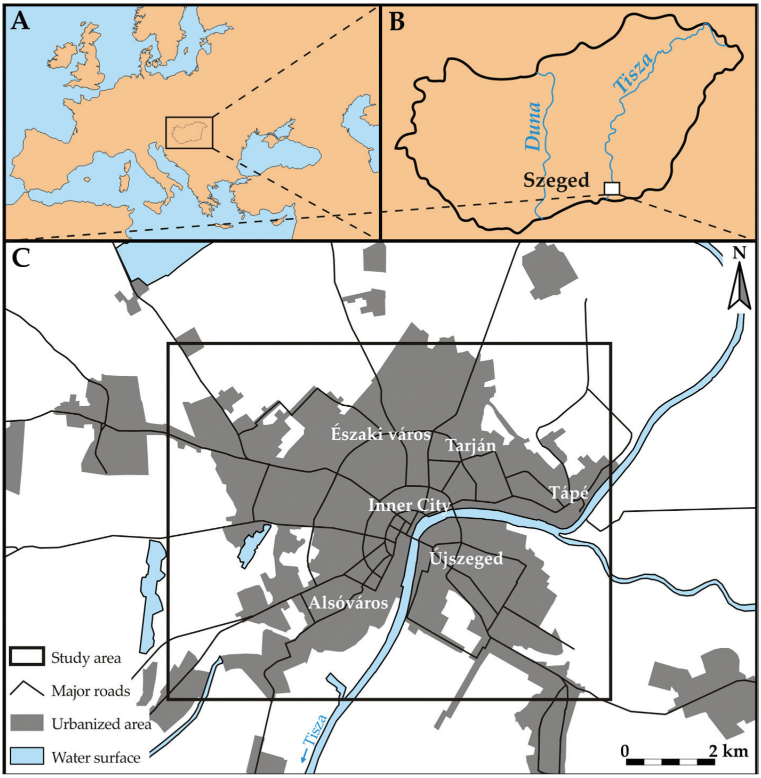

Fig. 1. Location of Szeged in Europe (A) and in Hungary(B) as well as the study area in and around Szeged (C)

GIS methods developed for LCZ mapping

Parameter calculations for lot area polygons

Using our method we can determine seven properties out of ten listed by Stewart, I.D. and Oke, T.R. (2012) for any given area inside the study area based on the available databases. From the initial parameters, we omitted the *aspect ratio* since it can be clearly calculated only in the case of the regular street network. The patterns of the *surface admittance* and the *anthropogenic heat output* were not available in the study area, either.

During the determination process of the other seven parameters the basic area of the calculation was the building block and the area belonging to it (called lot area polygon, *Figure 2*).

Fig. 2. Examples of lot area polygons in the study area. – a = building block; b = lot area polygon; c = open area without buildings

The determination of the building block footprints and lot area polygons is based on the 3D building database of Szeged which contains more than 22,000 individual buildings with building height information in ESRI shape-file format (Gál, T. and Unger, J. 2009). The calculation processes, the necessary databases and the outputs are shown in *Figure 3*.

All of the calculations were carried out with self-developed Fortran algorithms and for the visualization of the outputs, Quantum GIS was used. The calculation methods and the applied databases by parameters were as follows:

– *Sky view factor* (SVF): The input was a SVF database originated from our earlier studies (e.g. Gál, T. *et al.* 2009). During the SVF calculation, each building was considered with flat roofs and the effect of the vegetation was neglected. SVF values refer to the street level and they are averaged inside the polygons.

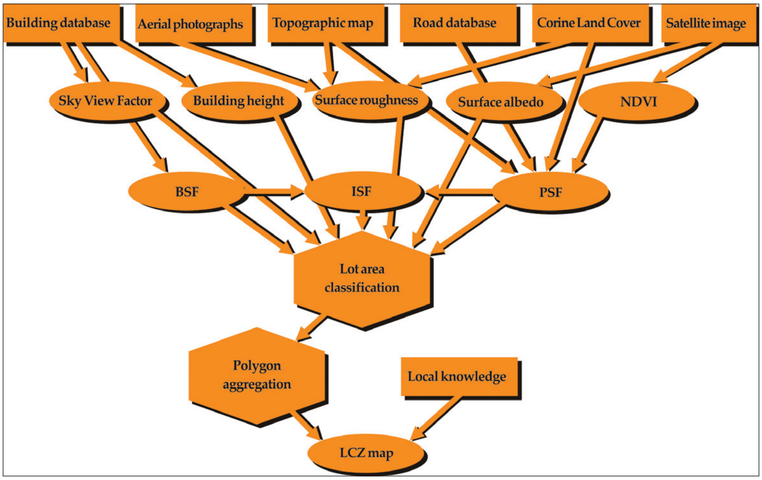

Fig. 3. Flow chart of the automated classification and aggregation of the lot area polygons to determine the appropriate size of LCZ areas

– *Building surface fraction* (BSF): The input was also the 3D building database. BSF is the ratio of the summarized footprint areas and the polygon area.

– *Pervious surface fraction* (PSF): The input was a built-up dataset calculated from RapidEye (2012) satellite image using NDVI index, a 1:25,000 topographic map, a road database and the Corine Land Cover (CLC) database (Bossard, M. *et al.* 2000). The RapidEye image (resolution of 5.16 m) was atmospherically corrected and the NDVI was calculated using bands 3 and 5 (Tucker, C.J. 1979), and the points where the NDVI was below 0.3 were regarded as a covered area. The CLC dataset was used to locate the agricultural areas as these areas have small NDVI (like the covered areas) because the amount of plants is negligible after harvest. As a second correction, the shapes of water bodies were digitized from the topographic map because in several cases the water had NDVI values very similar to the values of some building materials. As a last correction, the road database was used to locate the asphalt roads in the area because in the urban canyons asphalt roads are usually under tree cover and the roads which dissect agricultural areas do not appear in CLC dataset.

– *Impervious surface fraction* (ISF): It is the paved area outside the buildings and it can be calculated as the remnant from the total area, ISF = 1 – (BSF + PSF).

– *Height of roughness elements* (HRE): Using the 3D building database for each area, the building heights were averaged weighted with their footprint areas.

– *Terrain roughness class* (TRC): For describing the roughness, the Davenport roughness classification method was used (Davenport, A.G. *et al.* 2000). The widespread method comprises eight classes of roughness. Larger areas were classified into different roughness classes using CLC dataset with the visual interpretation of aerial photographs, the topographical map and the building database.

– *Surface albedo* (SA): As an input, the atmospherically corrected reflectance values of the 5 band RapidEye satellite image were used. Broadband albedo was calculated as an average of the reflectance values weighted with the integral of the radiation within the spectral range of a given band (Starks, P.J. *et al.* 1991; Tasumi, M. *et al.* 2008).

In order to illustrate the obtained patterns of the calculated parameters with some examples, *Figure 4.* shows the spatial patterns of two parameters in the study area. Regarding the PSF, the pattern is generally higher on the edge of the city and near the city centre.

The largest parks and green areas of the city (e.g. banks of the Tisza, the forested areas along the circle dam) also appear on the map. In the case of HRE, most of the values are between 10 and 20 metres in the inner part of the city and only a few of them (e.g. church, clinical block, educational centre, theatre) are higher than 30 metres in the Western side of the Tisza. Some blocks of flats exceed this height on its Eastern side. Family houses are generally below 5 m.

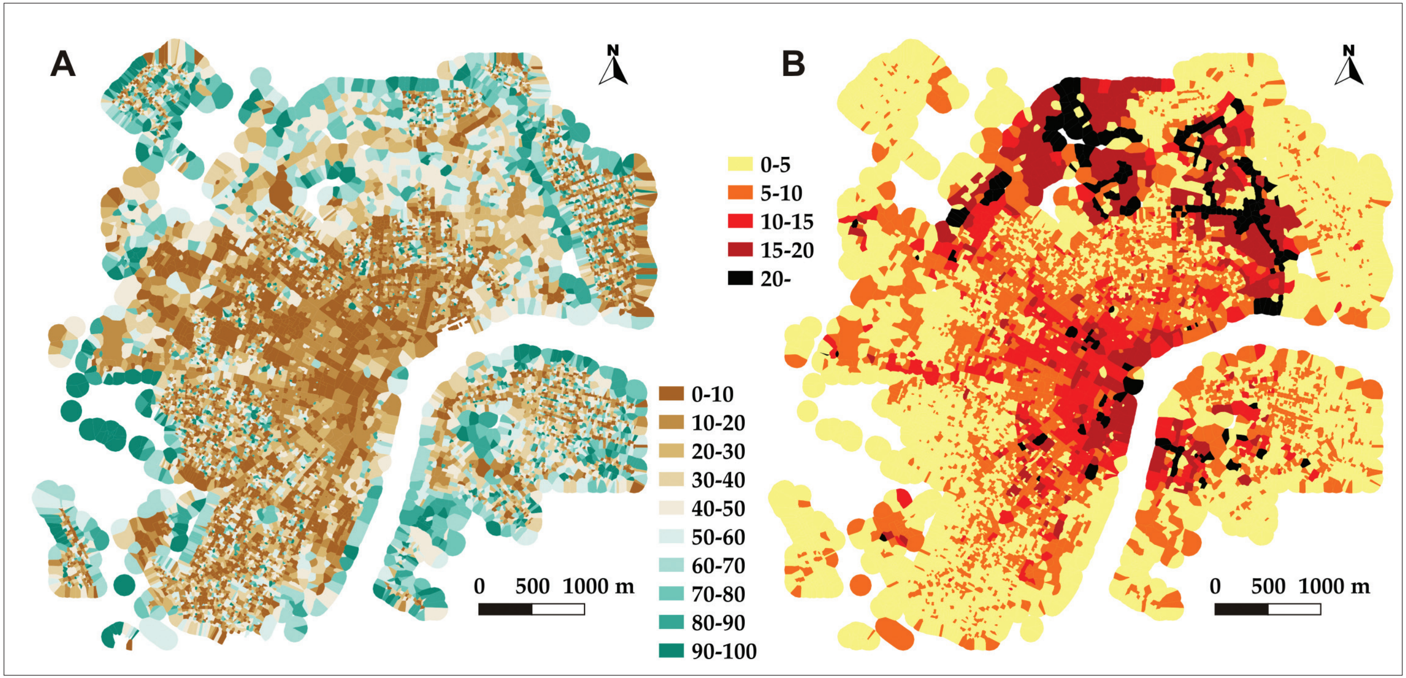

Fig. 4. Patterns of pervious surface fraction in % (A) and the height of roughness elements in m (B) based on their values in lot area polygons

To get some verification, the PSF field was compared to the European soil sealing database published by EEA (2009) which is available with a spatial resolution of 20 metres. The patterns of the two PSF databases are very similar to each other, both represent the structure of the city well. The main difference between them is that the EEA database is less detailed.

Aggregation and generalization of lot area polygons

In line with the definition of LCZs, the lot area polygons classified into the same or similar LCZ classes (*Figure 5.* A) were merged into zones of hundreds of metres to several kilometres (*Figure 5.* B). In that case, we meet the minimum condition that the central point of an LCZ is at least 250 metres from the boundaries of the zone, such the relatively homogeneous area constitutes an area with a radius of 250 metres or greater. In order to get LCZ areas with appropriate size, the lot area polygons were aggregated into groups according to the following procedure.

First, the polygons were classified separately.

(1) From the obtained surface parameters, areal mean or percentage values were calculated to represent the polygons. Seven scores were assigned to each LCZ categories by polygons according to its fit (*Figure 6*) into the typical ranges given by Stewart, I.D. and Oke, T.R. (2012) and then they were summarized.

Two of the best fitting LCZ categories were assigned to every polygon (for each polygon the best was LCZ_1 and the second best was LCZ_2) if their scores were high enough. In the case of too low scores to fit to any LCZ categories, the polygon was considered unclassified.

Secondly, the lot area polygons were merged according to their LCZ categories and their locations related to each other.

(2) If a small polygon was located inside another polygon, the first LCZ class of the small polygon was set to the same as the outer polygon.

(3) If all of the neighbours of a polygon (except perhaps one of them) belonged to the same LCZ class, the class of the polygon was modified to the same as its neighbours.

(4) If a polygon did not have any neighbours in the same class, there were two cases: if there was a neighbour with the same LCZ_1 like the polygon's LCZ_2 or same LCZ_2 like the polygon's LCZ_1, the LCZ_1 of the polygon was set to the same like its neighbour; if there was a neighbour with LCZ_1 category similar to the polygon's LCZ_1 category, the LCZ_1 of the polygon was modified to the LCZ_1 of the neighbour.

In this context, 'similarity' refers to the condition when categories share certain properties. For example, the "compact mid-rise" or LCZ 2 class

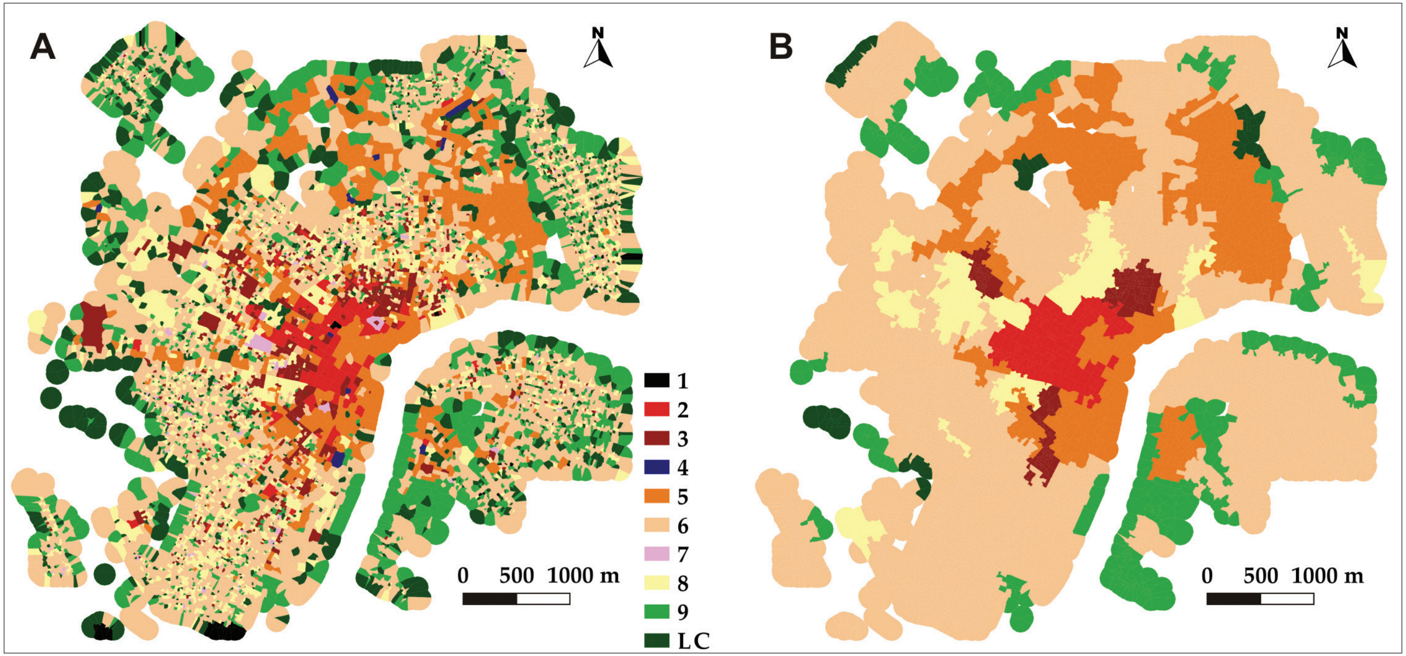

Fig. 5. Originally classified lot area polygons (A) polygons aggregated into groups and (B). – LC = land cover LCZ types. 1–9 = For explanation see the text.

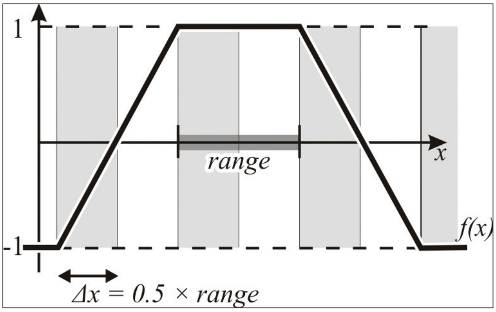

Fig. 6. Function of score assignment to a polygon according to its surface parameter values

is similar to the "compact high-rise" (LCZ 1) and "compact low-rise" (LCZ 3) classes as they belong to the same density category. Likewise, the "open mid-rise" (LCZ 5) class can also be regarded as similar to LCZ 2 as they share the same height category.

(5) The LCZ categories of the remaining unclassified and non-aggregated polygons were defined as the most frequent classes of their neighbours.

Thirdly, the groups of adjacent polygons with a given LCZ category were investigated according to their spatial extension.

(6) If the area of a group covered at least one circle with a radius of 250 m, it was regarded as an independent LCZ area.

(7) The polygons of groups which did not satisfy the criterion of the size were merged without considering their properties if they were adjacent. If the obtained group was large enough, the category of the group was set to the most frequent category of its parts; otherwise it was joined to one of the adjoining LCZ areas which had the largest number of contacting lot area polygons with it.

Finally, some manual corrections were made according to aerial photographs and our local knowledge of the area because of inadequate detachment of the zones. The most difficult task is the recognition of LCZ 8 (large low-rise) from the surface parameters. As a final result, we obtained several LCZ polygons in ESRI shape-file format suitable to produce maps or to extract spatial information as well.

LCZ map of Szeged

As the study area covered mostly the urbanized parts of Szeged, we focused on the "built" LCZ types. Due to the peculiarities of the city, it was to be expected prior to calculations that some "built" types did not occur there, namely the high-rise, lightweight low-rise and heavy industrialized zones (LCZ 1, 4, 7 and 10).

Aggregating the similar lot areas using the methods described above (the result is shown in *Figure 5.* B) and supplemented by the authors' local knowledge on the study area, a generalized LCZ map was obtained (*Figure 7*).

Fig. 7. The obtained LCZ map of Szeged. – LCZ 2 = compact mid-rise; LCZ 3 = compact low-rise; LCZ 5 = open mid-rise; LCZ 6 = open low-rise; LCZ 8 = large low-rise; LCZ 9 = sparsely built

During the generalization, the outlines of the polygons were simplified, some corrections and supplements were made according to aerial photographs and our local knowledge. For example, for our method the most challenging task was to separate LCZ 6 (open low-rise) and LCZ 8 (large low-rise) because of their similar properties. Water surfaces were not handled by our algorithms because they were located outside the lot area polygons for which the calculations were applied. These surfaces were digitized from the topographic map and the areas on the edges of the city without building database (and so without lot area polygons) were also digitized.

As the map shows, the remaining six "built" types cover the urbanized parts of Szeged (LCZ 2, 3, 5, 6, 8 and 9). Their extent and the number of constituent lot area polygons are different (*Table 3*) and altogether they cover an urban area of 46.50 km^2 in Szeged.

Table 3. Areal extensions of the delineated LCZ zones

LCZ zones	Number of polygons	Summarized	Mean	Largest
		area, km^2		
LCZ 2	176	0.63	0.63	0.63
LCZ 3	248	0.67	0.33	0.35
LCZ 5	796	4.35	1.18	1.98
LCZ 6	9,303	19.63	2.80	5.22
LCZ 8	798	5.91	2.96	5.87
LCZ 9	566	15.32	1.93	5.71

Conclusions

In this study we determined the LCZ types in Szeged which are representative for the urbanized area of the city using seven geometric, surface cover and radiative properties from the ten listed by Stewart, I.D. and Oke, T.R. (2012). The values of the properties were calculated by GIS methods developed for that purpose and for the appropriate classification of the selected areas, we used also our local knowledge about the districts of Szeged. As a result, six built LCZ types were distinguished and mapped in the studied urban area.

The developed method could be used in any urban area if the necessary input databases are available. The further steps in our investigation will be the application of the developed method in the LCZ mapping of Novi Sad (Serbia) and the discussion about the relation of the findings of this paper to the existing knowledge on an international level. Furthermore, we are going to acquire and utilize more GIS databases (e.g. EEA Urban Atlas) to have an even more detailed description of the urban surface.

Acknowledgement: The study was supported by the Hungary-Serbia IPA Cross-border Co-operation Programme (HUSRB/1203/122/166 – URBAN-PATH) and in the case of the second author by the TÁMOP 4.2.4.A/2-11/1-2012-0001 „National Excellence Program – Elaborating and operating an inland student and researcher personal support system convergence program" which project was subsidized by the European Union and co-financed by the European Social Fund. In the case of the third author this research was realized in the frames of the Hungarian Scientific Research Fund (OTKA PD-100352) and the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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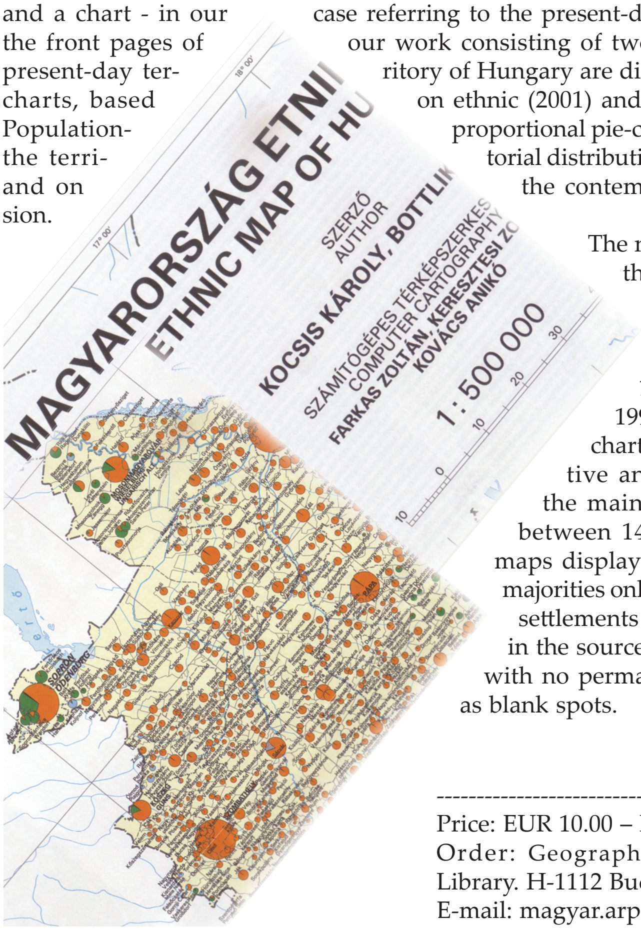
Ethnic map of Hungary 1941 + Ethnic map of present territory of Hungary 2001

Scale 1:500 000

Authors: KOCSIS, K. and BOTTLIK, ZS.

Geographical Research Institute, Hungarian Academy of Sciences, Budapest, 2009

The latest (eighth) piece of ethnic map series of the Carpathian Basin was an attempt to draft the changes that have taken place in the ethnic structure during the past five hundred years as well as to display its present state with the help of ethnic maps and a chart - in our case referring to the present-day territory of Hungary. On the front pages of our work consisting of two sheets ethnic maps of the present-day territory of Hungary are displayed with the help of pie-charts, based on ethnic (2001) and mother tongue (1941) data. Population-proportional pie-charts provide information on the territorial distribution of the major ethnic groups and on the contemporary administrative division.



The nine supplementary maps on the reverse show the lingual-ethnic composition of the present-day territory of Hungary in 1495, 1715, 1784, 1880, 1910, 1930, 1941, 1990 and 2001 respectively. The chart here explores the quantitative and proportional changes of the main ethnic groups' population between 1495 and 2001. The series of maps displays absolute or relative ethnic majorities only in the inhabited areas of the settlements which had been mentioned in the source referred. Uninhabited areas with no permanent settlements are shown as blank spots.

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DOI: 10.15201/hungeobull.63.1.4

Investigation of ecological potentials of the Eger Model Region by GIS methods

Anna Őrsi[1] and Ádám KERTÉSZ[1]

Abstract

Various parts of a landscape unit or region can be used for multiple purposes. Before the collectivisation of agricultural fields in the 1960s, the use of the land was more or less in accordance with the given natural conditions. After collectivisation, huge plots were created, neglecting the features of the capability of the area. The map of ecological potential types shows favourable and unfavourable conditions for agricultural and forestry use, i.e. it indicates which parts of the region offer the best ecological conditions for arable cultivation, viticulture, fruit production, cultivation of meadows and pasture, just to mention a few. A capability assessment using GIS is being carried out for the total area of the Eger region. The database used for the capability analysis contains the Corine 1990 and 2006 data, soil maps and the National Gully Cadastre. The map is compared with present-day land use and the discrepancies between landscape capability and present land use are identified. Suggestions are made to optimise land use according to the capability map. Alterations since the change of the regime in 1989 have been determined and analysed from the aspect of suitability, as well.

Keywords: map of ecological potentials, ecological potential types (ecopottyp), land use, capability assessment, GIS

Introduction

Landscape science, landscape ecology deals with the interactions between the abiotic and biotic spheres and the human society. It studies the causes and the consequences of differences and heterogeneity among the landscapes at different scales, thus seeking to establish a scientific foundation for practical applications, including landscape planning and landscape management. The discipline of landscape ecology was the first applied science in the field of physical geography.

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The demand for applied landscape studies and landscape ecology emerged in the middle of the last century all over the world. Landscape planning, landscape management, landscape prognosis, landscape protection and nature conservation stood in the focus of research of the Russian and German schools of landscape science. Landscape ecology was flourishing in the 1960s and 1970s in Europe, especially in Germany, mainly in the German Democratic Republic, e.g. Troll, C. (1968, 1970), Leser, H. (1976) and in the Soviet Union (e.g. Solntsev, N.A. 1968; Sochava, V.B. 1971).

Applied landscape research was carried out in many other countries of Europe. Ecodynamical mapping was the main activity of the French school (Tricart, J. 1976; Journaux, A. 1975, 1981). The Anglo-Saxon school was very much practice-oriented, focusing, first of all, on land evaluation (Howes, C.K. 1980; Naveh, Z. and Lieberman, A.S. 1984).

The importance of applied landscape science increased significantly in the second half of the last century, however, that time the centre of landscape studies shifted from Europe to the United States. This shift can be verified by the appearance of major publications (Forman, R.T.T. and Gordon, M. 1986; Naveh, Z. and Lieberman, A.S. 1994; Naveh, Z. 2000).

In the 1960s, Hungarian physical geographers also started to focus on applied geography and landscape ecology. Land evaluation, land capability assessment aimed at exploring and evaluating natural conditions favourable or unfavourable for various branches of the economy. Various landscapes dispose of different features providing utilization options, i.e. landscapes have a potential to meet various requirements of the society. Landscape potential is the basis of landscape evaluation. According to their potentials, landscapes can be classified into different types.

In the 1960s, Marosi, S. and Szilárd, J. (1963b) evaluated the area of the Somogy Hills from the point of view of agricultural use. They classified the landscapes according to the natural conditions (geology, topography, climate, hydrology and soils) provided for agriculture. These territorial units were defined as the "spatial unit types of natural conditions for farming", landscape potential types or *ecological potential types*, the abbreviation is *"ecopottyp"*. The same concept is applied in this paper.

Before the collectivization of private farms in the 1960s, farming was more or less in accordance with the natural conditions. As a consequence of collectivization, huge plots were created in order to facilitate large-scale farming.

It has to be emphasized that the ecological potential types are considered to be homogeneous in terms of natural conditions, i.e. the natural conditions predestine the optimal use of a given area. Generally, areas aren't used in an optimal way, therefore the question arises whether this situation can be justified by economic or political considerations. In many cases, an area with heterogeneous conditions is used homogeneously. Landscape ecologists suggest the adaptation to the heterogeneous, diverse natural conditions in order to make the management of the area more environment-friendly and thus better adapted to natural conditions.

According to Marosi, S. and Szilárd, J. (1963a), landscape scientists should consider which landscape forming factors are the most relevant for the identification of the ecological potential types. Among the landscape forming factors, topography plays a crucial role by affecting other landscape forming factors (soils, vegetation, hydrological conditions etc.). Even the variety of the meso- and microclimate is strongly influenced by the heterogeneity of topography.

Contemporary Hungarian papers also deal with various aspects of the topic. Lóczy, D. (2002) published a textbook on landscape and land evaluation, surveying international and national assessment methods. Recent trends of landscape assessment are reviewed by Hervai, A. (2010). Landscapes with various natural conditions are evaluated by Csorba, P. and Szabó, Sz. (2008) applying the method of landscape metrics. Barczi, A. *et al.* (2008) published a paper on landscape and agri-environmental assessment.

The objective of this paper is to present the map of the ecological potential types and to compare it with the map of current land use in order to explore the differences and the discrepancies between them and finally to propose optimal land use. Another important aim is to investigate whether land use changes after the change of the regime, i.e. after the reprivatisation process led to a healthier land use and plot structure corresponding to the natural endowments.

Study area

The study area contains the administrative area of the 23 settlements of the Agria InnoRegio. The Agria InnoRegio itself is not an administrative unit, its boundaries were established for the TÁMOP 4.2.2/A project[2] (*Figure 1).*

The topography of the study area is very varied, extending from the Northern part of the Great Hungarian Plain to the Southern part of the North Hungarian Mountains, including lowlands, hilly countries and mountains (111–928 m a.s.l.). The greatest part of the area, extending to the South and South-East from the city of Eger is a piedmont plain, a glacis dissected by valleys. In spite of being dissected, the overwhelming part of that gently sloping

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[2] ”Complex analysis of the potential use of natural resources considering the effects of climatic change in order to develop an energetically sustainable model region under German-Hungarian cooperation.”

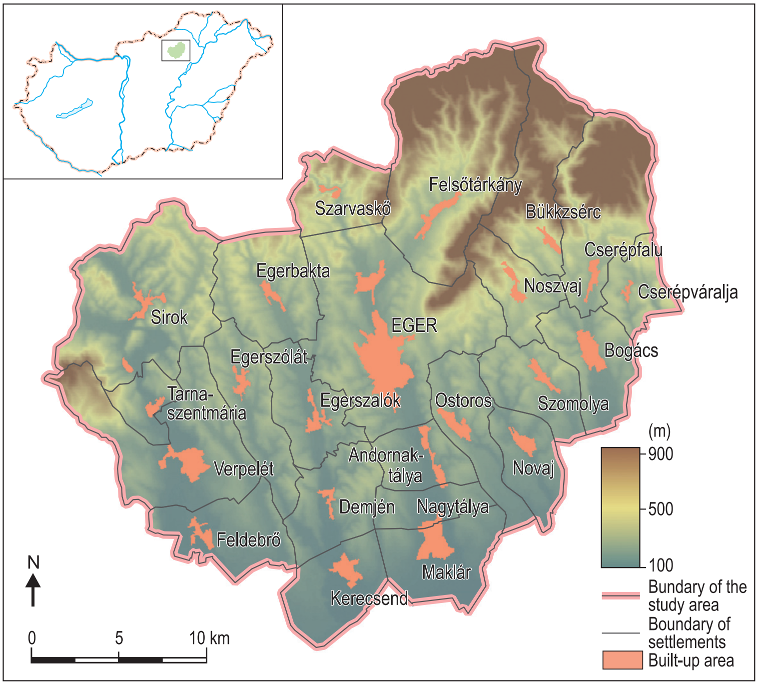

Fig 1. The location and the terrain of the study area

plain is homogeneous, there are large uniform fields between the valleys offering ideal conditions for agricultural use. North of Eger hilly and mountain ridges are characteristic with moderate or steep slopes. Soil parent rocks are Oligocene schlier, marl and sand in the northern part, Lower Miocene rhyolite tuff and loess in the South and Pliocene clayey-loamy sediments in the South-West.

The climate is moderately warm – moderately dry except the northern part which is cool. The number of sunshine hours exceeds 1850 a year. The mean annual temperature is around 8–10 °C, the annual rainfall is about 600 mm. Luvisols dominate in the foreground of the mountains, Cambisols and Chernozems are characteristic in the areas close to the Great Hungarian Plain, Fluvisols along the watercourses. The area is intensively cultivated, vineyards, croplands, pastures and orchards are typical on the not forested parts of the study site. The forests in the mountains are *Quercetum petraeae-cerris* forests. The *Quercetum petraeae-cerris* forest is in many cases replaced by acacia (*Robinia pseudoacacia*) and pasture. *Querceto petraeae Carpinetum* forests can be found at the bottom of steep valleys (Dövényi, Z. ed. 2010).

Data and methods

The methods applied in this paper are based on the above mentioned papers of Marosi, S. and Szilárd, J. (1963a,b). The innovativeness of our approach is the application of geoinformatics, i.e. exploiting the possibilities offered by GIS. In the last century ecological potential maps were prepared manually and topographic maps were used as a basis of map compilation. The manual method did not allow for putting a very detailed and precise map together.

The calculations presented below were performed by the ArcMap software. The following data sources were used: the Corine Land Cover Database (Büttner, G. *et al*. 2002) for the years 1990 and 2006, SRTM data (Rabus, B., *et al*. 2003), the AGROTOPO database (RISSAC, 1991) and the National Gully Cadastre (Mari, L. and Mattányi, Zs. 2002; Kertész, Á. *et al.* 2012).

The methodological steps are as follows:

1. Slope gradient and slope aspect maps were derived from the digital terrain model.
2. A gully density map was prepared using the data of the National Gully Cadastre.
3. The valley network was determined by calculating the flow direction and flow accumulation from the terrain model.
4. Fluvisols and Vertisols were selected from the AGROTOPO database.

The following categories were distinguished on the map of ecological potentials:

1. Areas suitable for arable use without soil conservation measures,
   - slope gradient 0–5%.
2. Areas suitable for arable use applying soil conservation measures,
   - slope gradient 5–17% and northern exposure.
3. Areas suitable for vineyards and orchards,
   - slope gradient 12–25% and southern exposure.
4. Areas suitable for forestry,
   - slope gradient above 25%,
   - slope gradient 17–25% and northern exposure,
   - areas dissected by gullies,
   - areas above 300 m elevation a.s.l.
5. Areas suitable for meadow and pasture,
   - areas covered by Vertisol and Fluvisol.
6. Wetlands on valley bottoms.
7. Settlements were excluded.

In the following, we intend to find answers to the question how much of current land use (the most recent data reflect the 2006 status) is in accordance with the natural conditions, with the ecological potential. The second question is whether land use has been moving since the change of regime land use towards the ecological potential of the area, i.e. to the optimal state, or moving away from it. We compared the map of ecological potentials with the Corine Land Cover (CLC) databases for the years 1990 and 2006.

The CLC database had to be reclassified according to the categories of the map of ecological potentials. As the Corine database does not distinguish between arable land with or without soil conservation measures, we used six categories: anthropogenic surface, arable land, vineyard and orchard, grassland (meadow, pasture, grassland), forest, scrubland and wetland *(Figure 2).*

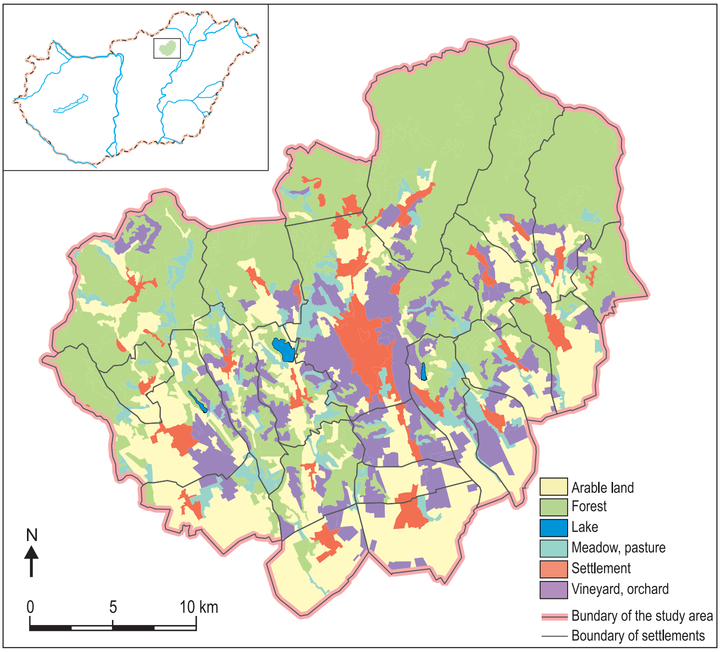

Fig. 2. Simplified land use map of the Eger Model Region

Results

According to the map of ecological potentials the flattest, southern part of the study area is the most suitable for arable use without applying soil conservation measures *(Figure 3).* These areas continue further northwards along the valley bottoms on the alluvial plains. The northern territories, i.e. the Bükk Mountains are suitable for forestry use. The areas located between these two are characterised by medium steep slopes (5–25%). Among them, the slopes

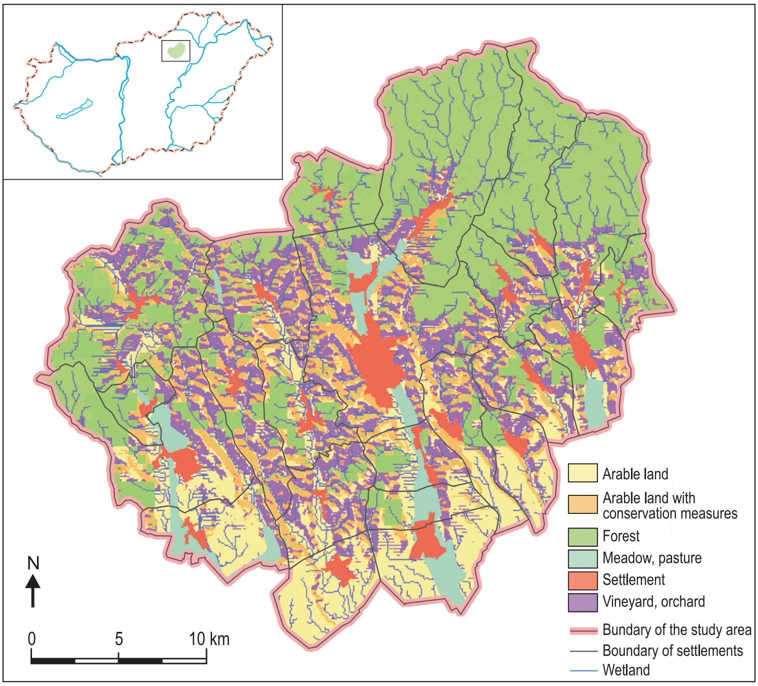

Fig. 3. The map of ecological potentials of the Eger Model Region

exposed to the South are proposed to be utilized as vineyards, those with northern exposure are proposed to be used as arable land with soil conservation measures. They are interrupted by areas suggested for afforestation. They cannot be recommended for agricultural cultivation due to their high dissection and vulnerability to soil erosion.

Wetlands are located in the valleys of the hills and mountains and on lowland, as well. Based on the map of ecological potentials, meadows and pastures should only be located alongside the larger watercourses.

Comparing the map of ecological potentials with the Corine Land Cover databases for the years 1990 and 2006, there is very little difference between the two maps (only a few percent). The difference is so small that it may be due to the differing resolution of the databases. The scale of the 1990 Corine map is 1:100,000 and that of the 2006 map is 1:50,000. (No 1:50,000 maps for the year 1990 were available.) Because of this discrepancy, only the 2006 data will be taken into consideration in the below analysis.

In 2006, 46% of the area was utilized in accordance with the categories of the ecological potential map. Of course, it cannot be asserted that the remaining 54% of the land was used and managed totally unsuitably as a given territory may be used for multiple purposes even if the applied use is not the optimal one. On the other hand, economic and political aspects also have to be considered: in many cases, the ecological potential map created by GIS is too detailed, while homogeneous areas may be more suitable for cultivation. In this case, the adverse local circumstances have to be improved by the means of ameliorisation.

Table 1 shows the percentage of each land use category corresponding and not corresponding to the ecological potential. 57% of the arable land can be found in the areas suitable for arable cultivation, 15% in areas suitable for vineyards and orchards and 12% in areas suitable for grassland and pasture. It is not necessarily bad to have arable land in areas suitable for vineyards and orchards if the slope angle is below 17% and the soil conditions are also favourable.

Table. 1. The relationship between present land use and ecological potential in the Eger Model Region in 2006, %

Land use		Ecological potential				
		arable land	vineyard-orchard	pasture	forest	wetland
Corine Land-Cover 2006	arable land	*57.49*	14.52	11.85	5.38	10.76
	vineyard-orchard	47.54	*31.52*	1.38	14.40	5.60
	pasture	34.57	26.15	2.34	24.37	12.57
	forest	15.52	14.29	0.18	62.74	7.27

Nearly 50% of the vineyards and orchards are located in areas suitable for arable cultivation, namely the slopes with northern slope aspect, whereas vineyards are mostly larger connected fields. Another 14% of the vineyards and orchards are located in the areas suitable for forestry. It is very inconvenient because the risk of soil erosion is high if the area is too steep or if it is already dissected by gullies.

It is surprising that 35% of the meadows and pastures is located on areas suitable for arable cultivation and only 2% of the area is suitable for meadows and pastures. It can be explained by the scale of the soil map (1: 100,000) which is not detailed enough and because of that, Vertisols and Fluvisols covering the alluvia of small streams are not shown on the soil map. In reality, meadows and pastures are on the alluvia of smaller streams, but the patches of them are too small to be represented on the soil map which was the basis of the delineation of the areas suitable for meadows and pastures.

Almost two-thirds of the forests are in the areas suitable for forestry use, which is the largest coincidence comparing present land use with the ecological potential. The wetlands which were identified on the valley bottoms are too narrow to be represented in the 1:50,000 scale Corine Database.

Conclusions

The GIS method proved to be a very good and very precise tool for the identification of the units of the ecological potential map. The comparison of the ecological potential map with present land use brought very interesting results *(Figure 4)*.

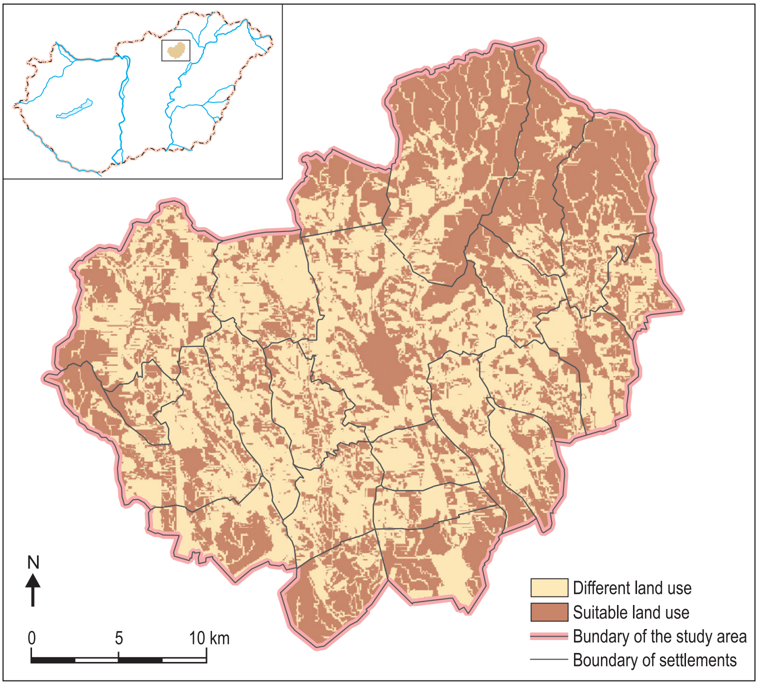

Fig. 4. Map of the areas with the type of land use corresponding to the ecological potential where present land use is different from the ecological potential in the Eger Model Region

The highest coincidence between ecological potential and land cover was found in the case of forests and arable lands. The coincidence is the lowest in the case of grasslands because of the scale of the available soil map. A more detailed soil map will be necessary to improve the present result concerning grasslands. It should be discussed whether land use changes are necessary if the land is not used as it would be optimal from the aspect of land capability.

Changes in land use are the most necessary where areas hazardous to erosion are cultivated as vineyards, orchards or arable land. In all other cases, a very thorough analysis of the situation is needed taking both ecological and economic factors into account.

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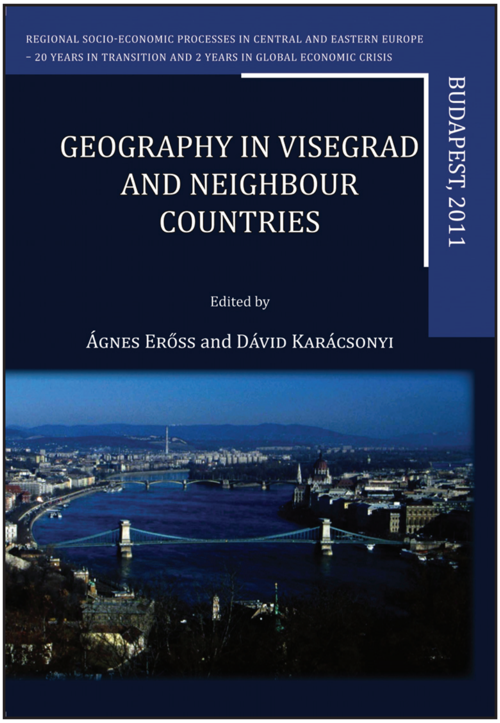
Geography in Visegrad and Neighbour Countries

Regional Socio-Economic Processes in Central and Eastern Europe – 20 Years in Transition and 2 Years in Global Economic Crisis

Edited by
Ágnes Erőss and Dávid Karácsonyi

Geographical Research Institute Hungarian Academy of Sciences
Budapest, 2011. 169 p.

During the last twenty years the erstwhile Soviet bloc countries in Central and Eastern Europe (CEE) have taken distinct routes in post-socialist development, wherein the national trends and internal regional processes proved to be in deep contrast. Responses to the challenges of the global economic crisis also varied, repeatedly brought to the surface long existing regional issues, structural problems and ethnic conflicts. Human geographers are divided in the assessment of the shifts that occurred during the past twenty years and the exchange of experience is vital for finding adequate answers to the new challenges. In order to provide a forum for discussion the Geographical Research Institute Hungarian Academy of Sciences with the generous support of the International Visegrad Fund Small Grant Programme organized a conference in order to induce the revival of contact between the institutes of geography of Visegrad Countries and their Western and Eastern neighbours. Present volume is a selection of presentations aiming to provide a deeper insight in socio-economic processes and their interpretation from geographical aspects taking place in the broader region of CEE countries.



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BUDAPEST, 2011

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Price: EUR 10.00
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Hungarian Geographical Bulletin 63 (1) (2014) 55–67.
DOI: 10.15201/hungeobull.63.1.5

How the climate will change in this century?

Judit BARTHOLY[1], Rita PONGRÁCZ[1] and Ildikó PIECZKA[1]

Abstract

In order to support political and economical decision makers by providing climate information for the future, it is essential to analyze regional climate model results. These models are capable to describe the regional climate conditions of individual countries using 25 km horizontal resolution, whereas global climate models are too coarse for such details. This paper discusses the regional effects of global warming using regional climate model experiments from the PRECIS model developed at the Hadley Centre of the UK Met Office. Since PRECIS was adapted at the Department of Meteorology, Eötvös Loránd University in the recent years, important regional/local conditions could be taken into account during the modelling process. In the experiments of PRECIS, three different emission scenarios (A2, A1B, B2) are considered to provide estimations for the 21st century. Our conclusions highlight the significant warming tendency in Hungary, especially in summer. The frequency of cold temperature extremes is projected to decrease significantly while warm extremes tend to occur more often in the future. Furthermore, significant drying is projected in the region, especially, in summer. In winter the precipitation is likely to increase.

Keywords: regional climate modelling, PRECIS, temperature, precipitation, extremes

Introduction

The Intergovernmental Panel on Climate Change (IPCC) started to publish the Fifth Assessment Report (AR5) with the physical science basis (IPCC, 2013). That contribution of IPCC Working Group I clearly states (i.e. as virtually certain with 99–100% probability) that global warming is detected in the last 110 years on the basis of regular meteorological observations worldwide. The anthropogenic effect is quite evident due to the increased emissions of greenhouse gases, and consequently, their increased atmospheric concentrations compared to the preindustrial values. The concentration of carbon dioxide was 41% larger

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in 2012 than a few centuries ago since the global mean levels were 393 ppm and 278 ppm in 2012 and in 1750, respectively (WMO, 2013). The major anthropogenic contributions include the intense fossil fuel use to feed the growing energy demands of the Earth's population. The increases of other greenhouse gas concentrations were also substantial, especially in case of methane with an atmospheric level of about 160% higher in 2012 than in the 1700s.

Overall, between 1901 and 2012 the global mean annual temperature increased by 0.89 °C (IPCC, 2013). In Hungary the regional mean annual temperature has increased by about 1 °C since the beginning of the 20th century (Lakatos, M. and Bihari, Z. 2013). The detected changes mentioned above raise the questions how and what we can project for the future decades of this century. For those purposes, models are needed.

The detected climate changes and the human influence are assessed in climate model simulations. Global climate models (GCMs) contain complex mathematical formulae based on well-known physical laws (i.e. thermodynamics, motion, continuity equations) and they are able to reproduce the past climatic conditions. In order to estimate the likely or possible future conditions, they can be also used. The spatial resolution of a GCM is typically 1–3°, which limits the accuracy of fine scale details in smaller regions (e.g. the Carpathian Basin). For instance, the effect of complex topography cannot be reflected using that coarse resolution.

GCMs serve as driving fine resolution regional climate models (RCMs). The RCMs are limited area models embedded in GCMs (Giorgi, F. 1990). Their physical bases are similar to GCMs'; parametrizations typically consider 10–50 km spatial scales. In Hungary four different RCMs have been adapted for our region. One of the models is the PRECIS model (Bartholy, J. *et al.* 2009b) which is briefly introduced in the next section. Then, the climate change results for Hungary by the middle and the end of the 21st century are discussed. Since the often-used emission scenarios do not differ remarkably in the next few decades in terms of greenhouse gas emissions and global warming rates, in this paper only one of them is evaluated in case of the mid-century projections, whereas three different emission scenarios are analyzed for the later period of the century.

Regional climate modelling using PRECIS

The installation and the adaptation of the regional climate model PRECIS at the Department of Meteorology, Eötvös Loránd University started in 2004. The PRECIS is a high resolution limited area model with both atmospheric and land surface modules (Wilson, S. *et al.* 2010). The model was developed at the Hadley Climate Centre of the UK Met Office, and it can be used over any part of the globe (e.g. Hudson, D.A. and Jones, R.G. 2002; Rupa Kumar, K. *et al.* 2006; Taylor, M.A. *et al.* 2007; Akhtar, M. *et al.* 2008). The PRECIS regional climate model is based on the atmospheric component of HadCM3 (Gordon, C. *et al.* 2000) with substantial modifications to the model physics (Jones, R.G. *et al.* 2004). The atmospheric component of PRECIS is a hydrostatic version of the full primitive equations and it applies a regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate. The horizontal resolution can be set to 0.44°×0.44° or 0.22°×0.22°, which gives a resolution of ~50 km or ~25 km, respectively, at the equator of the rotated grid (Jones, R.G. *et al.*, 2004). In our studies we used the finer horizontal resolution for modeling the Central European climate (Pongrácz, R. *et al.* 2010).

Hence the target region contains 123×96 grid points with special emphasis on the Carpathian Basin and its Mediterranean vicinity containing 105×49 grid points. There are 19 vertical levels in the model, the lowest at ~50 m and the highest at 0.5 hPa (Cullen, M.J.P. 1993) with terrain-following sigma coordinates (which is a ratio between the pressure at the coordinate level and the surface pressure) used for the bottom four levels, pressure coordinates for the top three levels and a combination in between (Simmons, A.J. and Burridge, D.M. 1981). The model equations are solved in spherical polar coordinates and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain quasi-uniform grid box area throughout the region. An Arakawa B grid (Arakawa, A. and Lamb, V.R. 1977) is used for horizontal discretization to improve the accuracy of the split-explicit finite difference scheme. Due to its fine resolution, the model requires a time step of 5 minutes to maintain numerical stability (Jones, R.G. *et al*. 2004). In the post processing of the RCM outputs, daily mean values are used.

The necessary initial and lateral boundary conditions for PRECIS runs are provided by the HadCM3 ocean-atmosphere coupled GCM (Gordon, C. *et al.* 2000; Rowell, D.P. 2005) using ~150 km as a horizontal resolution. The reference period used in our studies is set to 1961–1990. For the future (2071–2100), three experiments were completed (Bartholy, J. *et al.* 2009a; Pieczka I. *et al.* 2009, 2011), namely, the A2, A1B, and B2 global emission scenarios (Nakicenovic, N. and Swart, R. 2000). The estimated global mean CO_2 concentration level for the end of the century is 856 ppm, 717 ppm, and 621 ppm, respectively. Thus, A2 can be considered the most pessimistic, and B2 the most optimistic among the scenarios. Our findings for the projected change of temperature and precipitation (compared to 1961–1990) are discussed in the next section.

Results

RCM simulations provide time series of more than 100 meteorological variables for each grid cell. In this paper we focus on the two most important variables describing climatic conditions, namely, temperature and precipitation. We discuss the projected changes of both the mean and the extreme values.

In the past (1961–1990) the annual mean temperature values for Hungary were between 8 °C and 11 °C, however, most of the area could be characterized by 10–11 °C. Due to the annual temperature cycle, seasonal mean temperature values in spring and autumn did not differ significantly from the annual means. In winter the seasonal mean temperature was between –2 °C and +1 °C, the area of the country could be divided into two large regions: in the southwestern part the values were above the freezing point, whereas in the northeastern part they were below 0 °C. In summer the seasonal mean temperature was between 17 °C and 21 °C, however, the majority of the country area experienced a summer mean temperature above 19 °C.

The projected seasonal temperature increases averaged for the entire country are summarized in *Table 1.* The projected summer warming is the largest among the four seasons. Evidently the warming signal is the largest in the case of A2 scenario, while B2 and A1B scenarios indicate somewhat less future warming, which can be explained by the estimated lower CO_2 concentration compared to A2. The projected annual mean temperature increase for Hungary is about 2.6 °C by the middle of the century, and 4.0–5.4 °C by the end of the century.

*Table 1. Projected seasonal mean temperature change (°C) in Hungary (Reference period 1961–1990)**

Changes of T_{mean} °C, compared to 1961–1990		Winter	Spring	Summer	Autumn
2021–2050	A1B	2.5	1.9	3.7	2.2
2071–2100	B2	3.2	3.1	6.0	3.9
	A1B	4.1	3.7	6.7	5.0
	A2	4.2	4.2	8.0	5.2

* All the projected warming rates are significant at 0.05 level.

Table 2 summarizes the projected seasonal mean precipitation changes. The largest changes are estimated for summer, for which the drying trends are significant at 0.05 level by the end of the 21st century in the entire country in case of all the three scenarios.

The projected change in the annual distribution of the simulated monthly mean precipitation is shown in *Figure 1.*

In the present climate (1961–1990), the wettest months in Hungary are in late spring, early summer (May, June) when the monthly mean precipitation sum exceeds 60 mm. The driest months are January and February with about 30 mm total precipitation on the average. The PRECIS simulations suggest that the annual distribution of monthly precipitation is very likely to be restructured in the future. The driest months will no longer occur during winter, but in July and August (with about 20–30 mm precipitation on aver-

*Table 2. Projected seasonal mean precipitation change in Hungary (Reference period 1961–1990)**

Precipitation changes compared to 1961–1990		Winter	Spring	Summer	Autumn
		%			
2021–2050	A1B	13	2	*–17*	8
2071–2100	B2	–6	–8	*–43*	*–18*
	A1B	*34*	5	*–33*	–4
	A2	14	*–13*	*–58*	–8

* Characters in italics indicate significant projected changes at 0.05 level

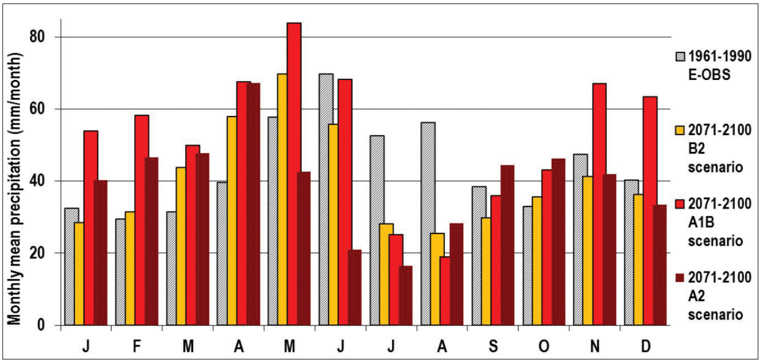

Fig. 1. Annual distribution of observed and simulated monthly mean precipitation in the reference period (1961–2100) and in the future (2071–2100)

age by 2071–2100) according to current projections. A2 simulation suggests an average value less than 20 mm which is significantly lower than the present value and the value of the two other scenarios. The wettest month of the A2 scenario run is projected to be April with about 65–70 mm precipitation on the average, while in the case of the B2 and A1B simulations the wettest months are April, May and June with about 60 mm (B2) or even more than 60 mm (A1B) total mean precipitation on average.

The projected precipitation tendencies and the inter-annual variability for the summer and winter seasons in the case of A1B scenario are illustrated in *Figure 2*. The negative trend in summer and the positive trend in winter are both evident. Moreover, the variability of winter precipitation is likely to increase in the 21st century.

For end-users it is also important to have information on the projected climate change. Projected seasonal mean temperature and precipitation changes for Hungary are combined in *Figure 3*. By the end of the century the summers are likely to be warmer and drier, whereas the winters milder and wetter. In spring and autumn warming trends are projected, but the simulated changes in precipitation are small (less than 20%) and not significant at 0.05 level.

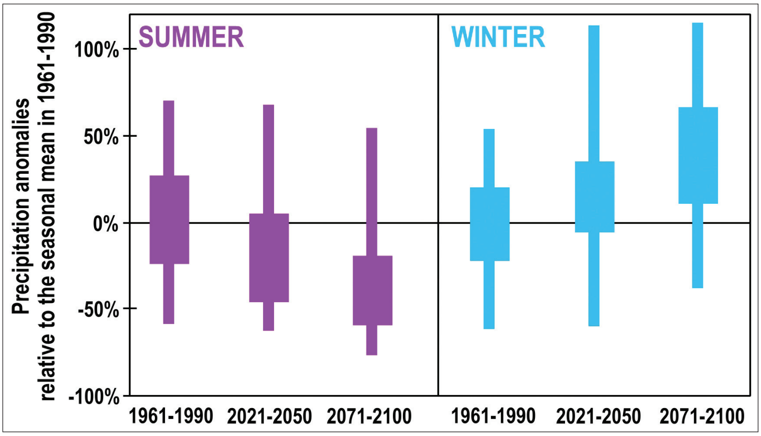

Fig. 2. Projected changes of summer and winter precipitation by the mid- and late century decades (A1B scenario), reference period: 1961–1990. Thin columns indicate the extremes of the period. Thick boxes show the middle 50% range (between the lower and the upper quartiles)

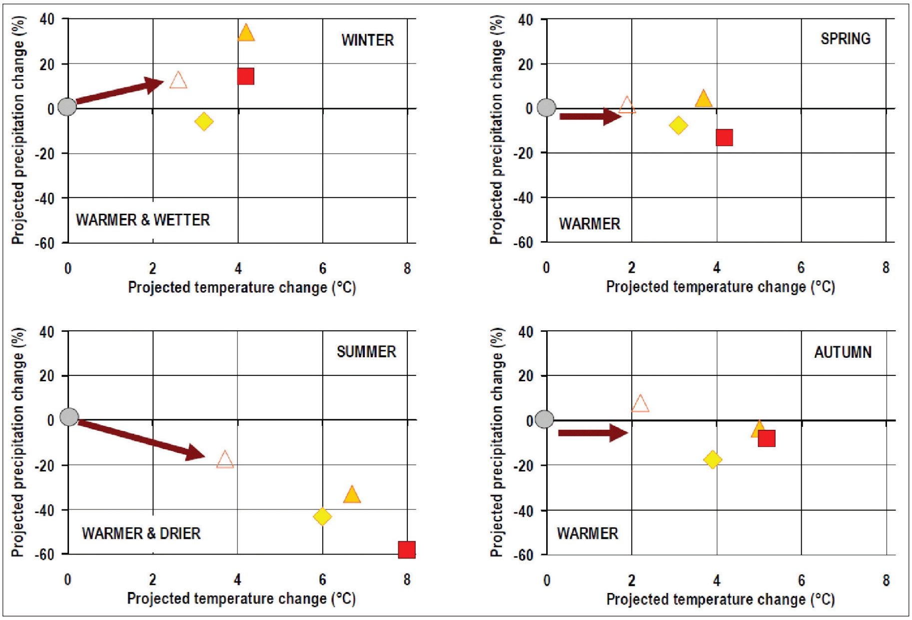

Fig. 3. Projected seasonal temperature and precipitation change in Hungary for the 21st century based on PRECIS-simulations, reference period: 1961–1990 (indicated by the grey circle). Empty and filled symbols indicate the projected changes by 2021–2050 and by 2071–2100, respectively. Red squares, orange triangles and yellow romboids indicate the results for the different scenarios (A2, A1B, and B2, respectively)

In order to develop appropriate adaptation strategies besides the mean changes, it is especially important to provide estimation of extremes. First, the daily minimum and maximum temperatures are analyzed here. In the reference period (1961–1990), the annual average of daily minimum temperature values in Hungary were 3–7 °C (based on the gridded E-OBS data, Haylock, M.R. *et al.* 2008) and in the central region of the country it exceeded 6 °C. The annual average of the daily maximum temperature values were 13–16 °C and in the southeastern part of the country it exceeded 15 °C. In the warmest part of the year, in summer, the averages of the daily minimum and maximum temperatures were 12–15 °C and 24–27 °C, respectively.

In winter, the averages of the daily minimum temperature were mainly between –4 °C and –2 °C with the exception of the northeastern regions of the country with average daily minimum temperatures between –6 °C és –4 °C. The winter averages of the daily maximum temperature were 1–4 °C. The extreme daily values above are projected to increase similarly to the daily mean temperature values. *Table 3* summarizes the projected warming concerning the daily minimum and maximum temperatures (upper and lower part of *Table 1*, respectively). The largest projected changes and the largest uncertainty due to different scenarios are both in summer.

After analyzing the daily extreme values, several extreme temperature indices were calculated since they provide useful information on extreme climatic conditions. *Table 4* summarizes the definitions and the observed average values (based on the gridded E-OBS data, Haylock, M.R. *et al.* 2008) of the following temperature indices for Hungary: the number of frost days, summer days, hot days, extremely hot days and heat wave days. *Table 4* also summarizes the projected changes averaged for the grid cells located in Hungary by the mid- and the late 21st century compared to the reference period.

Table 3. Projected seasonal mean change in daily minimum and maximum temperature (°C) in Hungary (Reference period 1961–1990)

Changes of T_{min} °C, compared to 1961–1990		Winter	Spring	Summer	Autumn
2021–2050	A1B	2.7	1.9	3.5	2.3
2071–2100	B2	3.3	2.9	5.3	3.7
	A1B	4.3	3.9	6.3	5.1
	A2	4.2	4.1	7.1	5.0
T_{max} °C, compared to 1961–1990		Winter	Spring	Summer	Autumn
2021–2050	A1B	2.5	2.0	4.0	2.1
2071–2100	B2	3.4	3.3	6.6	4.0
	A1B	4.2	3.9	7.2	5.3
	A2	4.0	4.5	8.7	5.2

Table 4. Observed average values and projected changes in the 21st century for extreme temperature indices for Hungary

Indices	Average, days	Projected change, days			
Temperature index (Definition)	1961–1990 E-OBS	2021–2050 A1B	2071–2100 B2	2071–2100 A1B	2071–2100 A2
Number of frost days ($T_{min} < 0$ °C)	93.0	–35	–43	–54	–51
Number of summer days ($T_{max} > 25$ °C)	67.0	38	66	68	76
Number of hot days ($T_{max} > 30$ °C)	14.0	34	68	65	86
Number of extremely hot days ($T_{max} > 35$ °C)	0.3	12	30	34	53
Number of heat wave days ($T_{mean} > 25$ °C)	4.0	30	59	59	80

Statistically significant decrease of the annual number of frost days is projected which is a clear consequence of the overall warming tendency. For the same reason the average annual numbers of summer days, hot days, extremely hot days and heat wave days are projected to increase significantly in the country. The projected changes by 2021–2050 are about the half of those by 2071–2100. The largest changes are projected in the A2 scenario, which estimates the highest CO_2 level by the end of the 21st century.

The detailed spatial structures of the projected changes of extreme temperature indices are shown in *Figures 4–8*. The regional temperature-related climatic changes projected for the different emissions scenarios are not substantially different by the middle of the century. The scenario-related contributions to the total uncertainty for Europe does not exceed 25% for a few decades ahead, whereas it is about 70% for a century ahead (Hawkins, E. and Sutton, R. 2009). Therefore the projected changes are mapped for the three different scenarios by the end of the 21st century and for only A1B scenario by the middle of the century.

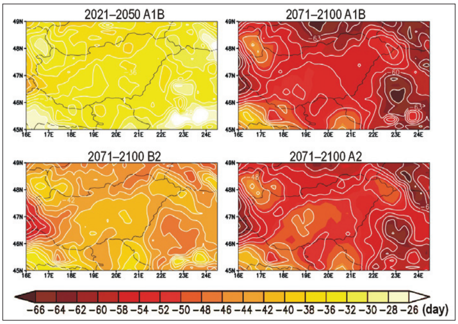

Fig. 4. Projected changes in the number of frost days ($T_{min} < 0$ °C) compared to the reference period (1961–1990)

Larger decreases of the number of frost days are indicated by darker colors *(Figure 4)*. The overall structures of the simulated changes are quite similar: the annual number of frost days is projected to decrease more in the higher elevated regions than in the lowland areas.

On the maps indicating the projected changes of warm extremes, the larger increases are shown by darker colors (*Figures 5–8*). The annual number of summer, hot and extremely hot days are all defined using daily maximum temperatures with increasing limit values (25 °C, 30 °C, and 35 °C, respectively). However, the spatial structures of the projected changes of summer days *(Figure 5)* are more similar to those of the frost days than those of the hot *(Figure 6)* or extremely hot *(Figure 7)* days.

Besides the topography effect, zonal structures can also be recognized on the maps indicating the projected changes of the hot and extremely hot days. The projected increases are larger in the southern part of Hungary than in the northern regions. Similar structures dominate the maps indicating the projected changes of the heat wave days *(Figure 8).*

Finally, the precipitation related climate indices (e.g. the number of wet days exceeding different threshold values, the maximum length of dry periods, intensity) are analyzed. *Table 5* summarizes the definitions and the observed annual average values (based on the gridded E-OBS data, HAYLOCK, M.R. *et al.* 2008) for Hungary.

Table 5 contains the projected annual changes averaged for the grid cells located within the country by the mid- and the late century compared to

Table 5. Observed average annual values and projected annual changes in the 21st century in case of precipitation indices for Hungary

Indices	Average, days	Projected change, days			
Precipitation index (Definition)	1961–1990 E-OBS	2021–2050 A1B	2071–2100 B2	2071–2100 A1B	2071–2100 A2
Number of precipitation days exceeding 1 mm, RR1 ($R_{day} > 1$ mm)	106.0	–8.0	–21.0	–15.0	–24.0
Number of precipitation days exceeding 5 mm, RR5 ($R_{day} > 5$ mm)	36.0	–1.0	–8.0	–2.0	–10.0
Number of precipitation days exceeding 10 mm, RR10 ($R_{day} > 10$ mm)	11.0	2.0	–3.0	2.0	–3.0
Number of precipitation days exceeding 20 mm, RR20 ($R_{day} > 20$ mm)	1.3	0.9	–0.7	1.3	–0.2
Maximum number of consecutive dry days, CDD ($R_{day} < 1$ mm)	28.0	3.0	5.0	10.5	9.0
Simple daily precipitation intensity, SDII (R_{year}/RR1)	4.8*	0.4*	–0.1*	0.7*	–0.0*

* mm/day

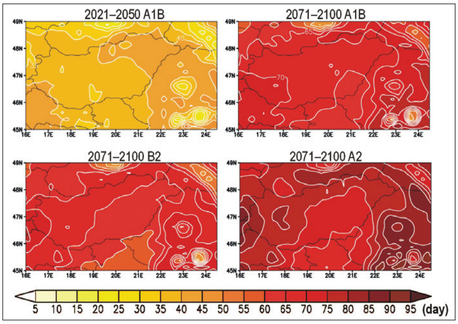

Fig. 5. Projected changes in the number of summer days ($T_{max} > 25$ °C) compared to the reference period (1961–1990)

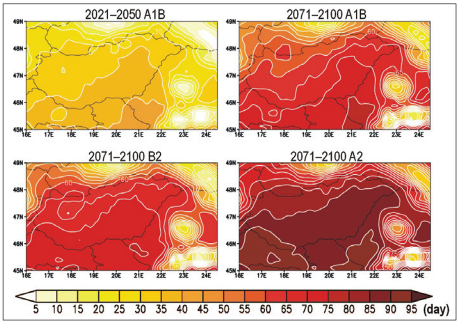

Fig. 6. Projected changes in the number of hot days ($T_{max} > 30$ °C) compared to the reference period (1961–1990)

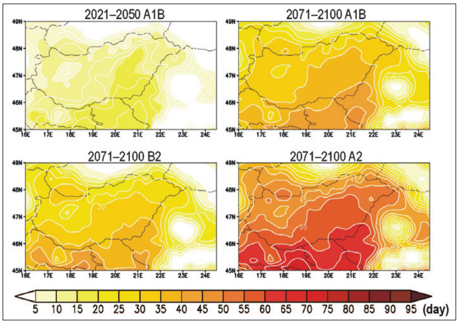

Fig. 7. Projected changes in the number of extremely hot days ($T_{max} > 35$ °C) compared to the reference period (1961–1990)

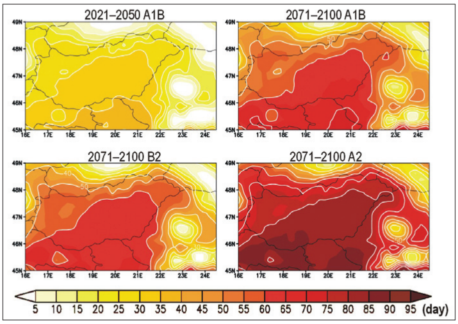

Fig. 8. Projected changes in the number of heat wave days ($T_{mean} > 25$ °C) compared to the reference period (1961–1990)

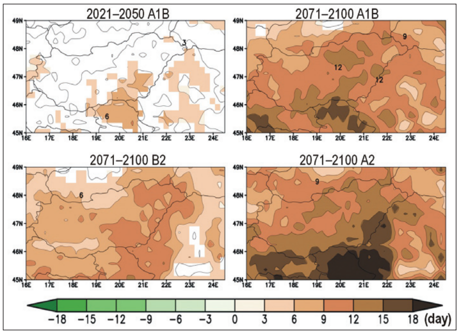

Fig. 9. Projected seasonal changes in CDD, the maximum number of consecutive dry days ($R_{day} < 1$ mm) in summer compared to the reference period (1961–1990). Only the statistically significant changes are colored in the maps

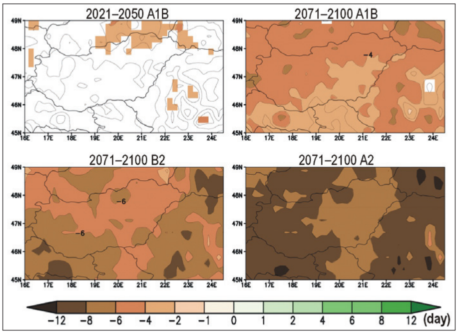

Fig. 10. Projected seasonal changes in RR5, the number of precipitation days ($R_{day} > 5$ mm) in summer compared to the reference period (1961–1990). Only the statistically significant changes are colored in the maps

the reference period. Projected changes of large precipitation days (exceeding 5 mm, 10 mm, 20 mm, etc.) in the 21st century are highly uncertain, whereas the annual number of precipitation days exceeding only 1 mm (RR1) is projected to decrease. The length of dry periods, i.e. the maximum number of consecutive dry days (CDD) is likely to increase in the future. The estimated changes for Hungary by the end of the century are statistically significant in summer (*Figure 9*), suggesting longer and more persistent dry spells.

Due to the overall projected summer precipitation decrease, the PRECIS-simulations point to a considerable increase of the drought risks in the country, especially in the regions near the southern and eastern borders. *Figure 10* indicates the projected changes of precipitation days exceeding 5 mm (RR5) in summer. The estimated changes are not significant in the other three seasons, neither in the summer by the mid-century.

However, by the end of the century the numbers of summer precipitation days exceeding 5 mm are projected to decrease in Hungary. The estimated decreases are larger in Transdanubia than in the eastern regions of the country. The largest decrease is estimated by the most pessimistic (A2) scenario.

Conclusions

Future climatic conditions of Hungary in the 21st century were estimated and analyzed using the PRECIS regional climate model simulations considering three different emissions scenarios (A2, A1B, B2). The following conclusions can be drawn.

– Temperature is projected to increase in the next decades. The projected increase of annual mean temperature by the late-century compared to the 1961–1990 reference period is 4.0–5.4 °C. The projected seasonal warming is the largest in summer.

– The projected regional warming in Hungary is the largest in case of the A2 scenario, according to which the highest CO_2 concentration level is estimated.

– As a consequence of the regional warming trend, more frequent warm and hot events and greater record hot conditions are projected for the future compared to the 1961–1990 reference period.

– The annual distribution of monthly mean precipitation is projected to change. The wettest months in Hungary are likely to shift from May and June to April and May, whereas the driest months from January and February to July and August.

– Significant drying is projected for Hungary, especially, in summer. The seasonal precipitation amounts are likely to decrease and the probability of drought occurrence is estimated to increase.

These results provide important information for both decision makers and civil associations. In addition, they play a key role in developing appropriate adaptation strategies in the coming decades.

Acknowledgements**:** Research leading to this paper was supported by the following sources: the Hungarian Scientific Research Fund under grants K-78125 and K-83909 the Swiss Hungarian Cooperation Programme (SH/2/1), the European Union and the European Social Fund through project FuturICT.hu (TÁMOP-4.2.2.C-11/1/KONV-2012-0013), also other projects (TÁMOP-4.2.1/B-09/1/KMR-2010-0003, TÁMOP-4.1.2.A/1-11/1-2011-0073, GOP-1.1.1.-11-2012-0164, KMR_12-1-2012-0206). We also acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://eca.knmi.nl).

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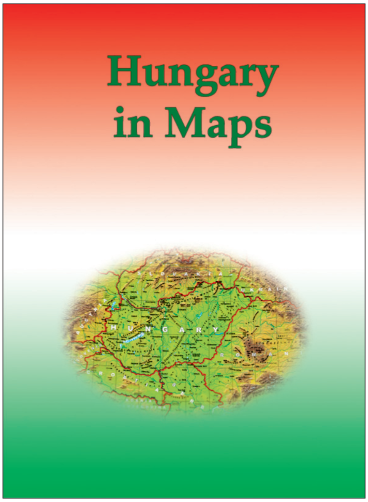
Hungary in Maps

Edited by
Károly Kocsis and Ferenc Schweitzer

Geographical Research Institute Hungarian Academy of Sciences
Budapest, 2009. 212 p.

‘Hungary in Maps' is the latest volume in a series of atlases published by the Geographical Research Institute of the Hungarian Academy of Sciences. A unique publication, it combines the best features of the books and atlases that have been published in Hungary during the last decades. This work provides a clear, masterly and comprehensive overview of present-day Hungary by a distinguished team of contributors, presenting the results of research in the fields of geography, demography, economics, history, geophysics, geology, hydrology, meteorology, pedology and other earth sciences. The 172 lavish, full-colour maps and diagrams, along with 52 tables are complemented by clear, authoritative explanatory notes, revealing a fresh perspective on the anatomy of modern day Hungary. Although the emphasis is largely placed on contemporary Hungary, important sections are devoted to the historical development of the natural and human environment as well.

In its concentration and focus, this atlas was intended to act as Hungary's 'business card', as the country's résumé, to serve as an information resource for the sophisticated general reader and to inform the international scientific community about the foremost challenges facing Hungary today, both in a European context and on a global scale. Examples of such intriguing topics are: stability and change in the ethnic and state territory, natural hazards, earthquakes, urgent flood control and water management tasks, land degradation, the state of nature conservation, international environmental conflicts, the general population decline, ageing, the increase in unemployment, the Roma population at home and the situation of Hungarian minorities abroad, new trends in urban development, controversial economic and social consequences as a result of the transition to a market economy, privatisation, the massive influx of foreign direct investment, perspectives on the exploitation of mineral resources, problems in the energy supply and electricity generation, increasing spatial concentration focused on Budapest in the field of services (e.g. in banking, retail, transport and telecommunications networks), and finally the shaping of an internationally competitive tourism industry, thus making Hungary more attractive to visit.



This project serves as a preliminary study for the new, 3rd edition of the National Atlas of Hungary, that is to be co-ordinated by the Geographical Research Institute of the Hungarian Academy of Sciences.

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Hungarian Geographical Bulletin 63 (1) (2014) 69–79.
DOI: 10.15201/hungeobull.63.1.6

The urban climate of Budapest: past, present and future

Ferenc PROBÁLD[1]

Abstract

Since the groundbreaking survey of Budapest's urban climate in 1974, little has been done to reveal how the summer heat island of the city has changed. During the last couple of decades, the impact of the anthropogenic heat release due to the spectacular expansion of automobile traffic and the widespread use of air conditioners may have added an estimated 1–1.5 °C to the temperature surplus of the city. As an evidence of the large-scale climate change, the homogenized temperature record of Budapest shows a strongly growing frequency and persistence of severe heat waves plaguing city dwellers. Regional models predict rising temperatures with more pronounced summer warming until 2100 in the Carpathian Basin. Therefore, the cooler local climates of the Danube islands and the Budai Hills should be appreciated as valuable environmental assets to be saved by more reasonable land use policies and stricter property development regulations.

Keywords: Budapest, urban climate, heat island, climate change, urban land use

The background: physiography and structure of the city

Budapest with its more than 1.7 million inhabitants is one of the largest and economically most dynamic cities in East Central Europe and stands out as the indisputable political, administrative and cultural centre of Hungary. It is situated on the banks of the Danube River, which crosses the city in a north-south direction, and divides it into a western (Buda) and eastern (Pest) part. The eastern side is flat, and the unimpeded spread of the built-up area has resulted in a quite regular morphological pattern, which can easily be described by the well-known urban model of concentric zones. The city centre (CBD) is surrounded by a densely built-up inner residential belt consisting of mostly dilapidated housing stock from the late 19th and early 20th centuries interspersed with neighbourhoods at different stages of renewal. The transi-

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tional zone embraces large derelict industrial areas: a rust belt at various stages of transition toward tertiary and residential functions, as well as some huge, monotonous housing estates with prefabricated high-rise buildings from the socialist era. In the outer residential belt of former suburbs, joined to the capital in 1950 giant housing estates also appear. This belt is dominated by detached family houses surrounded with small gardens.

On the west (Buda) side of the Danube River the somewhat delayed development and the emerging irregular pattern of the city have been due to the complicated orography. The Budai Hills rise to an altitude of more than 500 m (that is about 400 m above the level of the Danube River). The hilltops and the upper parts of the slopes are still covered by recreational forests forming a protected area, while most of the slopes were built up during the last century with good quality 4–5-storey houses surrounded by more or less green areas. High-density residential areas and large housing estates barely appear on the slopes; they are mostly restricted to the foothills and the minor plains adjacent to the Danube River.

Despite the heavy loss of vegetation due to extensive housing construction, the slopes of the Budai Hills are still sources of a frequently occurring night-time mountain breeze, which can mitigate the summer heat of the city by conveying cleaner and cooler air towards the densely built up areas. The tectonically preformed, NW–SE directed valleys are in good accordance with the prevailing wind direction and they serve, together with the Danube valley, as natural ventilation channels. The relief and the morphology of the city result in a great complexity of local climates, where the characteristic features of an urban temperature regime can be best detected and studied on the flat, densely built up eastern part of Budapest.

Climatological data: sources and constraints

Systematic meteorological measurements started in 1779 in Buda which was the southeastern outpost of the observatory network organised by the Palatine Meteorological Society of Mannheim. Thus, by now we have air temperature measurement records embracing more than 230 years with reliable data, which were homogenised by the scientists of the National Meteorological Service in order to eliminate errors and minor alterations that could be ascribed to repeated relocations and changes in the instrumentation of the station, as well as to the growth of the surrounding city that had taken place in the meantime. These data were first thoroughly evaluated by Réthly, A. (1947) in a pioneering work, which provided a fine assessment of all major macro-climatic features of the capital city of Hungary.

The first network for the purpose of measuring air pollution in Budapest was established by the National Institute for Public Health in 1958. The scope of its programme has been steadily broadened and its instrumentation improved several times accordingly. At present the National Air Pollution Monitoring Network operates stations equipped with automatic instruments at 12 points of Budapest, complemented by manual sampling at regular intervals on 15 additional sites. The task of the network comprises monitoring the concentration of SO_2, NO_2, NO_X, CO, ozone and particulate matter, thus providing an overall perspective on the actual and average state of ambient air quality in different parts of the city.

In the 20th century regular meteorological observations and instrumental measurements were started and continued for a shorter or longer period at 24 different sites within the present borders of Budapest. The data obtained at these stations could be used to throw light on local differences in the climate of the city. However, among these stations only one was located in the proper core of the city, within the large, grass-covered courtyard of the City Council Building (Madách Square). Measurements at this site were performed between 1965 and 1969, thus providing a database appropriate to reveal the properties of urban climate and to compare these with the natural background climate represented by the Pestlőrinc Observatory of the Hungarian Meteorological Service, located at the remote South-Eastern rim of the old suburban belt. By taking advantage of all the available, mostly unpublished datasets of the Hungarian Meteorological Service, the local differences and the particular urban features of the climate were first described and analysed in Budapest by Probáld, F. (1974).

Owing to financial difficulties the scope of meteorological measurements in Budapest has witnessed a sharp reduction since 1970 with only four stations remaining from the former network, none in the city centre. Hence, urban climate research has practically been abandoned in Budapest except for some attempts to utilise satellite imagery for studying the heat island (Bartholy, J. *et al.* 2005). Satellite measurements, however, cannot produce continuous data records and they provide information merely about the temperature of the surface instead of the ambient air at a height of 2 m. Since these figures can be quite different from each other, remote sensing is not a feasible substitute for field observations. Therefore, in describing the intensity and temporal changes of the urban heat island in the next section, we have to rely on the hourly breakdown of thermograph records taken in the 1960s at the station located in the city centre and from the Pestlőrinc Observatory. Nevertheless, recent changes in the macro-scale climate of Budapest allow us to draw some conclusions concerning the actual state and the future of the urban environment, too.

The heat island of Budapest in retrospect

Ever since its first scientific demonstration by L. Howard in London in the early 19th century, the urban heat island has received keen attention from climatologists realising the significance of this phenomenon from both theoretical and practical points of view. The spatial pattern and temporal changes of the heat island are determined by a great variety of factors, such as location, background climate and weather conditions, size of the city, the fabric of roads, buildings, parks, and their geographical distribution over the urbanized area. Consequently, the thermal regime of each city is more or less unique, thus it deserves careful study. In Budapest, key features of the heat island, represented by the temperature surplus of the urban core compared to surrounding areas, can be summarised as follows.

The annual mean temperature in Budapest downtown is 1.2 °C higher than outside the city. The annual cycle of urban-rural temperature difference reaches a peak in January (1.5 °C) and a second one in July (1.3 °C). March, which is usually quite windy and cloudy, is characterised by a minimum in the temperature surplus of the city (1.0 °C). By establishing the monthly means of its components, early enquiries about the surface energy balance in Budapest revealed the physical background of the urban heat island (Probáld, F. 1971). The summer warming of the city can be explained mainly by a higher direct turbulent heat transfer to the air, which is due to the decrease in evaporation and, consequently, in latent heat transfer as well. In winter the heat released by human activities can be regarded as the key factor shaping the temperature difference between the city and its surroundings. While city dwellers are certainly not displeased with a warmer environment in winter, they may feel quite different in the hot season when human comfort is adversely influenced by the diurnal variation of heat island intensity.

The rugged urban surface made up of massive concrete and stone structures is able to absorb large amounts of solar radiation during the day, store this energy and release it to the atmosphere at night. This process leads to a substantial delay of the diurnal temperature cycle and results in a characteristic variation in the intensity of the urban heat island: the minimum difference in urban-rural temperatures is observed late in the morning and the peak of about 2 °C in the evening, a difference that remains for most of the night (*Figure 1*). For the same reasons, similar daily temperature regimes were detected by measurements performed in other cities, too.

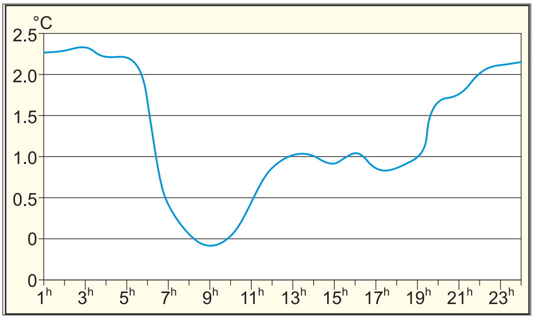

Fig. 1. Diurnal cycle of the difference in temperature between the downtown (City Council) and suburban outskirts (Pestlőrinc) in July (1965–1967). *Source*: Probáld, F. 1974.

Cloudy and windy weather conditions slightly weaken the urban heat island, whereas on clear, sunny days it gets stronger and the urban-rural temperature difference may exceed the average figures by several tenths of a degree with a tendency of further growth during periods of lasting heat waves. There are also remarkable micro-climatic differences within the densely built up area of the city. This has been demonstrated for example by measurements which were performed on three consecutive clear and hot days in July 1966 at a height of 2 metres above a safety island in the middle of Madách Square, located in downtown Budapest. The air of the large square lacking any greens and permanently exposed to sunshine was found to be warmer by roughly 1 °C than the nearby grassy courtyard of the City Council throughout the afternoon and the evening. In comparison with rural areas the difference amounted to 3 °C. The human comfort in such urban spaces is adversely affected, and the stress is increased also by thermal radiation emitted by the pavement and the walls of the buildings, which are even warmer than the adjacent air.

The calm and clear anticyclonic weather, characteristic for lasting heat periods, is often coupled with the accumulation of various pollutants in the ambient air of the city. The bulk of these pollutants, such as NO_2, the well-known precursor of ozone, as well as CO and particulate matter of various sizes come from heavy car traffic. Concentration of ozone exceeding the alert level in summer, similarly to dangerous levels of fine particulate matter in winter, occurred several times during the last couple of years. Heat alerts became even more frequent.

The prospect: rising heat stress in the city

After a steady decline for more than two decades, the population of Budapest today is not larger than it was fifty years ago. During its last period of growth in the 1970s and early 1980s, however, large housing estates were built in the former industrial and suburban belts of the city. These constructions certainly had some impact on the microclimate of their surroundings, but they could hardly bring about significant changes in the intensity and meso-scale pattern of the heat island. Meanwhile, the city witnessed the emergence of at least three new factors that are likely to affect the present and future features of the urban climate: the spread of vehicle traffic, the use of air conditioners and the impact of changes in the regional climate.

Tremendous changes have taken place in the quality of the fuel used in the city, too. Until the early 1960s the heating of the dwellings were largely based on coal, which caused frequent winter smog due to the accumulation of sulphur dioxide and soot particles in the air. In the subsequent decade, however, coal burning was quickly and almost totally replaced by natural gas.

This was done for pure economic reasons, but as a favourable side effect, air quality greatly improved. Nevertheless, this success was largely offset by the spectacular expansion of automobile traffic over the last decades that probably peaked recently, at least in the inner city, where more measures have been implemented to reduce traffic congestion. Thus, transportation as a whole has become the major source of air pollution and it is heavily contributing to anthropogenic heat release concentrated along the main traffic routes.

The last one or two decades have also witnessed the increased use of air conditioners in Budapest, responsible for a new summer peak of electricity consumption. This process is mainly due to technical development and higher living standards, but the urge to mitigate the indoor impact of the more frequently occurring heat waves cannot be disregarded either. At the same time, air conditioning systems produce a positive feedback that may strengthen the heat stress of outdoor urban climate, particularly on the hottest summer days and in the most densely built up areas.

During the last couple of decades numerous attempts were made to quantify the anthropogenic heat emission of transportation and of the buildings in several cities (e.g. in Tokyo and Philadelphia). The methods and conclusions of these surveys have recently been reviewed by Sailor, D.J. (2011). According to the building model calculations of Seprődi-Egeresi, M. and Zöld, A. (2011), the summer daily heat output of the houses in the densely built up inner city of Budapest would amount to a territorial average of 45 W/m^2. Another starting point is offered by the electricity consumption data of the utility company MAVIR.

The national consumption figures for the heat wave in June 2013 were higher by 20,000 MWh/day than on an average weekday in May. The difference can largely be attributed to the use of air conditioners. Since about 10% of the increase may appear in the inner city of Budapest (30 km^2), our estimate suggests a heat output amounting there to 25–30 W/m^2 from this source alone. Both of the above estimates ignore, however, the heat emission of the traffic which falls in most cities considerably behind the energy consumption of the buildings (Sailor, D.J. 2011). Based on the inquiries in cities with a climate more or less similar to Budapest, we can assume that the combined meso-scale impact of the vehicle traffic and the air conditioning systems have resulted in an additional urban summer air temperature rise of 1.0–1.5 °C since the 1960s. Though this difference itself is certainly not negligible, the threat coming from recent changes in macro-scale climate and weather conditions put the issue of urban heat stress in an even more sinister perspective (Stone, B. 2012).

These changes have manifested themselves in the growing frequency (*Figure 2*) and longer persistence (*Figure 3*) of heat waves (Vincze, E. *et al.* 2013). The figures reveal rather worrying trends in the homogenised temperature record of Budapest. However, the station of the Hungarian Meteorological Service, which is located on the Buda side in a densely built up neighbour-

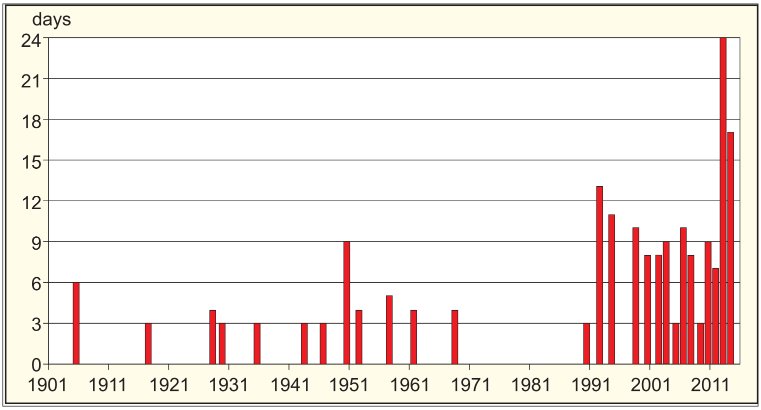

Fig. 2. Annual number of days in heat periods (daily mean temperatures higher than 27 °C on three consecutive days). *Source:* Vincze E., Lakatos, M. and Tóth Z. 2013.

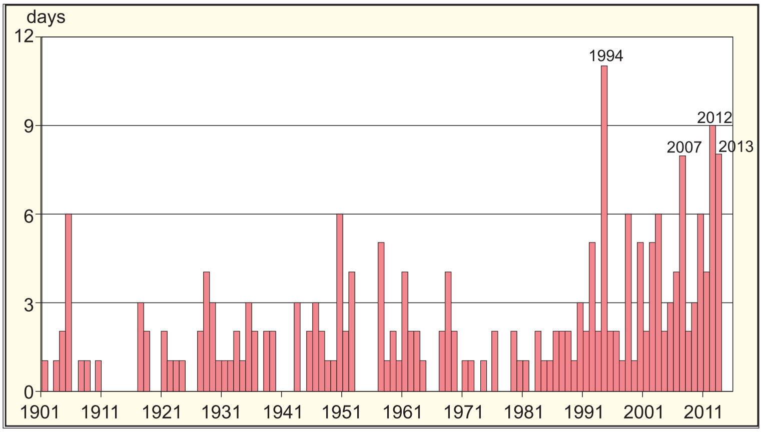

Fig. 3. Persistence (in days) of the most lasting heat waves in the given years (daily mean above 27 °C) *Source*: Vincze, E., Lakatos , M. and Tóth, Z. 2013.

hood, shows about 0.5 °C lower temperature than the city centre. The daily mean exceeding here 27 °C on three consecutive days indicates the threshold of the most serious 3rd grade heat alert in the city.

According to the most likely scenarios of regional model estimates, temperatures in the Carpathian Basin are bound to rise in accordance with the medium projection of the IPCC (2007). However, warming will be more distinct in the summer with an expected temperature increase of at least 4 °C until 2071–2100 against the reference period at the end of the 20th century (Bartholy, J. *et al.* 2007, 2011). This change will be coupled with a dramatic increase in the frequency of heat waves. The annual number of hot days (t_{max}≥30 °C) will triple during the 21st century, thus getting 34-38 days higher than the average of 18 days registered in the last 30 years of the millennium. (Bartholy, J. *et al.* 2011; Vincze, E. and Szépszó, G. 2012). These are merely average figures, which do not take into account the additional warming effect of the city.

Climatic assets to be saved

It is hard to admit, but except for some measures with micro-scale impacts only, in a city with an inherited rigid structure like Budapest, precious little can be done to change the general characteristics of urban climate in order to cope with the trend of global warming and to relieve the growing thermal stress that people will suffer from in summer. Therefore, one has to pay special attention to those areas where natural conditions are more or less able to counterbalance the discomfort caused by the typical urban climate. Within the confines of Budapest one can find two areas with particularly favourable atmospheric conditions, namely the banks and small islands of the Danube River and the Budai Hills with their great variety of microclimates. The remarkable differences compared to the downtown were reflected even by monthly mean temperatures in the 1960s (*Table 1*) and they must have substantially grown since that time.

Table 1. Deviations of the monthly mean temperatures between 1954 and 1968 on Szabadság Hill and Margaret Island** from those of the city centre/City Council*** in ⁰C*

Site	April	May	June	July	August	September	Year
Margaret Island	-1.0	-1.3	-1.6	-1.7	-1.6	-1.7	-1.2
Szabadság Hill	-2.9	-3.2	-3.2	-3.1	-2.8	-2.7	-2.9

Height: *470 m a.s.l., **103 m a.s.l., ***105 m a.s.l. *Source*: Probáld, F. 1974.

In calm, sunny anticyclonic weather one can measure afternoon and evening temperature differences between Margaret Island and large downtown squares more than 2 times higher than monthly means (*Figure 4).*

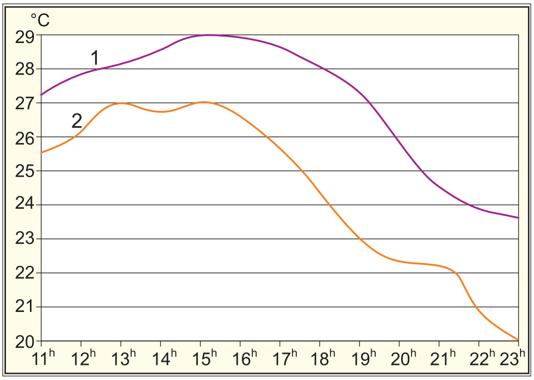

Fig. 4. Diurnal change of the air temperature on the safety island of Madách Square (1), and the park of Margaret Island (2); average of field measurements on three consecutive summer days in 1966. *Source:* Probáld, F. 1974.

Under similar conditions surface temperature differences reaching 8–10 °C between the downtown and Margaret Island as well as between the downtown and the Budai Hills are quite usual as it has been demonstrated by satellite measurements (Bartholy, J. *et al.* 2005). This is of course also linked with less frequency and shorter persistence of heat periods when daily peaks exceed 30 °C and night-time lows are higher than 20 °C.

Thus, the population dwelling in the hilly districts of Buda suffers much less from summer heat, while it can enjoy more sunshine and snow in winter. Due to prevailing west winds, the air is much cleaner on the Buda side, and severe air pollution is restricted to the key traffic routes that follow the main valleys. There is abundant evidence provided by recent polls and actual real estate prices that districts in Buda have the highest prestige and stand out among the favourite target locations of those intending to move, while there are only few people willing to leave Buda for the sake of a new dwelling in Pest. The equally easy access to nature and to the city centre, the various amenities provided by the Budai Hills are remarkable assets for the Hungarian capital even in the international competition of cities, since supply of quality dwellings and environmental issues rank high among the priorities of postmodern societies.

Regrettably enough, the development of land use during the second half of the 20th century largely disregarded the limited extent and particular value of the natural endowment of this area. The orchards, vineyards and nice gardens of the 19th century have receded and the rest of the forests have been encroached upon by construction with functions that simply do not fit to this environment, but are now difficult to remove. In the 1970s and 1980s large prefabricated housing estates appeared and high-rise buildings were erected on the slopes. As most obvious examples of the misuse of environmental assets, military barracks, institutions of higher education and training of the police and the army, as well as nuclear research facilities still occupy considerable areas in the Budai Hills, which should have been saved for more reasonable purposes.

From the islands of the Danube River, Margaret Island with an area of 96.5 hectares is the closest to the city centre. The whole island is a beautiful park suitable for walking, jogging, and other leisure time activities. Beyond several sports facilities one can also find a wellness hotel there taking advantage of the thermal water from local wells for medical purposes. Thus, the island has become a favourite public place and its amenities are properly utilised, sometimes even crowded with a great number of visitors. While Margaret Island is threatened by eventual overuse, the advantages offered by two similar islands situated a bit further northwards (Óbuda Island, Nép Island) seem to be located almost idle in lack of reasonable management and development strategies which would serve public interests. This can be most clearly exemplified by the southern half of Óbuda Island, which has been sold to a foreign-owned development company wanting to build there a high-rise hotel, casinos and a large-scale entertainment centre. This highly controversial project, however, has been pending for about ten years already.

The banks of the main branch of the Danube River have a total length of 58 km within the confines of Budapest. In a survey conducted in 2007 by using both field trips and aerial photos we have found that the total length of densely built up areas amounted to 18.6 km (Izsák, É., Probáld, F. and Uzzoli, A. 2008). The embankments serve here as the main N–S directed arterial traffic roads and they are bordered by a dense row of tall buildings that blocks any air exchange between the water surface and the nearby streets. Opening direct access to the cool and nice riverside for pedestrians has been envisaged several times, but the problem is still to be solved.

Derelict and entirely abandoned industrial establishments of the brownfield belt occupy 16 km (27.6%) of the banks, while sections of altogether 12.4 km (21.4%) length seem to be void of any reasonable human use, though even here the willow and poplar groves of the floodplain fulfil a valuable ecological function as wildlife corridors. At some places on Csepel Island the potential use of the riverside is restricted because of the vicinity of wells providing piped water for the city. In most cases, however, the key obstacle of utilisation is the lack of flood control levees or the heavy pollution of the soil. To overcome these difficulties considerable investments would be required from property developers.

Nevertheless, the brownfield belt and other idle sections of the riverside still offer great perspectives for future development. At the turn of the century the opportunities of profitable investments also aroused the interest of some large foreign-owned real estate companies, which started to construct gated communities with luxury apartment houses at the river, taking advantage of the favourable environment and the magnificent vista to be enjoyed at the sites selected for development. However, the drive to make as much profit as possible is manifested in the extreme density of buildings, the shortage of greens, and sometimes the quite dull architecture of these projects (Kauko, T. 2012). The realization of further grandiose development plans were brought to a temporary halt in 2008 by the economic crisis and its disastrous impact on the real estate market.

Conclusion

Metropolitan growth and climate change have brought about new global ecologic conditions (Sassen, S. 2013). Thus, monitoring future changes in urban climate and adaptation to the trends has become more necessary than ever.

Much more responsibility would be required also in preparing decisions with regard to the values of environment. In Budapest the ultra-liberal mayor and council leading the city between 1990 and 2010 adopted a laissez-faire attitude, thus allowing private development companies to get through their interests at the expense of those of the whole urban community. In order to save the environmental assets of Budapest and to achieve a turn toward sustainability, reasonable property development, better governance, comprehensive planning, appropriate regulation measures as well as their rigorous implementation are needed.

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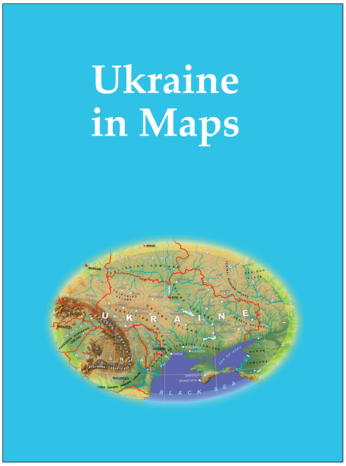
Ukraine in Maps

Edited by: **Kocsis, K., Rudenko, L. and Schweitzer, F.**

Institute of Geography National Academy of Sciences of Ukraine
Geographical Research Institute Hungarian Academy of Sciences.
Kyiv–Budapest, 2008, 148 p.

Since the disintegration of the USSR, the Western world has shown an ever-growing interest in Ukraine, its people and its economy. As the second-largest country in Europe, Ukraine has a strategic geographical position at the crossroads between Europe and Asia. It is a key country for the transit of energy resources from Russia and Central Asia to the European Union, which is one reason why Ukraine has become a priority partner in the neighbourhood policy of the EU. Ukraine has pursued a path towards the democratic consolidation of statehood, which encompasses vigorous economic changes, the development of institutions and integration into European and global political and economic structures. In a complex and controversial world, Ukraine is building collaboration with other countries upon the principles of mutual understanding and trust, and is establishing initiatives aimed at the creation of a system that bestows international security.

This recognition has prompted the Institute of Geography of the National Academy of Sciences of Ukraine (Kyiv) and the Geographical Research Institute of the Hungarian Academy of Sciences (Budapest) to initiate cooperation, and the volume entitled "Ukraine in Maps" is the outcome of their joint effort. The intention of this publication is to make available the results of research conducted by Ukrainian and Hungarian geographers, to the English-speaking public. This atlas follows in the footsteps of previous publications from the Geographical Research Institute of the Hungarian Academy of Sciences. Similar to the work entitled South Eastern Europe in Maps (2005, 2007), it includes 64 maps, dozens of figures and tables accompanied by an explanatory text, written in a popular, scientific manner. The book is an attempt to outline the geographical setting and geopolitical context of Ukraine, as well as its history, natural environment, population, settlements and economy. The authors greatly hope that this joint venture will bring Ukraine closer to the reader and make this neighbouring country to the European Union more familiar, and consequently, more appealing.



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Hungarian Geographical Bulletin 63 (1) (2014) 81–94.
DOI: 10.15201/hungeobull.63.1.7

Weather warning system in Hungary and the experiences of its operation

Márta SALLAI BURÁNSZKI[1,2] and Ákos HORVÁTH[1]

Abstract

Extreme environmental events may have catastrophic impacts on the society. Almost 90% of all natural disasters of the last 10 years have been caused by weather related hazards, i.e. floods, droughts, tropical cyclones and severe storms. The basic task of meteorology is to provide weather forecasts and warnings for public welfare to protect life and property. The weather warning system was set up by the Hungarian Meteorological Service (HMS) in 2006. The first system was capable to provide warnings and alerts for the 7 administrative regions of the country. In 2011 as a result of scientific and methodological development and infrastructural investment, financed by a competition support, the old system was replaced with a sub-regional weather warning system providing weather warnings towards the public, the disaster management and other decision-makers for 174 administrative sub-regions instead of the former seven regions. The first part of this paper provides an overview of the scientific and operational background of the nowcasting system. Then the two years' experiences of its operation will be reviewed. Finally, the problems caused by people's attitude to various weather situations and weather information will be discussed, together with some recommendations to improve the human factor of our professional efforts.

Keywords: meteorology, extreme weather, nowcasting, weather services

Introduction

Because of the swift changes in nature and society, which we have experienced recently, the economic importance of meteorological knowledge has increased. The societies all around the world are more and more sensitive to natural disasters and because of the dangers posed by atmospheric processes, the value of forecasts, nowcasts and their correct interpretation has increased.

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The advanced industrial and information societies of today are more sensitive to external natural effects, including the effects of meteorological origin. A devastating storm can cause a much bigger damage in high level technology production than 30–50 years ago. Our society is much more dependent on infrastructure than before. A power outage or a flooded main road can paralyze traffic, commerce, or everyday life for days. It is not incidental that damages caused by natural disasters are significantly larger in the developed countries. At the same time it is important to note that during the period between 1970 and 2008, 95% of fatalities caused by natural disasters happened in vulnerable developing countries (IPCC, 2011).

The overwhelming majority of natural disasters are of meteorological, climatic, or meteorological origin (e.g. floods) as it is shown by the diagram in the 2010 report of the European Environmental Agency (EEA) providing information on the number of natural disasters between 1998 and 2009, sorted by their types *(Figure 1).*

The data collected by the Münchener Rückversicherungs-Gesellschaft reinsurance company also shows the unequivocal predominance of weather and climate related catastrophes. In the examined 1980–2012 period, the number of catastrophes increased *(Figure 2).*

The role meteorology can play in reducing the damage caused by natural disasters is limited. Partly, because it is impossible to prevent extreme weather events, it is only possible to forecast them and partly because 100% accurate meteorological forecasts do not exist. While an accurate and well-interpreted forecast can save lives, the material value which can be protected is only a smaller part of the estimated value of the damage caused. In Hungary, there were no any research activities concerning on the exact material value, but in some European countries (e.g. Austria, Finland) related economic studies are available and the World Meteorological Organization (WMO) also made a statement about it. The studies on investment return of meteorology developments present rates between 1:6 and 1:10, meaning that every invested forint results in savings being 6–10 times larger than the prevented damage.

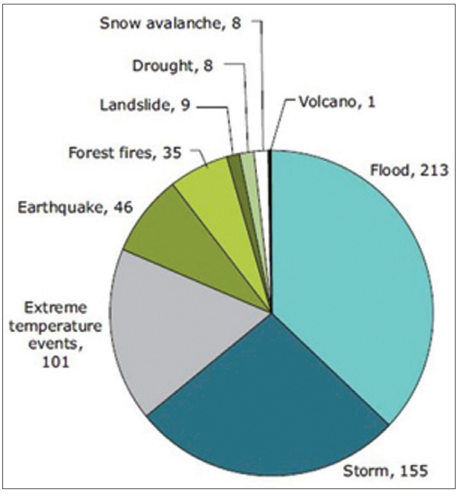

Fig. 1. Natural disasters in Europe between 1998 and 2009, grouped by the type of the catastrophes. *Source*: ETC-LUSI/EM-DAT, 2010

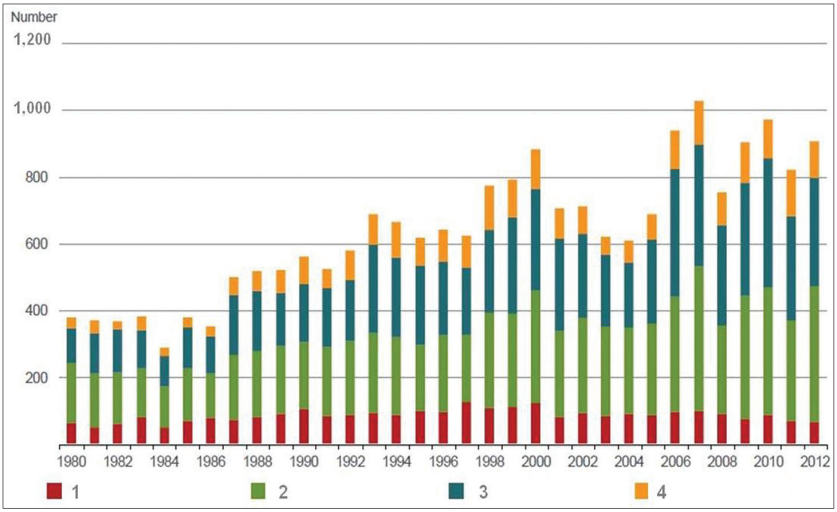

Fig. 2. Natural catastrophes worldwide 1980–2012. Number of events: 1 = geophysical (earthquake, tsunami, volcanic eruption); 2 = meteorological (storm); 3 = hydrological (flood, mass movement); 4 = climatological events (extreme temperature, drought, forest fire). *Source*: 2013 Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE

The professional basis of weather warnings

In forecasting atmospheric processes, meteorologists face two main tasks. One of their goals is to be able to create longer-term weather forecasts. The other issue is to tell very accurately whether there is going to be a dangerous weather event at a given point in the next one or two hours and how it will exactly happen. The latest task is the job of nowcasting.

The meteorological background of nowcasting

The most important requirements of nowcasting are the issues of exact weather forecasts and weather warnings for the next 1–2 hours for an exactly defined place. The ultra short range prediction differs from a regular weather forecast which is usually a prediction for longer periods and for larger areas like counties, regions or states. In that way, weather forecasts can be considered as the part of everyday life, while the importance of nowcasting appears in the case of unusual, severe weather conditions. The applied tools of nowcasting also differ from tools of weather forecasting. In the following section the background of ultra short range forecast and weather warning is presented.

The object oriented linear nowcasting

Most of the severe weather phenomena can be assigned to meteorological objects, such as thunderstorms or cold fronts. To identify them, appropriate meteorological analysis techniques are needed. The techniques apply a wide range of meteorological observations from the surface weather stations to the radar measurements. For example, for a proper description of a convective storm (e.g. a severe thunderstorm), radar measurements are needed to determine the radar reflectivity and the cloud tops of the thunderstorms; to calculate cloud top temperature, satellite information is used; surface observations provide data concerning the inflow of the storm etc. An objective nowcasting system is able to process the above data and recognize severe weather phenomena as objects. The time series of the recognized weather objects allow the computation of displacement and in that way, a forecast by linear extrapolation (*Figure 3).*

The advantage of the object oriented linear nowcasting method is that it is based on observations, so the meteorological objects get in the proper place and at the proper time on the meteorological map. The main disadvantage is the forecast itself: the evolution of severe weather phenomena is significant. The drifting object may become weak or a weaker object can develop to a severe level within a short time. That is why the Lagrangian approach cannot be applied for forecasts longer than 30–40 minutes.

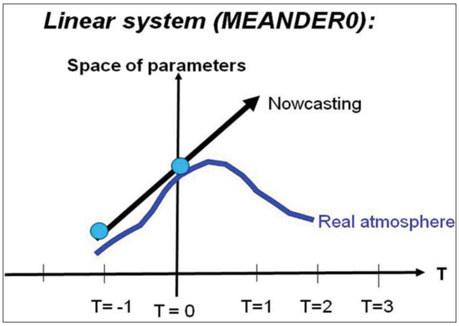

Fig. 3. Schema of linear extrapolation based nowcasting. Basic parameters and analyzed weather objects are linearly extrapolated

Quasi-linear nowcasting

Real atmospheric phenomena change in a non-linear way and they often define meteorological objects ambiguously. Instead of the Lagrangian approach, the Navier-Stokes equations based on numerical weather prediction (NWP) models are used for making a dynamical forecast. The highly complex mathematical equations can be solved only by numerical methods requiring large computing capacity. Although NWP models are complex physically based methods to describe the atmosphere, from the point of view of nowcasting, they have limitations. Even the highest resolution and the physically most sophisticated non-hydrostatic models are not able to predict severe weather events like thunderstorms exactly. A numerical forecast can be considered as successful if the simulated convection appears close to the place where they are in reality in a few hours. Nevertheless, 6 hours from now, NWP probably produces better forecast than the linear extrapolation because of the non-linear changing feature of the atmosphere.

During the quasi-linear nowcasting procedure a wide range of weather observations is applied to make an objective analysis to describe the present state of the atmosphere. The objective analysis provides the basic parameters (pressure, wind, humidity, etc.) for all grid points of a 3 dimensional grid which covers the domain. At the end of the predicting time interval (for example +3 hours from now), the NWP calculated basic parameters are considered as the most accurate data. Between the analysis and the NWP predicted parameters (between the start and the end point of the forecast period) a linear interpolation is applied for the basic parameters *(Figure 4).* Using basic parameters the so-called motion vectors can be computed. Motion vectors describe the replacements of weather objects which can be identified in the above described way.

The advantage of the quasi-linear method is that interpolation is applied for meteorological objects instead of extrapolation. Interpolated basic parameters also provide time-dependent surrounding conditions to estimate the development of weather objects. The disadvantage is the uncertainty of NWP computing the second pillar of the interpolation.

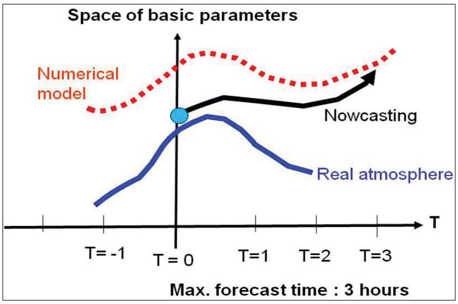

Fig. 4. Schema of quasi-linear nowcasting. At the beginning of the nowcasting period, the analysis is carried out and at the end of the period, an independent numerical forecast is given. The applied method is a linear interpolation.

The coupled nowcasting system

Due to the development of NWP techniques and the growing computer capacities, the dynamical models play a more important role in nowcasting than before. The main objective is to introduce the real meteorological objects into the models, so that the models can deal with the phenomena complying with the demands of nowcasting. Only high resolution, non-hydrostatic models are suitable for the tasks above because most severe weather events take place at 2–20 km scale (mezo-scale). The models are very sensitive to the initial condition: non-balanced initial fields can produce gravity waves and other numerical instability making the results hardly useable. That is why the assimilation procedure introducing significant weather phenomena into the initial fields has to be very prudent.

The assimilation of significant weather phenomena consists of 2 steps. The first step is the projection of the measured parameters into the model area. In the case of thunderstorms, radar measurements can provide the most detailed information about the phenomena. Radar data consist of radar reflectivity and tangential wind (Doppler wind). From this information, the so-called radar-operator procedure calculates which parameters are acceptable for the numerical model (pressure, humidity, wind, hydrometeor contents, etc.). The second step is the introduction of the observed and transformed data into the model. It is an efficient method when the model is able to accept the data many times during the integration term. For example, observations are available for 0, 1, 2 and 3 hours. The present time is 3 hour and the model starts now, but the simulation time starts at 0 hour. That is way the model can to use 0, 1, 2 and 3 hours measures.

When the simulation time is longer than 3 hours, the model runs without any outside forcing. Between 0 and 3 hours, a so-called "nudging term" is applied which forces the model equations to approach the measured data in a way that the effect of the physical consistency doesn't cease. The magnitude of the nudging can be set arbitrarily but it must be kept at a moderate level to avoid instability. The conclusion is that nudging technique may help the model to place the severe weather events to forecast for the appropriate place in appropriate time.

During the coupled nowcasting technique, the above mentioned assimilation procedure is applied for the numerical model and the model runs every hour. Nowcasting analyses are produced more frequently (every 10 or 15 minute) and the linear coupling between the analysis and the model forecast is made in the same way as in the case of quasi-linear nowcasting *(Figure 5).*

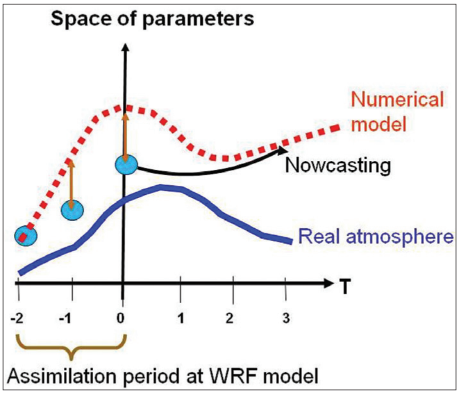

Fig. 5. Schema of coupled nowcasting. Circles represent objective analysis, the nowcasting (black line) blends to numerical forecast. The model has an assimilation period during which significant weather objects are taken into account

MEANDER: the nowcasting system of the Hungarian Meteorological Service

The MEANDER (MEsoscale Analysis, Nowcasting and DEcision Routines) nowcasting system is based both on NWP and real time observation. The MEANDER system makes ultra short range forecast and weather warnings in three steps.

The *first* step is the downscaling of the larger-scale weather phenomena to mezo-scale. Larger-scale data come from the ECMWF (*European Centre for Medium-Range Weather Forecasts*) forecast. ECMWF forecast data are available every 6 hour and they are used for WRF (Weather Research and Forecasting), a limited-area model for initial and lateral conditions. The ECMWF data as boundary conditions for the WRF limited-area model were chosen because of their higher space and time resolutions. The verifications available at the Hungarian Meteorological Service (HMS) also show that the ECMWF model provides better scores for the European domain than any other available large-scale model. The WRF model has several options to set and it uses the non-hydrostatic option with sophisticated cloud physic, boundary layer, radiation and other schemes.

Several experiments and case studies were performed to set up the ensemble of the physical parametrization concerning the planetary boundary layer, radiation, cloud physic and soil model parts of the model. The WRF model uses high resolution soil data of Hungary coming from Hungarian academic soil surveys. The land-use input data originate from the Hungarian CORINE database. That model segment is called WRF-ALPHA and the 2.5 km horizontal resolution allows the cumulus scheme to turn off, i. e. the model is able to compute convective phenomena by basic equations and there is no need for additional parametrization. Regarding the importance of the convection in severe weather events it is an important advantage. WRF-ALPHA runs every 6th hours providing +36 hours numerical forecast allowing to use this product for early warning.

The *second* step also belongs to the WRF model: 1 km horizontal resolution is applied for more frequent (every second hour) model runs. The WRF-BETA creates +8 hours forecast with 2 hours nudging time. During the very fine model run, the assimilation techniques mentioned at the coupled system are applied. The wind, temperature and humidity observations of automatic weather stations, radar reflectivity and satellite data are involved into the objective analyses which are made every hour. The WRF-BETA model uses the analyses for 2 hours nudging period, that way involving the local scale phenomena into the computations.

The *third* step of nowcasting is made by the linear segment. That part of the system makes an objective analysis every 10th minutes using data of automatic weather stations and radar and satellite observations. First guess data for the objective analysis come from the actual WRF-BETA model run. The grid of WRF-BETA also defines the domain of the nowcasting system which roughly covers the Carpathian Basin *(Figure 6).*

The resulting objective analysis contains the basic parameters (pressure, temperature, humidity, wind, etc.) calculated for all grid points. There are several derived parameters, such as visibility, precipitation intensity, the phase of precipitation, etc. A particular method is used for calculating the phase of

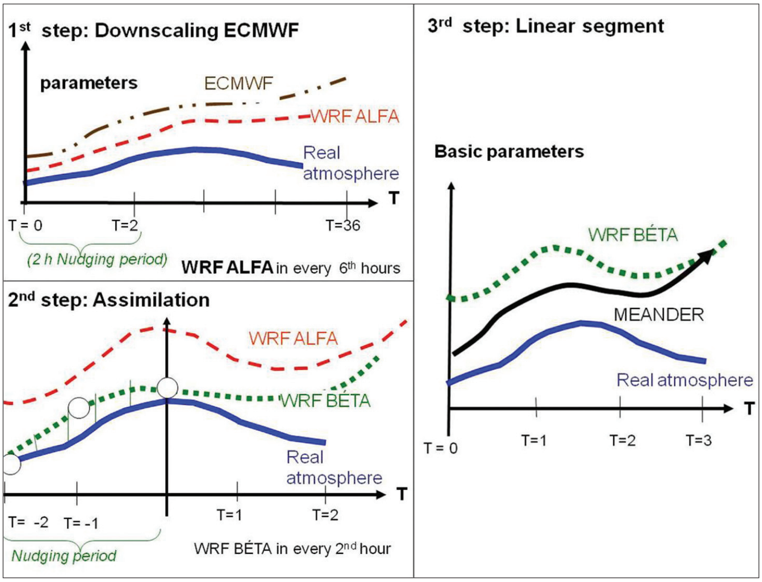

Fig. 6. Scheme of three steps of the MEANDER nowcasting system

precipitation (Geresdi, I. and Horváth, A. 2000). The cloud physic based procedure uses the air column for all grid points and from the vertical profiles of the basic parameters it estimates the phase of the precipitation falling on the surface. The procedure is able to distinguish freezing and frozen rain, snow, graupel and rain. The visibility calculation is based on a simple atmospheric scattering method where the content of hydrometeors is estimated from the mixing value of cloud elements coming from WRF calculations (Bencze, P. *et al.* 1982).

Based on the grid data of the objective analysis, the weather objects can be defined: showers, thunderstorms, hailstorms, etc. The final results are "current weather", parameters which identify the actual weather of all grid points. The next step is the linear interpolation of basic parameters between the analysis time and the forecast time 3 hours later coming from the actual WRF-BETA forecast. The basic parameters are three-dimensional data and they allow to calculate atmospheric motion vectors describing the movement of weather objects. The nowcasting of the MEANDER system is based on the movement of weather objects driven by the motion vectors. The moving objects are not necessarily static. Using the WRF-BETA forecast, it is possible to estimate the dynamically predicted weather objects. Comparing them with the analysis, some estimation can be made concerning their development. That phase of MEANDER is still under development.

Human contribution before final issue of warnings

The results of the objective procedures above are weather warnings for subregions. The offered warning patterns can be modified by the forecasters using a graphical editor. By rthe help of the editor, arbitrary domains can be assigned and warnings can be issued or cancelled. The forecasters are able to display all the meteorological parameters and fields by the HAWK workstation. The gained information combined with the subjective experience may upgrade the weather warnings.

Manual controls and in case of necessity, manual corrections are made before the final warnings which are sent to the Internet and to the users. On the home page of the Hungarian Meteorological Services everybody can be informed about weather hazards. Some authorities also get weather warnings via direct channels, such as the Civil Protection and Disaster Management Services *(Photo 1).*

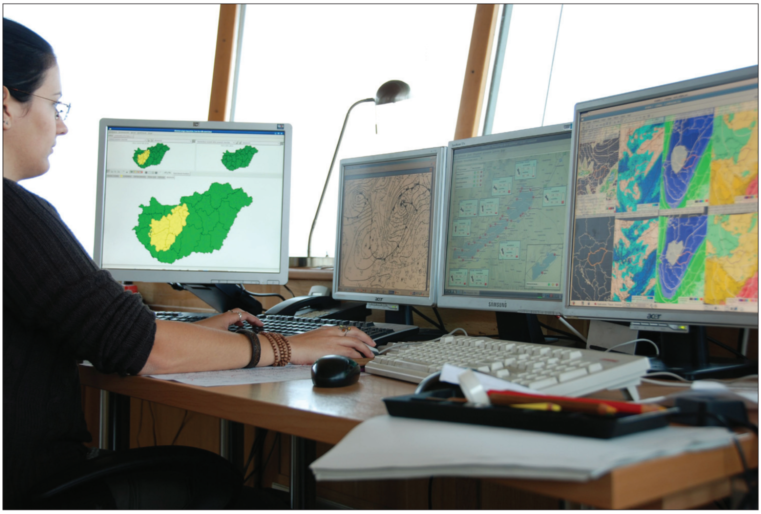

Photo 1. A graphical system is applied to enable the forecasters to modify the automatically produced warnings. The forecasters can use other weather data and they also apply their own experiences

The warning system of the Hungarian Meteorological Service

The warning system of the HMS realizes the forecast in two steps. During the first step a warning containing the description of the most probable dangerous weather events for the given and the following day is created in the form of a text and a map.

During the second step, a meteorologist ascertains whether if the given dangerous weather event indicated in the warning is possible under the given weather conditions. Then, 0.5–3 hours before the event (depending on the weather conditions and the type of the event) an alarm for the dangerous weather event is issued in form of a map.

Warnings and alarms are issued in the case of the following events: intense thunderstorms, heavy rains, wind gusts, sleets and snowdrifts. Some warnings for dangerous weather conditions are issued without any alarms by the system, such as the warnings for long-lasting, high-volume rainfall and snowfall events and the special warnings about the possibility of heat, extreme cold, long-lasting dense fog and ground frost.

During the alarms and warnings, the system distinguishes among three danger levels. If there is no chance of a dangerous event fitting the predefined criteria, the area shows up on the map as green.

- *First level (yellow).* The weather events in that category are not unusual, but they are potentially dangerous, therefore caution is advised, especially during activities more susceptible to weather.
- *Second level (orange*). Weather events which carry danger and can lead to damages or even injuries and accidents. It is advised to obtain detailed information regarding the weather.
- *Third level (red).* Dangerous weather events which can lead to serious damages and threaten human lives. They usually affect extensive areas.

The public can get information on weather emergencies on the Hungarian Meteorological Service website – http://www.met.hu/idojaras/veszelyjelzes/riasztas/.

Operational experiences

The sub-regional weather warning system has been in operation since 11 August 2011. On 16 July 2013, the Hungarian Meteorological Service replaced the sub-regional boundaries to district boundaries in its database connected to nowcasting, so alarms will be issued by districts in the future.

However, it does not mean that there is a substantial change in spatial resolution.

Alarm statistics

Full-year alarm statistics from 2012 were available only at the end of 2013 when this study was accomplished. There were warnings on 135 days out of 365 days *(Figure 7).*

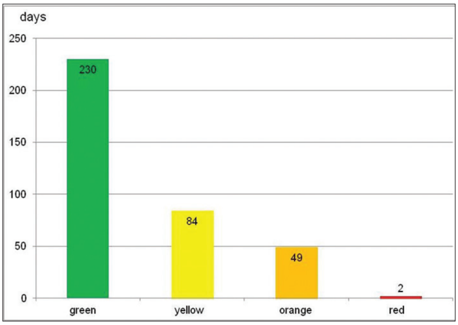

Fig. 7. The number of days for each danger level in 2012 (according to the highest danger level on any given day)

From the point of view of nowcasting, the busiest season is the so-called convective season during the summer. Nearly half (48%) of all the orange (level 2) alarms can be linked to intense thunderstorms (with ice pieces reaching 2 cm and wind gusts over 90 km/h) in the country. The alarms which can be linked to weather events usually happening during the winter season are only about one-fifths (17%) of all the alarms. In 2012, there were two red level alarms: one of them was on 19 July because of the strengthening of a thunderstorm system preceding a cold front, the other one happened on 8 December, at the beginning of the meteorological winter when a Mediterranean cyclone caused a snowdrift in the southern regions of the country.

Communication

Be prepared! But how? The communication of weather forecasts and warnings and the education are very important to make the public aware and prepared. A weather forecast can never be 100% accurate. In case of nowcasting, on a local scale, the behaviour of the atmosphere is chaotic. So it is necessary to communicate forecast uncertainty to help people make more effective decisions. Presenting potentially hazardous conditions in terms of probabilities, it is very important to make uncertainties understandable to the general public. It is not an easy process.

In the countries where meteorological information and the services of catastrophe management are available, subjective factors define the success of meteorological forecasts and warnings. They are the following:

- Knowledge of the general public about the weather and meteorological dangers.
- People’s attitude to weather situations and weather information.
- Media.

For the better understanding of forecasts, specific knowledge regarding meteorological concepts, forecasts and the question of predictability are necessary. While most of the knowledge could be gathered from various meteorological books and from the Internet, the most effective way would be the spreading of knowledge within the framework of the education system.

The descriptions in public textbooks dealing with the atmosphere, weather and climate are usually correct and professional, but some basic meteorological knowledge regarding forecasting weather and the benefits and limits of forecasts are missing. They do not deal with dangerous weather phenomena and practical behaviour patterns during weather emergencies, either. To make a progress in this respect, revision and supplementing of learning materials used in public education are needed.

In today's developed societies, especially in the countries where people don't have to face the destructive effects of weather every day, the vulnerability of people to the whims of the weather has decreased. At the same time, most people's behaviour regarding the management of weather events is characterised by becoming too comfortable and moving away from nature. Despite the fact that the communication channels are constantly spouting weather reports, most people don't look up for information about weather events or only do so superficially, even before outdoor activities, work, trips or public holidays.

Many meteorological service providers and the media disseminate a huge range of meteorological information. In many cases, meteorological websites contain information without any official background or quality control misleading the users and in the case of weather warnings, false information can cause catastrophes. People generally do not know which web pages contain accurate information. It is possible to improve the situation with the extension of objective knowledge and public pedagogy.

It is a significant progress that Hungarian broadcasters have been reporting on warnings and alarms issued by the HMS since 2011 when the regulation of catastrophe management and the related tasks of the media were introduced.

Conclusions

The science of weather forecasting has undergone huge advancements and as a result, meteorology can localize dangerous weather events more and more accurately. The correct usage and interpretation of information in forecasts and nowcasts can protect lives and it can increase the security of people and their valuables or simply contribute to the efficiency of our everyday work or to the spending of our free time.

Since its launch in 2006, the alarm system has become part of the weather related decisions made by the decision-makers and the general public. From an application aspect, replacing the original 7-region resolution to sub-regional and then to district-based alarms was a big step ahead.

With the methodological and IT developments, we decreased over-securing and we made a progress in increasing the accuracy of alarms. An important development is the continuous improvement of the MEANDER system providing the basis of nowcasting and the improvement of the communication of dangerous alarms.

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Submission

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All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail.

Publisher:
Research Centre for Astronomy and Earth Sciences HAS
H-9400 Sopron, Csatkai Endre u. 6–8.

Editorial office:
Geographical Institute, Research Centre for Astronomy and Earth Sciences
Hungarian Academy of Sciences
H-1112 Budapest, Budaörsi út 45.
Phone, fax: +36 1 309 2628   E-mail: geobull@mtafki.hu
Full text is available at www.mtafki.hu/konyvtar/geobull_en.html

Typography: ESZTER GARAI-ÉDLER
Technical staff: NORBERT AGÁRDI, ANIKÓ KOVÁCS, RENÁTA SZABÓ

Cover design: ANNA REDL
Printed by: Pannónia Nyomda Kft.

HU ISSN 2064–5031
HU E-ISSN 2064–5147

**Distributed by the Research Centre for Astronomy and Earth Sciences,
Hungarian Academy of Sciences**

Subscription directly at the Geographical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences (H-1112 Budapest, Budaörsi út 45), by postal order or transfer to the account IBAN: HU24 10032000-01730841-00000000. Individual copies can be purchased in the library of the Institute at the above address.