ANALYSES OF LANDSCAPE GEOGRAPHIC IMPACTS OF POTENTIAL CLIMATE CHANGE IN HUNGARY

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Abstract
Change of climate can be a remarkable turning point in the 21st century history of mankind. An important task of landscape geographic research is forecasting environmental, nature protection, land use demands and helping mitigation of disadvantageous processes from the aspect of society. ALADIN and REMO numeric climate models predict strong warming and lack of summer precipitation for the area of Hungary for the period between 2021 and 2100. There is a predicted growth in frequency of extreme weather events (heat waves, droughts hailstorms). Changes have been forecasted using data presented in table 1. For analyses of complex landscape geographic impacts of climate change the area of Hungary have been divided into 18 mesoregions with 5.000-10.000 km^2 area each (figure 1). The main aspect of choosing the regions was that they should have homogeneous physical, geographic and land use endowments and, for this reason, they should react to climate change the same way. Relationships between landscape forming factors and meteorological elements examined by us have been taken into consideration. Results of analyses of impacts of the meteorological factors on the changes of relief through the mass movements are presented in this paper. Changes of landscape sensibility of mesoregions to mass movements have been presented in the last chapter for the periods between 2021-2050 and 2071-2100 according to numeric climate models.

Keywords: Numeric climate models, Landscape use demands, mass movements

Introduction

Climate change has been one of the most popular but most debated issues in the field of environmental sciences for decades. The highest level international organization for research of climate change is the International Panel on Climate Change (IPCC), what was founded in 1988. IPCC publishes its reports based on results of numerous workgroups in 3-4 years intervals. Newest climate change scenarios and recommendations are presented in the IPCC reports (IPCC 2007, 2010). Carpathian Basin is among regions most strongly affected by warming and drought according to most of the scenarios.

The most detailed research work the VAHAVA report has been accepted by the Hungarian Parliament in 2010, so it is the official national action plan for mitigation the adverse effects of climate change in Hungary (Faragó et al. 2010). Most tasks in the document have been addressed to branches of the economy, in other words it deals with that what strategies should follow pomology, forestry, hydrology building industry, etc. in order to minimize adverse impacts of weather extremities and changing climate on economy and society.

Research has not gone into the details of nature protection aspects of potential climate change yet, however the authors believe that on the base of the accuracy and technical resolution of forecasts well established landscape and nature protection strategies can be elaborated today (Mezősi et al. 2012).

The aim of the research is to estimate the impacts of potential climate change on functioning of landscapes, landscape use stability, landscape sensitivity.

Climate change models

Demands for regional climate forecasting based on numeric models beside conventional statistic models arose in 2003 (Szabó et al. 2010). Two regional climate models have been adapted at the Numeric Modeling and Climate Dynamics Department of the Hungarian Weather Service: ALADIN-Climate 4.5 (www.cnrm.meteo.fr/aladin/) and REMO 5.0 (http://www.remo-rcm.de). The two climate models have been applied for Central Europe by Austrian and German researchers (Meyer et al. 2009; Renetzeder et al. 2009). Naturally there are weaker points in both models, where accuracy of their forecasts is lower but significant drawbacks have not known yet.

A new landscape level climate change forecasting model has been elaborated in the frame of the Research University Project of the University of Szeged (TÁMOP 4.2.1/B) between 2010 and 12 (Csorba et al. 2012; Mezősi et al. 2012).

Climate models had been tested first. For this reason they had been run for the decades between 1961 and 1991. Model results have been compared to results of climate measurements. High correlation levels made possible to run the models for the decades between 2021-2050, and 2071-2100.

One of the most serious theoretical uncertainty factors of both models global scale anthropogenic “forcing”, especially future carbon-dioxide levels. ALADIN and REMO models take into consideration the relatively optimistic A1B scenario. It presumes a strong decrease of atmospheric CO_2 concentration after its maximum around 2050 reaching 700 ppm at the end of the century (IPPC 2007).

Database and climate change trends for Hungary

Datasets used here are results of model simulations and they are presented as differences between outputs of calculations of meteorological data for 2 meters height for the periods between 2021-2050 and 2071-2100 and simulated averages in the reference period between 1960 and 1990. As it was mentioned before model outputs are in are in good accordance with measured time series of the reference period between 1960 and 1990. Data used in the analyses were detailed in Table 1.

Table1. Details of Meteorological data used in the analyses

air temperature	Monthly means
amount of precipitation	Monthly means
number of frosty days	$T_{min} < 0$ °C
number of heat days	$T_{max} > 30$ °C
number of hot days	$T_{max} > 35$ °C
number of extreme precipitation days	$R_{day} > 30$ mm
diurnal precipitation intensity indexes	whole amount of precipitation/number of rainy days Rday > 1 mm

According to the two before mentioned climate models a persistent but not uniform increase of **air temperatures** can be expected for Hungary in the next one hundred years with the strongest trend in the summer season. It means essentially, that warming tendencies of the decades between 1980 and 2010 would proceed with a similar rate.

In the next decades (2021-2050)

- Number of frosty day will decrease by 30% in the first half, and 50% in the second half of the century,
- Number of hot days can be doubled or even tripled compared to the average of the last decades according to the model a (Szépszó et al. 2009, 2011).

For **precipitation,** the models predict a slight decrease in the first half of the century, while an increasing trend is expected for the last three decades of the next one hundred years.
According to model simulations :

- longer heat waves,
- more frequent droughts and the same time,
- more frequent hailstorms can be expected.

Data published so far denote an increase in the frequency of extreme weather situations unambiguously (Pieczka et al. 2011). However, it is a question, whether the autumn-winter or the spring-summer period will have a stronger tendency to extreme weather situations (Bartholy et al. 2007). Forecasts for precipitation are less unequivocal than those for air temperatures, models have some imperfections in this field, even so they seems suitable for drawing conclusions in that aspect on landscape level.

Data of both models refer to intersections of a grid network of 34 columns and 15 rows with longitudes λ: 15.94^o - 23.20^o, and altitudes φ: 45.58^o - 48.66^o, resolution in x, y direction is 0.22^o. Simulations in the case of ALADIN and REMO models have a **resolution of 25 km** (~0.22°), what means they are suitable for relatively differentiated analyses of Hungarian landscapes.

Landscape research and planning interpretation of the datasets

An important aim of the research project was to gain data suitable for landscape geographic analyses. Scale of prediction in this study was chosen according to the requirements that results should be interpreted in the mesoregion level in the Hungarian hierarchical system of landscape classification (macroregion - mesoregion - microregion). Since Hungary has a relatively small area (93 030 km^2), and there are not great differences in relief − 2/3 of the area of the country are occupied by two plains and less than 10 % of its area lies above 500 meters above sea level – it is not an easy task to trace differences in climate. Besides, there is a low diversity of landscape use, what means, practically that all plains and low hilly regions are agricultural landscapes. However, there is a great micro diversity from landscape geographic aspect in Hungary, since there are loess sand alkaline and alluvial plains in a mosaic-like pattern. Low-hilly regions are less diverse from lithologic and pedologic aspects, while there are mountains built up of volcanic, limestone dolomite and crystalline rocks.

The area of Hungary was divided into 230 micro regions on the base of geologic, pedologic, biogeographic, climatic, hydrologic and landscape forming factors in the 1980s. Micro regions have an area of 100-200 km^2 on the average, while they are larger on plains and smaller in hilly regions and mountains.

Micro regions can be classified into landscape types on their natural characteristics and land use. Classification of geographic landscapes in Hungary started almost a hundred years ago. Gábor Strömpl completed the first landscape type map in the 1920s. Gyula Prinz and László Kádár dealt with landscape classification later (in 1936 and 1941). Landscape classification had based on natural landscape forming factors in the beginning. Relief was considered as the strongest landscape forming factor. This strong geomorphologic aspect, especially its genetic morphologic school was dominant in Hungarian physical geography till the 1960 years (Pécsi). The landscape type map of the Hungarian National Atlas was elaborated on the base of a more modern landscape classification, where 44 landscape types are distinguished (Jakucs et al. 1989). Geographic landscape types refer to the relief, climatic, hydrologic, pedologic, endowments, vegetation and land use characteristics of a given landscape type. For instance a sandy plain in the Great Hungarian Plain are described as follows: “Plain with moderately continental climate, sandy region with partly fixed dunes, alluvial fan with blown sand, deep groundwater level, mosaic like afforestations with remnants of original *Astragallo-Festucetum rupicolae* vegetation”.

Beside geographical classifications other fields of research elaborated their own types of landscape classifications from the 1950-ies. On the base of the well established silvicultural habitat classification, silvicultural landscape types were determined (Babos, 1954). Landscape architecture in Hungary uses three planning landscape categories: productive landscapes with industrial, mining, agricultural, silvicultural and horticultural sub categories; residence landscapes with urban and rural sub categories and recreation landscapes (Mőcsényi, 1967; Csima, 2006).

Establishing the mesoregions

Since the present paper is focused on determination of land use and environmental political consequences of climate change it seemed reasonable to form 18 regions from the mesoregions with area of some thousands of square kilometers used in regional planning (Fig. 1). In establishment of the 18 regions it was an important aspect that units created this way should react in a similar way to some important indicators of climate change. It is expected that functioning and important features of landscapes in the given regions will be affected in a similar way by changing climate, what can be identified well using some indicators.

Climate change will have a strong impact on wetlands in the Great Hungarian Plain probably. For this reason Mid-, Lower-Tisza and Körös-valley were contracted into one region (Central part of the Great Hungarian Plain). Climate change will affect cultivated hilly regions in the same way presumably, where change of the climate will impact on soil erosion processes remarkably. It was expedient to place the agglomeration belt of the capital into one region due to its high ratio of buildup. Unfortunately, micro regions around the greatest lake of Central-Europe, the Balaton could not be placed into one mesoregion. It is one of the permanent problems of Hungarian spatial planning classification.

Climate sensibility of relief

Landscape evolution is influenced by the mass movements and erosion processes, especially in the areas having high relief energy (Brunsden, 2001; Rózsa and Novák, 2011). In connection with relief it is precipitation from the before mentioned climate elements what can provide a base for drawing relevant conclusions from the aspect of forecasting landscape sensibility and changing landscape usage.

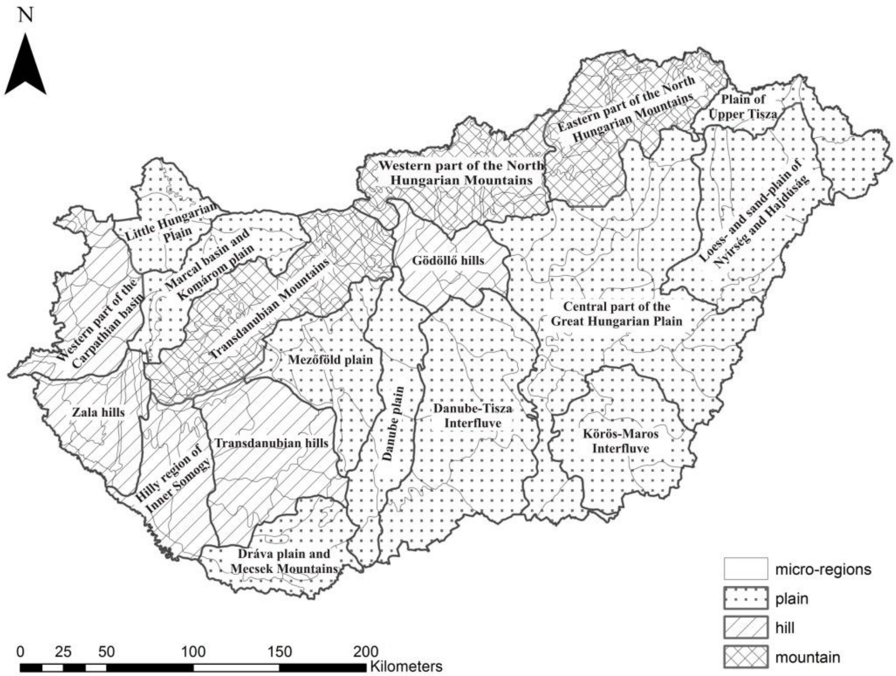

Fig. 1. Mesoregions of Hungary, created from 230 microregions – by combination with the geomorphological categories and landscape types

Due to the growing urbanization the extent of built-up areas and other intensively used lands are increasing, thus more and more steep and instable slopes have unfavorable land use type.

Therefore the better knowledge of the process, causing mass movements on these slopes and the relationship with climate factors are important. Moreover climate change enhancing the relevance of the problem, because the future change of the climate parameters can affect negatively this process. The important influencing climatic conditions in the process are the extreme precipitation conditions (longer-term wet periods, precipitation sum above the average, seasonally fluctuating precipitation, Juhász, 2004), in long term (decades) the increasing humidity (Szabó, 1996)

Changes in erosion sensibility can be detected plausibly on the base of average relief energies of mesoregions from relief data and number of days with hailstorms. Forecasts for relief sensitivity can be improved by involving diurnal precipitation intensity indexes, annual mean precipitation and number of frosty days. If these “second order” factors accumulate in a given spatial unit, their synergic effect can increase the probability of relief modification processes − occurrence of landslides for instance − not negligibly.

From relief factors valley density can be an additional element what can improve sensibility forecasts especially in regions with medium relief energies, slopes of 15-20 degrees and strong dissection. It can be a second order indicator as well.

Naturally, some types of vegetation like plough lands; vine yards and orchards increase erosion hazards. On steep slopes over 25 degrees agrotechnical measures are taken against erosion, but the scale of research do not make possible to deal with vineyards on terraces e.g. separately. Ratio of plough lands-vineyards-orchards type of land use can be taken into account as a second order factor also, especially in areas where synergies of several second order factors can be presumed.

From the aspect of relief sensibility indicators we can classify the factors as:

First order indicator:

- high relief energy + number of days with hailstorms

Second order indicators:

- valley density + diurnal precipitation intensity index
- relief energy + annual amount of precipitation + number of frosty days
- plough lands-vineyards orchards + number of days with hailstorms

First results: slope processes and mass movements

Mass movements are rapid, natural hazard-like processes of relief forming. In the case of 100 ones from the 230 Hungarian micro regions such surface forming processes are expected but a part of them are fossil, inactive ones. Only those micro regions have been taken into consideration, where mass movements are active processes (Szabó et al. 2007). Typical scenes of mass movements are steep banks of rivers, and hilly regions in the case of appropriate lithological and orographic endowments. In the case of these processes anthropogenic impacts have a great importance. Frequently, especially in mountain regions it is hard to separate natural processes from those that are triggered by human activities.

Mass movements are hard to be taken into consideration on mesoregion level because they have rather small spatial extent. For the evaluation registered cases with mass over 10 000 m^3 since 1960 have been taken into account. From climate indicators amount of precipitation in the winter half year has been involved in the analyses. (Fig. 2).

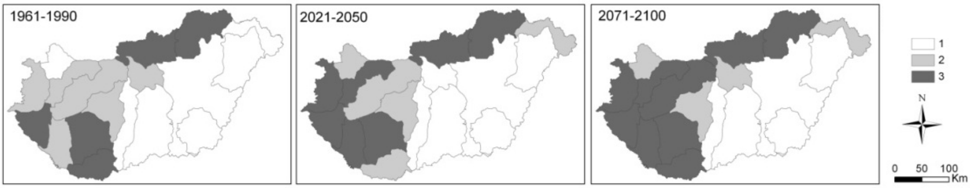

Fig. 2. Sensibility of mesoregions to mass movements in the decades between 1961-1990, 2021-2050, and 2071-2100 (Legend: 1: less sensitive, 2: moderate sensitive, 3: most sensitive areas)

On the base of the output maps in Fig. 2 increasing amount of precipitation in the winter period can result in increasing frequency and spatial extent of mass movements. Compared to the past decades (1961-1990) 3 more mesoregions will be endangered by strong mass movement processes between 2021 and 2050 and then 2 more ones till 2100. In one hundred years half of the 18 mesoregions (and about the half of the area) of the country will be endangered by such processes. Surprisingly, in the case of two mesoregions – Gödöllő hills and Dráva plain (see Fig. 1) – extent of areas endangered by mass movements will decrease till 2021 and increase again after 2071.

Conclusions

Partial results of a pending research project are presented in the present paper. Its main aim is to analyze the landscape geographic consequences of the climate change forecasted by two numeric climate models till 2100.

The models have 25 km spatial resolution what makes possible to examines meso regions on the base of 5-15 data sites. The main objective in the establishment of mesoregions was that parts of the mesoregions should give uniform responses to climate change.

Reliability of tendencies determined by the models is good; however their landscape geographic interpretation especially forecasting land use tendencies for the period between 2071-2100 has a high error ratio. It seems reasonable to involve first and second order indicators in the analyses and differentiate among them by weighting. Weight of weaker factors in the calculation can be decreased this way. Another task is to estimate the collective sensibility of landscape forming factors like water bodies, soil and vegetation to predicted climate change. Knowledge on the functioning of landscape forming factors within the given mesoregions is necessary for that.

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