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Quarterly Journal of the Hungarian Meteorological Service
Vol. 121, No. 4, October – December, 2017, pp. 345–370

National Adaptation Geo-information System in climate adaptation planning

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(Manuscript received in final form November 7, 2017)

Abstract—Climate change impacts determine the long term development possibilities in Hungary. Due to the different vulnerability and adaptive capacity of various regions, the impacts and problems should also be handled in a differentiated way. The key areas of climate safe planning are: water safety, food security, human health security, safety of infrastructure, energy security, natural environment. Successful adaptation to climate change is inconceivable without having a sound knowledge of the impacts of climate change. The National Adaptation Geo-information System (NAGiS) may be used by national, regional, and local decision makers and stakeholders. It provides information on the climate status of the country, on the impacts of strategic risks connected to climate change and other long-term natural resource management issues, and on the correspondent adaptation possibilities, based on indicators, analyses, and impact studies. Data layers of NAGiS were elaborated by the Geological and Geophysical Institute of Hungary and partner projects funded by the Adaptation to Climate Change programme of the EEA Grants. The main parts of the NAGiS are a map-visualization system with 650 data layers; a database containing the calculation results based on modeling (GeoDat with 910 data layers); and a meta-database to help finding relevant data. NAGiS can be a useful tool for climate safe planning, analyzing, decision-support activities in governmental strategic planning; or for municipalities in spatial planning, settlement planning, organizing public services. It can be used in climate policy, energy policy planning, transport, and energy infrastructure design and numerous other fields. The further development of NAGiS is financed by the Environmental and Energy Efficiency Operative Programme. Between 2016 and 2018, the project will elaborate a decision support toolbox for underpinning policy and municipal adaptation measures, based on the development of the databases, methodologies, and evaluation modules of NAGiS.

Key-words: National Adaptation Geo-information System, climate change, GIS, vulnerability, adaptation, climate safety, policy planning, municipal planning, decision support system

1. Introduction

Climate change can have serious impacts on Hungary and determine the long term development possibilities of the country. For the 21st century, climate model projections show that the warming trend that has been witnessed during previous decades will continue (*Sábitz et al.,* 2015). The changes can affect almost all spheres of life: human health, ecosystems, economy, infrastructure systems, agricultural productivity, just to mention some of the most important ones. Settlements have to face with the expected changes, too. The impacts have different territorial scopes, and the vulnerability diverses regionally (*Pálvölgyi et al.*, 2012), Hence, the mitigation and adaptation capabilities of the regions also differ from each other. The problems should also be handled in specialized ways, aiming to find customized solutions based on each area and its capabilities (*Sütő et al*., 2016).

Adaptation has recently become an increasingly important strategic field besides mitigation in international and Hungarian climate change policies (*Antal,* 2015). The strategy of the European Union on adaptation to climate change was adopted in 2013. In parallel, Hungary started the revision of her National Climate Change Strategy 2008, and gave a greater emphasis for adaptation in climate change policy. Local governments also have a strong interest in planning local climate change adaptation activities and other developments based on the known and expectable effects of climate change. Having the relevant, available data and information are inevitable for planning. Ideally, geo-information systems with maps showing the necessary quantitative or qualitative information on relevant topics should be available.

There are different groups of decision support web based applications around the world, according to their types, goals and functions. Some portals *compile available knowledge* (articles, books, papers, project descriptions, best practices) on various topics; others *help interaction between users and exchange of knowledge* by fora; while several web platforms focus on *planning, strategy building for adaptation, and education*. Some systems offer *databases with map visualization*, which can be analyzed and evaluated. European solutions rather help the exchange of information, knowledge, and interactive communication of partners; while in North America, numerous decision support systems can be found as well, which are based on geographic information system (GIS) with databases and maps of concrete territories. Some applications are as follows:

- The primary function of several homepages and applications is the *dissemination of information and education* on the theory and methods of planning (e.g., Urban Adaptation Support Tool[1], UKCIP Adaptation Wizard[2]). They usually lack decision support functions based on

[1] http://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast

[2] http://www.ukcip.org.uk/

information generated by indicator analyses and map visualization. They can help enhancing planning capacities and decision making in strategic planning on adaptation issues.[3]

- Several web tools are suitable mostly for *awareness raising or introduction into climate change related topics*. They are usually rich in information, but due to the weaknesses of available databases, limited number of indicators, low resolution (giving only country-level or regional overviews), or map visualization deficiencies, they do not provide interactive applications, and can only help getting a basic introduction into climate change problems for decision makers and other stakeholders concerned. Climate-ADAPT Map Viewer[4] and Urban Vulnerability Map Book[5] are from this group. Another example of such solutions is the Climate Wizard[6], which works based on numerous climate and greenhouse gas emission projections, but only with two exposure indicators. The Climate.gov Data Snapshots[7] has an excellent design with a rich and clearly structured homepage, but territorial information is provided only in low resolution. The EPA's Climate Resilience Evaluation and Awareness Tool (CREAT)[8] application can be mentioned here either, with its imaginative, informative solutions (challenge logos, polished map designs, a well structured homepage).

- One of the *best practices of useful decision support tools* is the CLIMSAVE project[9], which uses and visualizes a lot of indicators (impact, adaptation, vulnerability, and economic efficiency) based on a solid theoterical foundation. Another one is the North American CalAdapt[10] supplying a detailed spatial resolution database (on a 10 km × 15 km grid), and the large number of analyzed topics. The logical framework, the detailed information basis and maps make these applications suitable for preparation of climate policy decisions on different territorial levels, or they can be foundations for further web based developments.

Prior to the launch of the NAGiS project, Hungary had no complex and multisectorial data- and information basis, which could have provided information on the expected changes necessary for planning adaptation measures for each region of the whole country. The VAHAVA project (*Láng et al.*, 2007) was an important milestone to draw the attention to the importance of climate change adaptation, however, its investigations used the traditional tools

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[3] Other examples of this type are http://DataBasin.org, https://coast.noaa.gov/digitalcoast.
[4] http://climate-adapt.eea.europa.eu/knowledge/tools/map-viewer

[6] http://www.climatewizard.org/
[7] https://www.climate.gov/maps-data/data-snapshots/start
[8] https://www.epa.gov/crwu/build-resilience-your-utility
[9] http://www.climsave.eu/
[10] http://cal-adapt.org/

and approaches. Nevertheless, the theoretical basis for the NATéR analyses can be found in the VAHAVA project. The new element in NATéR is that it contains additional territorial contents to the sectoral approach of the VAHAVA. As a consequence of the insufficiency of data and methodology, analyses on climate change vulnerability and possibilities of adaptation were done only for several areas and were limited in scope (*Sütő et al*. 2016), for instance in the European ESPON Climate project. Though, the National Adaptation Geo-information System (NAGiS) could build on the result of recent researches and evaluations carried out in the field of climate change. Naturally, the ESPON projects concentrated mostly on the European level, but its NUTS-2 and NUTS3-level examinations show some information from lower territorial levels as well. One of the real contributions of NATéR in this regard is the possibility and provision of real territorial level analyses.

In 2013, the Geological and Geophysical Institute of Hungary (MFGI) was awarded a grant of the European Economic Area (EEA) for creating the National Adaptation Geo-information System. The EEA-C11-1 project entitled Establishing the NAGiS was the first initiative launched by the EEA Grants funded Adaptation to Climate Change programme area in Hungary. The fund operator for this programme was the Regional Environmental Center for Central and Eastern Europe (REC), and the donor partner was the Norwegian Directorate for Civil Protection and Emergency Planning (DSB). The EEA-C11-1 NAGiS Project lasted from 24 September 2013 until 30 April 2016. The project promoter was the Geological and Geophysical Institute of Hungary. The National Adaptation Centre (NAC), a unit of the institute was responsible for the implementation process with involvement of plenty of scientific institutes in Hungary (*Kajner*, 2016).

The overall objective of the project was to develop a multipurpose geo-information system that can facilitate the policy-making, strategy-building, and decision-making processes related to the impact assessment of climate change and founding necessary adaptation measures in Hungary. The NAGiS operating principles are in line with international climate protection obligations as well as with EU policies, guiding principles, strategies (e.g., EU 2020, Territorial Agenda 2020).

The three main objectives of the NAGiS project were:

- To support decision-making on the adaptation to climate change by setting-up and operating of a multifunctional, user-friendly geo-information database, based on processed data derived from several other databases.

- Develop the methodology for data collection, processing practices, analytical processes, and climate modeling related to the impact and vulnerability assessment of climate change and corresponding adaptation methods in line with INSPIRE requirements, accommodating to the Hungarian National Spatial Data Infrastructure.

- Operate a web-based “one-stop-shop”, an information hub for all stakeholders concerned to obtain reliable, objective information, derived and processed data on climate change and other relevant policy areas.

2. Methodology

Urban, economic, rural development and other planning activities of municipalities, regions, counties can not miss including adaptation issues and measures. Quantitative input data from vulnerability assessments form an inevitable basis (in accordance with international directives) for impact assessments and decision-support analyses on which spatial, regional and sectoral policy planning is based. (*Czira et al*., 2010; *Pálvölgyi* and *Czira*, 2011). In order to successfully integrate climate change issues into policies, it is necessary to define the areas of intervention, which influence the adaptation of regions, sectors the most. The key areas of *climate safe planning* are: water safety, food security, human health security, safety of infrastructure, energy security, natural environment (*Pálvölgyi et al*., 2012). It is important to investigate to what extent the physical environment of everyday life is climate safe, and how it can adapt to the impacts of a changing climate (*Pálvölgyi* and *Czira*, 2011). Therefore, a specific evaluation method and model is needed which can handle the processes in their complexity, taking also into account the whole chain of climatic impacts, including their social consequences as well (*Sütő et al*., 2016).

The climatic impacts to be examined form a complex chain. The direct climatic effects appear in the form of changes which can be described using regional climate indicators. Complex local natural phenomena generated by climate change, interacting with each other (having repercussions on the climate indicators as well) may be identified as indirect climatic and complex natural impacts. Unfavorable socio-economic consequences are produced jointly by the direct climatic impacts and the indirect impacts that natural systems and ecosystems are exposed to (*Sütő et al.,* 2016). The climate change may deepen the existing economic and social differences and may cause new, serious inequalities (*Láng et al*., 2007).

In connection with the assessment of the impacts of climate change, the aim of the Climate Impact and Vulnerability Assessment Scheme (CIVAS) model is to provide a standardized methodological background to quantitative climate impact assessments. The model is based on the approach published in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), but numerous experiences of application can be found in scientific literature. CIVAS has been developed in the framework of the

CLAVIER[11] international climate research project, amongst others to examine the impacts of climate change on ecology and on the built environment. *Fig. 1* gives an overview of the method used during the establisment of NAGiS. (The terminology used by the figure was detailed in IPCC, 2014; *Pálvölgy*i and *Czira*, 2011; *Pálvölgyi et al*., 2010; *Selmeczi et al*., 2016a).

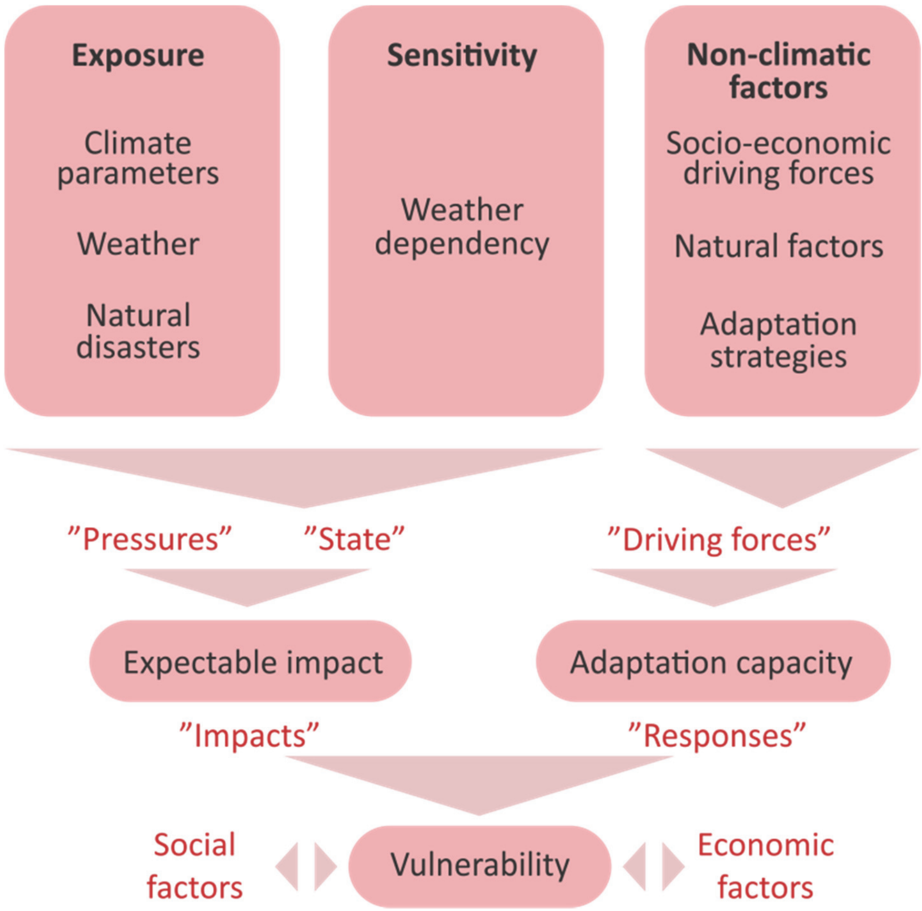

Fig. 1. The structure of the CIVAS model (*Pálvölgyi,* 2008).

The NAGiS is of special importance in Hungary for the complex monitoring of climate change impacts in several sub-topics as well as for providing a basis for mitigation and adaptation solutions. Its development was aimed to outline a comprehensive view on Hungary regarding the above described issues, creating the basis of future monitoring activities at the same time.

[11] Climate Change and Variability: Impact in Central and Eastern Europe, EU 6th Framework Programme. http://www.clavier-eu.org

3. *Scientific investigations and results*

3.1. Climate information used for NAGiS

Climate change exposure, sensitivity, potential impacts, adaptability, vulnerability indicators were calculated and developed in NAGiS, using climate information, i.e., measurements and regional climate model (RCM) projections as input data. For the past and present, the CarpatClim-Hu observation database was applied, created with interpolation of measured climate datasets to a 10 km × 10 km grid by the Hungarian Meteorological Service. Four different regional climate models have been adapted by the Hungarian Meteorological Service and the Department of Meteorology of the Eötvös Loránd University and used for analyzing future climate change in detail for the territory of Hungary (*Bartholy et a*l., 2011). Two of these RCMs provide projected climate information (both with the medium A1B SRES anthropogenic emission scenario; *Nakicenovic at al*., 2000) for the users of NAGIS: ALADIN-Climate (*Csima* and *Horányi*, 2008) and RegCM models (*Torma*, 2011). Climate model data cover three climate windows. The 1961–1990 period was used as a reference in most analyses. Future projections were made for the 2021–2050 and 2071–2100 periods.

Climate model simulations are characterized by a set of uncertainties arising from the different approaches to describe the climate system, the approximate way of representing the physical processes involved in the calculations, the impact of the socio-economic changes which can not be forecast, and the natural variability of the climate. Therefore, when investigating future climate, analyses are suggested to be carried out with data of several climate models or simulations, in order to attain a probabilistic approach.

3.2. Projected climate change in Hungary

Since 1900, the annual mean temperature has increased with 1.3 °C in Hungary, which is much higher than the global average of 0.3 °C. The annual mean temperature is expected to increase with 1–2 °C by 2021–2050 and 3–5 °C by the end of the century in Hungary. Spring and winter mean temperature is likely to increase between 1 °C and 2 °C over Hungary by 2050 and approach +3 °C by 2100 according to ALADIN-Climate and RegCM simulations. The model results show that summer temperature rise in far future will be between 3 °C and 5 °C, or even higher – for instance, in August it may exceed 6 °C compared to today's levels. The number of warm extremes is projected to increase significantly, while cold extremes (frost days and extremely cold days) tend to become less frequent (*Sábitz et al*., 2015).

Model results are ambiguous for precipitation change projections. A slight, 10% decrease of annual average precipitation is projected by the end of the century. Summers tend to get dryer: a 5% decrease is projected for the near future, and even 20% less rain may fall on average in the 2071–2100 period. Winter precipitation may decrease by 10% on average (*Sábitz et al*., 2015).

The number of consequent dry summer days is expected to increase, and longer dry summer periods are projected than there are today. Parallel to this, the number of days with higher rainfall (20 mm or above) will also increase in each season, except for summer periods. Floods and inland water problems may get more frequent. The frequency of torrential rains, gale force storms, blizzards, and heat waves is also expected to grow, such as the incidences of extreme water levels and bushfires, the length of drought periods, and as a consequence of all the above, biological diversity is likely to decrease (*Sütő et al*., 2016; NCCS-2, referring to the Hungarian Meteorological Service data).

However, the changes of the climate affect the different parts of Hungary very diversely. The warming in 1981–2015 was stronger in the central part of Hungary and in the Mecsek Mountain. (NCCS-2, referring to the Hungarian Meteorological Service data.) According to the model results, larger warming is projected in the eastern and southern parts of Hungary by the end of this century. Precipitation can be expected to decrease in the southwestern part of the country and stronger, significant decrease may occur according to one of the RCMs (*Sábitz et al*., 2015).

3.3. Data layers based on impact studies

Based on the database and climatic models available in the framework of the NAGiS project, research has been carried out in several thematic fields, examining the vulnerability, exposure, and adaptation potential of particular geographical areas to given impact factors of climate change. NAGiS includes analyses and projections for the main topics described below (we provide some figures just to demonstrate their outcomes).

3.3.1. Changes in shallow groundwater conditions in Hungary

The aim of the groundwater-level monitoring workflow was to elaborate a methodology by which the shallow groundwater table can be modeled under different climate conditions, investigating the impact of climate change on groundwater and characterizing climate sensitivity of shallow groundwater flows. The introduced methodology is valid for the assessment of the impacts and sensitivity at various (regional and local) scales and by diverse methods.

During the examinations carried out, the CarpatClim-Hu database established from the data of hundreds of weather and rainfall observation stations of the Carpathian Basin was used; whereas for determining future groundwater conditions, the results of the ALADIN–Climate regional climate model were applied (*Kovács et al*., 2015b).

Delineation of climate and recharge zones, calculation of water balances using hydrological models, and simulation of groundwater table with numerical models were carried out in the first phase of the research. Predictive modeling was undertaken using regional climate model projections for three time intervals. One of the most important conclusions of the research based on measured data and model simulation results is that recharge rates and groundwater table levels are seriously decreasing in mountainous areas, and this tendency is expected to continue (*Kovács et al.,* 2015b). Nevertheless, the conclusions are drawn based on results of a single RCM, which is needed to be extended with uncertainty estimation later.

3.3.2. Changes in drinking water protection areas

The methodology of vulnerability assessment of drinking water resources was developed in the NAGiS project, including the development of exposure (*Fig. 2*), sensitivity, and adaptation indicators. Furthermore, a complex adaptation indicator was developed for the service area of a selected regional waterworks company, and using these, a complete climate vulnerability assessment was carried out for this pilot area (*Rotárné Szalkai et al*., 2016). The elaborated methodology makes it possible to provide decision makers with comprehensive information on the effects of climate change on drinking water resources. That may help the inclusion of the aspects of climate adaptation and sustainability into sectoral and regional strategic planning.

3.3.3. Changes in the risk of flash floods

Flash flood is a sudden flood caused by heavy rainfall in the course of a relatively short time. It may cause severe damage in mountainous and hilly areas. The intensity of the rainfall and special parameters of the water catchment area of a river (surface cover, hydrography, soil characteristics, geomorphology, gradient) influence the parameters of flash floods. The water catchment area, which includes the settlement endangered by intense rainfall can be delineated according to the lowest point of the rivers crossing the settlement (base level). For this reason, the flash flood risk classification of a settlement is given for the base levels (*Fig. 3*). As a result of our research, all water catchment areas including settlements in mountainous and hilly areas of Hungary were classified for flash flood risk, and the expectable occurrence of extreme downpours was investigated (*Turczi et al*., 2016).

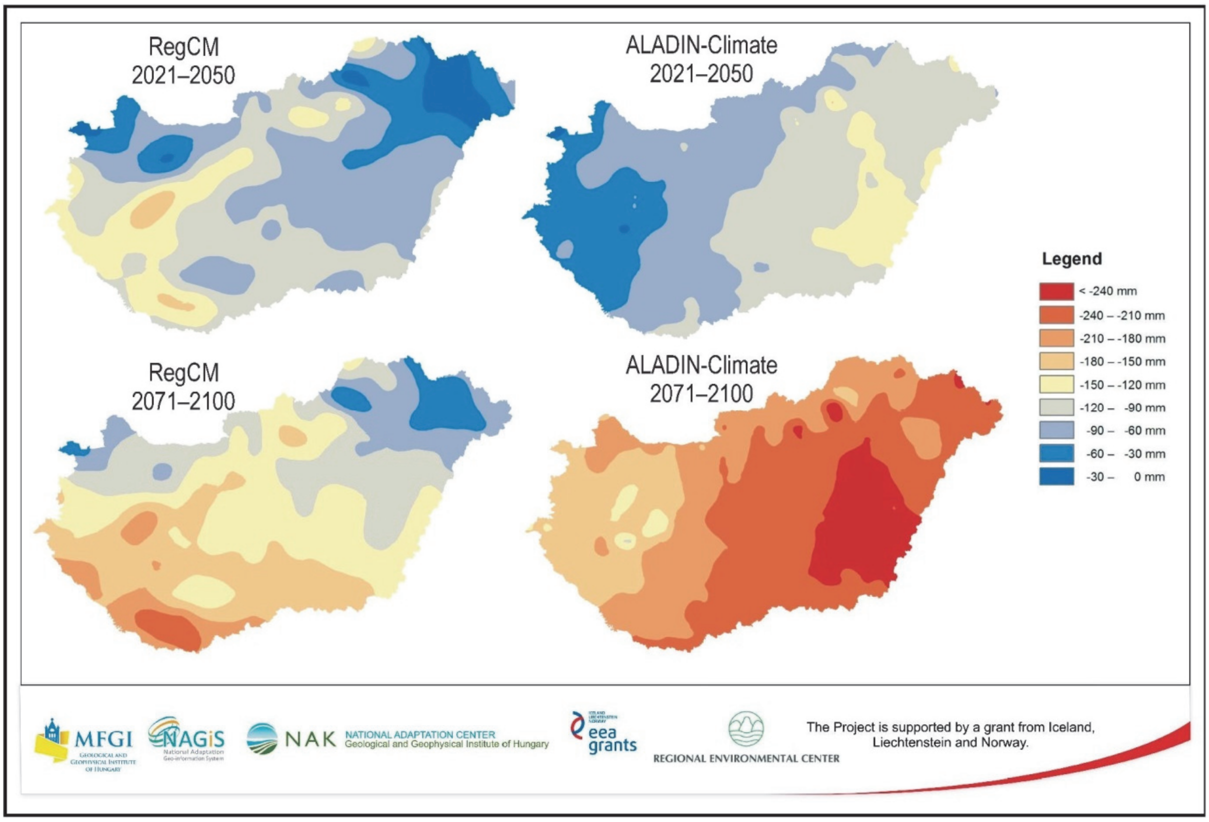

Fig. 2. The expected change of the climatic water balance in the 2021–2050 and 2071–2100 periods, based on RegCM and ALADIN-Climate data (*Rotárné Szalkai et al*., 2016)

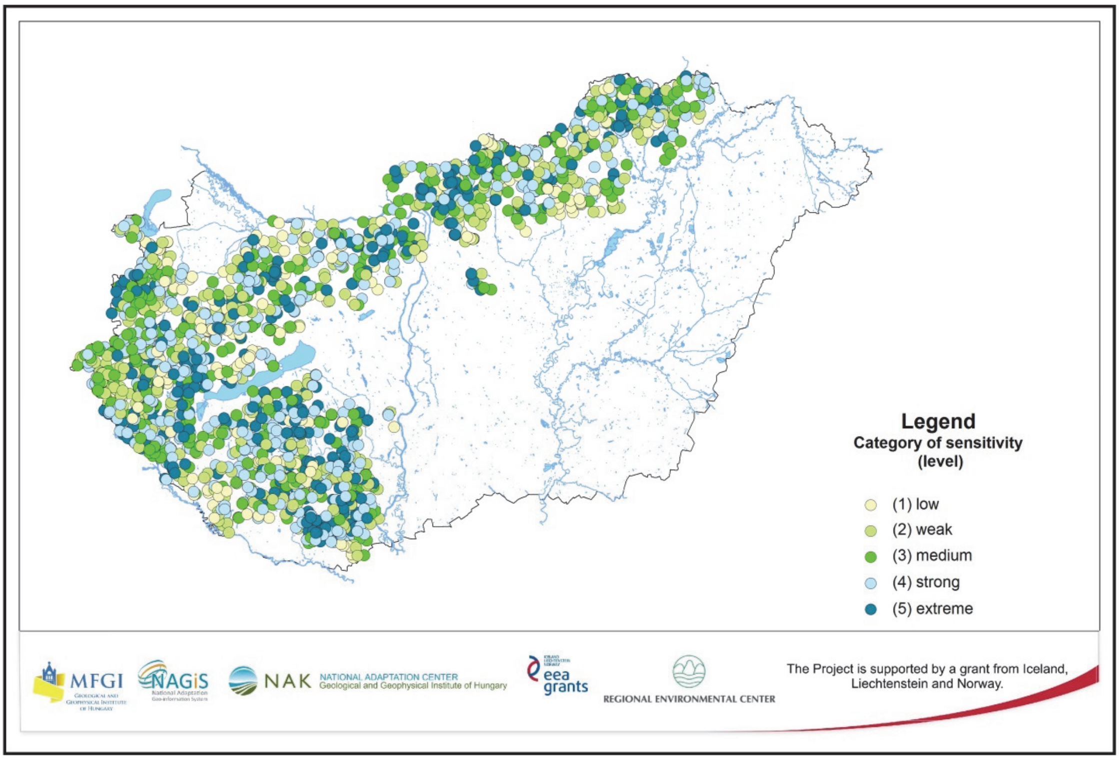

Fig. 3. Sensitivity of base levels and watersheds for flash flood risk in mountainous and hilly regions (NCCS-2, 2017, based on https://map.mbfsz.gov.hu/nater/)

3.3.4. Changes in hydrology of Lake Balaton

The research investigated the expected change of the water balance of Hungary's largest lake, using ALADIN-Climate model results. The changes were calculated for the 2021–2050 and 2071–2100 time windows compared to the 1961–1990 reference period. The most remarkable and robust change is manifest in the estimated temperature rise, as a result of which, increased evaporation is expected both on the watershed and the free water surface. The water budget pattern of the watershed changes due to the increasing territorial evaporation, which leads to a significant decline of runoff. Altogether, the decline of the in-flow side and the increase of the down-flow side can be predicted for the water budget of Balaton, particularly in the second future climate window (2071–2100). The water exchange activity of the lake will substantially deteriorate, here will be more frequent and longer periods without down-flow, and by the last decades of the 21st century, Lake Balaton may become practically a lake without down-flow (*Nováky et al*., 2016). Nonetheless, these results have to be interpreted with special care and taking into account that uncertainties of the estimations are not quantified.

3.3.5. Vulnerability of natural habitats

Climate vulnerability evaluations of natural habitats provide information on the potential impacts of climate change on the future potential survival of natural habitats where they are present now. The goal of the research was to elaborate a solid foundation for climate vulnerability assessments of Hungary's ecosystems, based on investigations carried out for 12 climate sensitive habitats. In the first phase, the climate vulnerability of Hungarian habitats was assessed. Then the expected climate change impacts (predicted probabilities of presence of habitats as consequences of environmental changes) on the 12 most climate sensitive habitats and the adaptivity of habitats (habitat diversity, natural capital index and connectivity) were calculated (*Somodi et al*., 2016). Input data for the research was gathered from The Landscape Ecological Vegetation Database & Map of Hungary (MÉTA).

3.3.6. Changes in agricultural biomass production and woodland management

The *AGRAGiS project*[12] examined the climate change impacts on arable farming and forest yield potential. The goals of climate vulnerability assessments on arable farming were the following: 1) giving quantified and spatial estimations for future yields of wheat, barley, rapeseed, corn, and sunflower, that will help to determine expected impacts of climate change; 2) giving quantified and spatial estimations on the adaptive capacity of arable farming; 3) delineating

[12] EEA-C12-12, Extension of NAGiS to the agri-sector, http://www.agrater.hu

vulnerable areas within Hungary using expected impact and adaptivity data layers; 4) elaborating recommendations for agrotechnological strategies, which may decrease climate vulnerability. The results show serious yield loss in the far-future (2071–2100) concerning spring crops (e.g., corn, see *Fig. 5*). Their crop safety will decrease on the whole territory of Hungary. Autumn crops (e.g., wheat) may produce increasingly higher yields as the end of the 21st century approaches. During the 2071–2100 period, wheat, barley, and rapeseed may have significantly higher crop yields (*Fodor et al*., 2016).

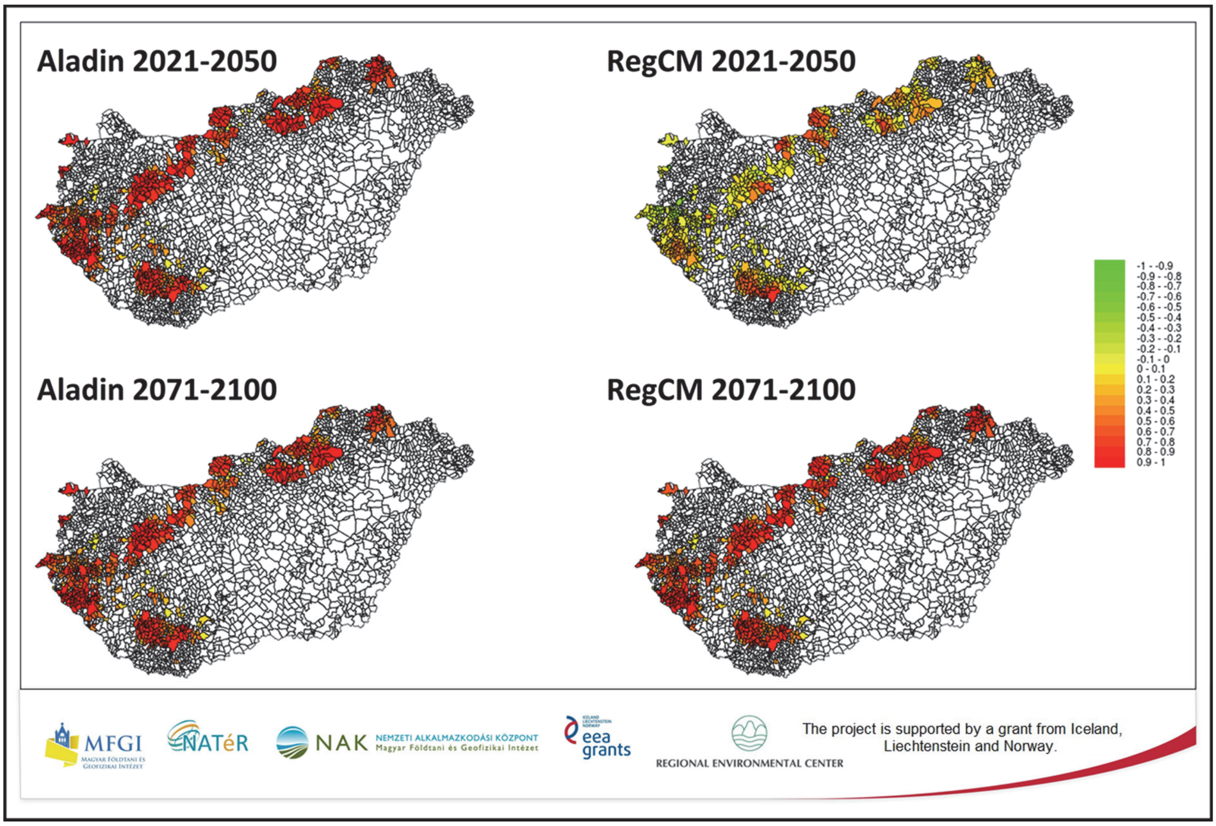

Fig. 4. Potential impact of climate change to existing stand of beech forests K5_K7a – aggregated for settlement boundaries in the 2021–2050 and 2071–2100 periods, based on RegCM and ALADIN-Climate data. Potential impact (PI) is expressed by the difference of predicted probabilities of presence given the climate of the reference period and under climate change scenarios within current locations of the habitat (unidimensional, depending on habitat type, location, and time horizon) (*Somodi et al*., 2016).

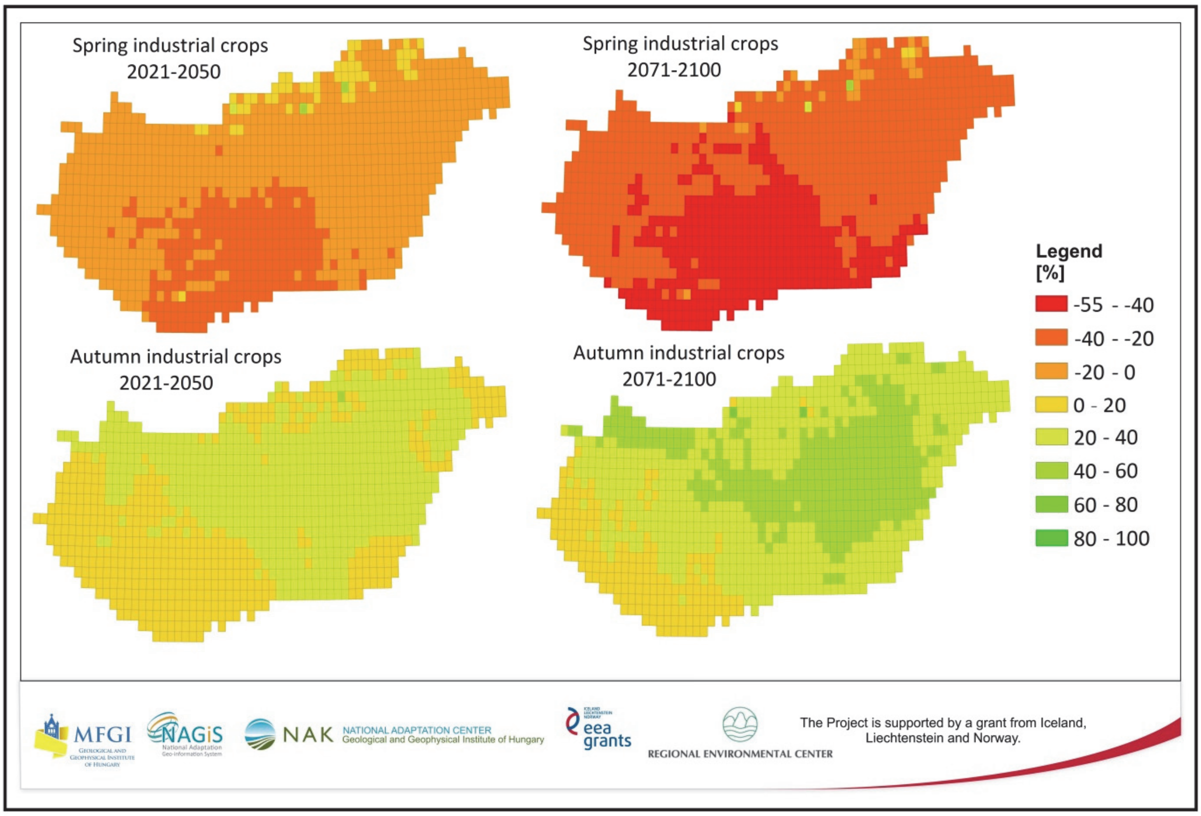

Fig. 5. Relative changes of crop yields as compared to the reference period (1961–1990), in case of spring (corn, sunflower) and autumn (wheat, barley, rapeseed) industrial crops. The yield changes are the average of the values calculated based on ALADIN and RegCM projections (*Fodor* and *Pásztor*, 2015).

The climate vulnerability assessments of forests aimed to investigate, test, and demonstrate methods, which may help the assessment of potential effects of climate change on Hungarian forests, and making adaptation decisions on large areas. The life expectancy, growth rate (yield) of forest tree species are determined mostly by their region, besides genetic features. So, the goal of the research was to understand, how forest climate type areas will shift within Hungary by the middle and end of this century according to the results of the two regional climate models, and what impacts these changes may exert on forest yields. The results show that the changes of climate conditions will make a significant impact on the spatial distribution of woodlands based on climate classification. All this is expected to make a serious effect on the exploitation of current woodland areas. The impacts may be witnessed under different forms: as the change of structure of forests with a main species of great yields but sensitive to climate, as a significant decrease of yields, as a change from economic woodland to protected woodland, or as the decrease of the woodland area because of becoming unsuitable for woodland coverage (*Illés* and *Fonyó*, 2016).

3.3.7. Impacts of heat waves on human health

The expected impacts of heatwaves were investigated by comparing excess mortality for past and future time windows in the *CRIGiS project*[13]. Analyses were elaborated using the CarpatClim-Hu database interpolated for the NAGiS grid and data series of the ALADIN-Climate climate model. Examinations were carried out on district and county level, using measured daily average temperature data between 2005–2014 and daily mortality data to describe the present period. The excess mortality for the present period of the climate model (1991–2020) was calculated taking into account the measured data. The effects of heatwaves on excess mortality was calculated by assessing the joint impact on the growth of heat units of the change of heat wave days and the excess temperature for the two projection time windows (2021–2050 and 2071–2100) of the climate models. The annual average excess mortality will rise with 107-182% in several districts of the country in the next decades, according to the projections (*Páldy* and *Bobvos,* 2016).

3.3.8. Impacts of weather extremes on road accidents

In the CRIGiS project, the impact of extreme weather events on road accidents was examined, too. Based on the the data content of the available database covering the period 2011–2014, a complex sensitivity indicator was formed, using three factors (number of road accidents, personal injuries caused by the accidents, intervention time of fire-fighter units). The two exposure indicators were the summer hot days and winter days with precipitation. Based on these, impact maps were elaborated. The impact maps were compared against the adaptivity indicator (arrival time of fire-fighter units), and vulnerability maps were elaborated for future periods (2021–2050 and 2071–2100) using this method. The results showed that middle and eastern parts of the country may be most vulnerable in summer, while in wet winter times, the capital city and its agglomeration and Transdanubia can be the most vulnerable areas (*Bihari*, 2016).

3.3.9. Climate change impacts on tourism

In the CRIGiS project, several climatic indices were calculated based on meteorological data to investigate the climate change impacts on tourism: the tourism climatic index (TCI) for areas of Hungary, its modified version, the mTCI and the climate index for tourism (CIT). The changes of these indices were quantified for the periods 2021–2050 and 2071–2100. The following variables were applied for determining the TCI: monthly mean temperature, monthly average of daily maximum temperature, monthly average of daily mean

[13] EEA-C12-13, Vulnerability and Impact Studies on Tourism and Critical Infrastructure, http://kriter.met.hu/en

relative humidity, monthly average of daily minimum relative humidity, monthly average of wind speed as well as monthly average of daily sunshine duration and monthly precipitation sum. In order to determine CIT, the Physiologically Equivalent Temperature (PET) bioclimate index was calculated (that represents thermal conditions) using the data on the daily average of total cloudiness, daily precipitation sum and daily average of wind speed. The results based on the indices are useful for assessing the expected climatological conditions of water, urban and cycle tourism (*Kovács et al*., 2015a).

3.3.10. Demographic, economic and land use changes

The project entitled *Long-term socio-economic forecasting for Hungary*[14] elaborated projections on the expectable change of the population of districts in Hungary, and the probability of the occurrence of diseases and causes of death, which are related to climate change. Furthermore, future projections for the most important economic indices (GDP, consumption, labour use, etc.) were also elaborated. Besides the socio-economic analyses, expected land use changes were modeled by the Land Change Modeler ArcGis software. The research included a survey on climate change attitudes of the population. The demographic projection results show that dramatic changes can be expected. Following the most probable scenario of the projections, the population of the country will decrease to 8.4 million people by 2051. Spatial differences of the population decrease will be considerable. Though, most districts of the country, will be expecting a population loss of over 30 percent. (*Czirfusz et al*., 2015)

3.3.11. Testing NAGiS

The operation and practical usability of NAGiS was tested by determining the vulnerability to climate change of the pilot areas Sárvíz River Valley and the region of Aba city (*Selmeczi et al*., 2016b). Areas in Aba, which are at risk of potential flooding from intense rainfall were delineated. The city's sustainable local water management development plan was elaborated, with regard to the potential impacts of climate change on water uses and the local vulnerability (*Kajner et al*., 2016).

3.3.12. Development of new climate change scenarios

The impact data layers of NAGiS are mostly based on outputs of 2 RCMs as mentioned above. The *RCMGiS project*[15] aimed at improving these climate data. The most important results of the project were developing the climate model data providing future climate information for NAGiS with application of two

[14] EEA-C12-11, http://nater.rkk.hu/

[15] EEA-C13-10, New climate change scenarios for the Carpathian-basin region based on changes of radiation balance, http://rcmter.met.hu/en

new anthropogenic emission scenarions (RCP4.5[16] and RCP8.5; *Moss et al.*, 2010); quantifying the uncertainties of climate projections; providing climate model data for impact assessments; training and support for the users to apply projection results and uncertainty information.

4. Geoinformation developments

NAGiS has three different user interfaces: a map view, a database interface, and the basic portal as shown in *Fig. 6*.

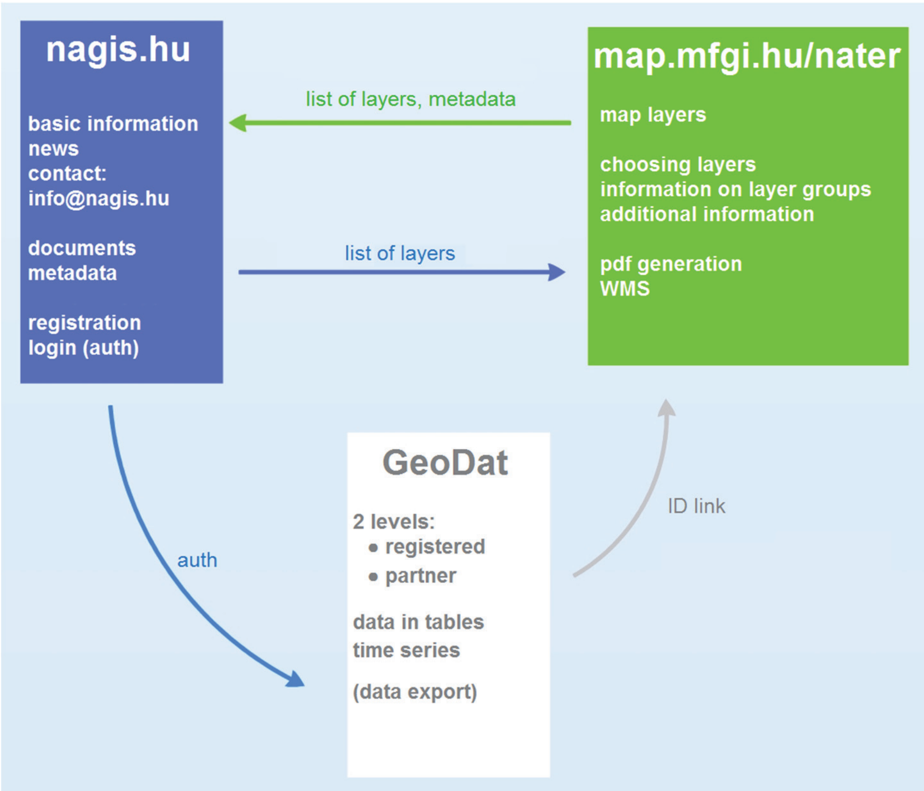

Fig. 6. Structure of the NAGiS portal system (Source: *Orosz et al*., 2016)

4.1. Main elements of the NAGiS

4.1.1. Map-visualization system

This sub-system contains 650 layers with a resolution of 10 km × 10 km, which show the way different aspects of climate change can affect certain areas of the country. Instead of one large database, NAGiS is built of smaller databases or file systems organized in thematic categories. The two main parts of the map system are the dataset stored on the public map server and a larger dataset stored in the internal NAGiS (MFGI / MBFSz) system.

[16] Representative Concentration Pathways

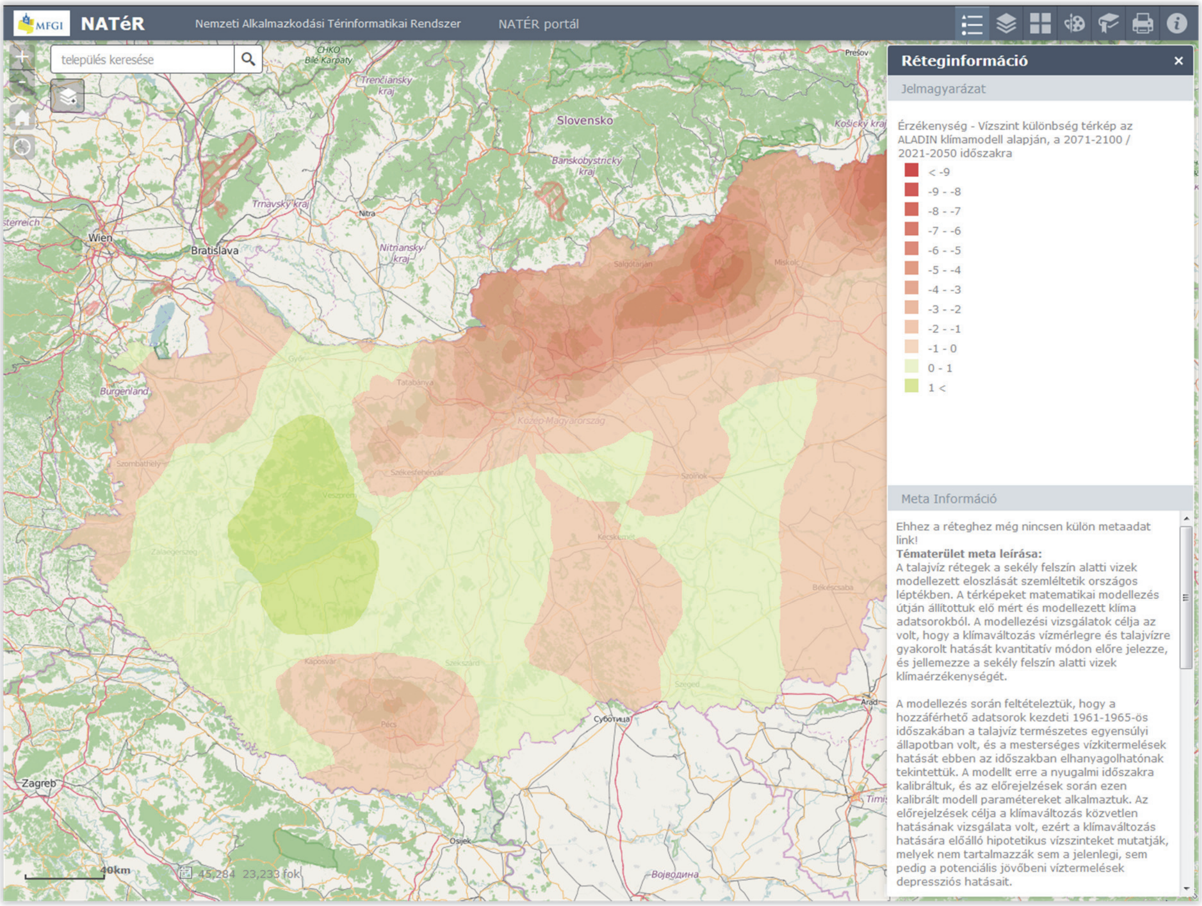

Fig. 7. A visualized sensitivity data layer of NAGiS: shallow groundwater level difference, 2071–2100/2021–2050, based on the ALADIN–Climate model. (Source: https://map.mfgi.hu/nater)

4.1.2. GeoDat

There are various geo-IT software programs available for creating map databases, but for the raw database containing a large number of thematic data (which constitutes the basic data of NAGiS), there is no off-the-shelf interface available. On that account, the NAGiS project had the GeoDat database management software program developed in a target-oriented manner. It is capable of receiving any kind of data and data series of any point-like object. The GeoDat core system provides a table view of the data as well as advanced research options. A separate module of the application has been designed for the display of time-series data. (*Orosz et al*. 2016)

GeoDat is a database containing the calculation results based on modeling (exposure, sensitivity, expected impact, adaptive capacity, and vulnerability) with 910 data layers. This database-management application was designed for

NAGiS with a supporting background database, built in a standardized system. The background database contains all numerical and alphanumerical data which are considered to be the end products of the project. Its content partially overlaps with the map-based database, but it is much more expanded. It also contains data that is not displayed on the maps.

4.1.3. Meta-database

The database of NAGiS stores several hundred maps and several thousand related work files. The metadata system enables users to find the information they need in the quickest possible way. It facilitates navigation through different kinds of information by a complex search interface. NAGiS metadata can be categorized into four main groups: map metadata, metadata of map figures, research metadata and registry metadata (*Orosz et al.*, 2016).

4.1.4. Nagis.hu portal

It is a basic, traditional web portal available at the http://nagis.hu or the http://nater.mfgi.hu addresses for entering the portal system. It enables the users to search metadata or to register and login to the NAGiS system. The maps and the GeoDat database can be accessed from here. It performs the identification of users as an engine portal and transmits the user data to the other two interfaces.

4.1.5. Main hardware elements

The system stores the data retrieved from various data management systems in the NAGiS basic database in a standardized way. The core data is stored in separate tables, whereas time series data is stored in parameter tables. The system enables to identify any point objects and to store all related core data and parameters.

The external data storage unit contains the public data of NAGiS. It was established in an environment and following a structure that are completely identical to that of the internal databases of NAGiS. All data made available for the general public are transmitted here from the internal databases. All actions of public data provision refer to this external data storage system.

IT equipment necessary for the research (e.g., desktop PCs, screens, GIS software, a large scanner, etc.), and for operating the system (e.g., servers, switches, servers, uninterruptable power sources, etc.) were purchased by the NAGiS Project (*Orosz et al.*, 2016).

5. *Application of NAGiS*

5.1. Legal framework

The legal foundation for NAGiS was laid down by Act LX of 2007 on the implementation framework of the UN Framework Convention on Climate Change and the Kyoto Protocol thereof. According to Paragraph 3 of the law, the implementation of the adaptation strategy framework (a part of the National Climate Change Strategy) has to be supported by a national adaptation geo-information system and the results of climate vulnerability assessments of the system. According to the law Government Decree No. 94/2014. (III. 21.) on the detailed rules of operation of NAGiS, the NAGiS Operational rules were adopted in May 2014.

NAGiS provides information on the climate status of the country, on the impacts of strategic risks connected to climate change and other long-term natural resource management issues, and on the correspondent adaptation possibilities, based on the indicators, analysis, and impact studies prepared using the data, according to the Government Decree No. 94/2014. The NAGiS is operated by the Mining and Geological Survey of Hungary (MBFSz – the successor of Geological and Geophysical Institute of Hungary). The MBFSz is under the authority of the Ministry of National Development.

Databases have an internal (for the participants of the project and the data administrators), and an external (intended for the public) version. Although the interface is identical, their data content is different. While external databases only contain derived and standardized data, internal databases contain the basic data too. The registry system of users runs according to Goverment Decree 94/2014. Geo-information work was carried out in an ESRI environment in the project (*Orosz et al*., 2016).

5.2. Potential future users of NAGiS in sectoral and spatial strategic planning

NAGiS is a source of information on the climate trends of Hungary; it contains the effects of strategic risk factors like climate change and other issues affecting long-term natural resource management, and the possibilities of adaptation to the changes. It is operated according to the Government Decree 94/2014. The information is based on indicators derived from basic data. At the portal of NAGiS, users may find analyses and impact assessments on the topics mentioned above.

NAGiS can be a useful tool for climate safe planning, analysing, decision-support activities in governmental strategic planning; or for municipalities in spatial planning, settlement planning, organizing public services, primarily in the following fields (*Pálvölgyi et al*., 2016):

- *Climate policy planning:* Founding the realization of climate policy actions for the country, regional and local levels, determining the vulnerability and adaptability of action areas.
- *Energy policy planning:* A potential use can be the sustainability evaluation of land use for food versus enegy crop production. Another field of use can be the re-evaluation of the potential production of conditionally and unconditionally renewable energy sources in regions, with regard to climate change impacts (trends of wind, sun, thermal, biomass, and biogas energy potential).
- *Transport and energy infrastructure design:* Climate proof planning of transport, production, forwarding and distribution infrastucture, enhancing technical conditions of security of supply.
- *Development policy planning:* Climate proof planning of inter alia flood protection works, power plants, bridges, etc.; necessary modification of standards, safety standards, elaboration and application of state subsidy spatial preferences in development policy decision-making (*Hrabovszky-Horváth et al.,* 2013). Evaluation of climate protection investments. Elaboration of the methodology of measuring the contribution of each supported development investment to greenhouse gas and carbon-dioxide emission reduction.
- *Planning in agriculture and rural development:* Impacts of climate change on the agro-ecological potential and the agricultural land use optimized for production conditions. Elaboration of action area types and measures based on the risk of erosion, agricultural water management, land cover, and soil attributes.
- *Spatial, settlement, and regional planning:* Founding climate protection strategies of regions and settlements with different endowments and development conditions. Elaboration of conditions of local adaptation; strengthening climate protection aspects in development programmes, tenders.
- *Planning in tourism:* Impact of climate change on touristic destinations and infrastructure serving the destinations; determining and enhancing the adaptability of tourism regions with different endowments (*Csete et al.* 2013).
- *Planning in the fields of human health and quality of life:* The adaptation tasks of the government and municipalities in the fields of health promotion and the enhancement of life quality are determined by different endowments and incidences, depending on the types and structure of settlements. Planning tasks are determined by the strength and frequency of extreme climatic events influencing people's life quality at settlements and the measures necessary to react. Furthermore, the safe operation of human health care systems and the accessibility of these are important factors in planning.

NAGiS may directly support the implementation, supervision and evaluation of the second National Climate Change Strategy, and the implementation and evaluation of the Environment and Energy Efficiency Operative Programme (EEEOP).

The main target groups / users of NAGiS include the national, regional, and local government bodies, decisions-makers of public bodies, policy makers; and the population of the areas that are vulnerable to climate change and people who are at risk of extreme weather events.

5.3. A practical example for using the NAGiS in planning

From 2016, EEEOP[17] development sources are available for Hungarian counties, which can be used for the development of county level climate strategies. A methodological resource (MFGI, 2017) was developed for the elaboration of these plans of the counties, which used the NAGiS database and selected maps. This resource gave a common background for planning, based on scientific results for making adaptation analyses of climate strategies of counties. The methodology helped the work of the planning experts in the following topics: vulnerability of drinking water resources, flash flood risk, expected impacts of droughts, vulnerability of natural habitats and forests. In 2017, several counties finished the elaboration of climate strategies. All of them used the NAGiS methodological resources.

6. Summary

Climate change can affect many sectors in Hungary and detailed, relevant, reliable data and information are inevitable for climate adaptation planning. The Geological and Geophysical Institute of Hungary (MFGI) established the National Adaptation Geo-information System (NAGiS) with the financial support of the European Economic Area (EEA) Grant Fund and with involvement of national institutes from different scientific areas. The project developed a multipurpose geo-information system that can facilitate the policy-making, strategy-building, and decision-making processes related to the impact assessment of climate change and the founding of necessary adaptation measures in Hungary. The NAGiS research processes were built on the CIVAS (Climate Impact and Vulnerability Assessment Scheme) model to have a standardized methodological background for quantitative climate impact assessments. Climatological research in NAGiS was based on the CarpatClim-Hu observational database and on projection results of the ALADIN-Climate and the RegCM regional climate models. Climate model data cover three climate windows: the 1961–1990, 2021–2050, and 2071–2100 periods.

[17] Environmental and Energy Efficiency Operative Programme, financed by the European Union and the Government of Hungary

Calculated climate parameters are available on a uniform 10 km × 10 km resolution grid. Climate change exposure, sensitivity, potential impacts, adaptability, and vulnerability indicators were calculated and developed for water safety, food security, human health security, safety of infrastructure, energy security, and natural environment.

The main parts of the NAGiS are a map-visualization system with 650 data layers; a database containing the calculation results based on modeling (GeoDat with 910 data layers); and a meta-database to help finding relevant data. The system includes research results of the NAGiS project and partner projects of the Adaptation to Climate Change EEA Grants Programme. Data layers on the following main topics are available at the nagis.hu portal: impacts of climate change on shallow groundwater conditions, drinking water protection areas, and on the risk of flash floods in Hungary; estimated change of hydrology of Lake Balaton; vulnerability of natural habitats; impacts of climate change on agricultural biomass production and woodland management; impacts of heatwawes on human health; impacts of weather extremes on road accidents; climate change impacts on tourism; demographic, economic, and land use changes; development of new climate change scenarios. The NAGiS was tested by determining the vulnerability to climate change of the pilot areas Sárvíz River Valley and the region of Aba city.

NAGiS can be a useful tool for climate safe planning, analysing, decision-support activities in governmental strategic planning; or for municipalities in spatial planning, settlement planning, organizing public services, primarily in the following fields: climate policy; energy policy; transport and energy infrastructure design; development policy; agriculture and rural development; spatial, settlement, and regional planning; tourism; human health and quality of life. In 2016, a methodological resource was developed for the elaboration of climate change strategies of Hungarian counties, which used the NAGiS database and selected maps. In 2017 several counties finished the elaboration of climate strategies. All of them used the NAGiS methodological resources.

7. Outlook

The 2013–2016 NAGiS project created the methodological basis built on the CIVAS model for quantifying climate change effects in Hungary, established the hardware system, and created the database, map portal, and meta-database from research results. The decision support tool is a powerful tool for the different territorial levels of Hungarian climate policy. However, the establishement of the system showed the necessary directions of further development. For instance, the project could not make projections on the hydrological impacts of climate change on Hungarian rivers, due to the lack of available climate modeling scenarios of the necessary 10 km × 10 km resolution for the whole Danube River basin. Enhancement of input databases and a better knowledge of uncertainties of model results could make NAGiS data more reliable (recall that some assessments used the results of only a single RCM simulation on the one hand, and on the other hand, even two simulations cannot represent the whole range of the projection uncertainty). The development process revealed a number of other shortcomings too, which will be cured in the next development phase described below.

In November 2016, the project plan of MFGI on the further development of the National Adaptation Geo-information System was granted by the "Adaptation to climate change" priority axis of the Environmental and Energy Efficiency Operative Programme (EEEOP). The aim of the EEEOP priority project is to elaborate a decision support toolbox for underpinning policy and municipal adaptation measures, based on the development of the databases, methodologies, and evaluation modules of NAGiS. In order to support sectoral and climate policy planning and decision-making, the further development of NAGiS will clarify the information on vulnerable sectors and affected parties, furthermore ameliorate climate change impact assessment planning and evaluation methodologies.

The land use modeling methodology of the system will be developed and tested in a pilot area. The project includes underpinning and assessment of climate adaptation tasks of agriculture, tourism, and several critical infrastructure elements. A new addition to the system will be the elaboration of a method for the assessment of geological risk sources with regard to the climate change aspect and interpretation of results.

Development of comprehensive, horizontal tools for social policy and economic development will cover the assessment of impacts of climate change on human health, presenting climate change impact on migration trends within Hungary, and on the country's labour market processes.

Tools for supporting climate policy planning of the government and the county municipalities will be elaborated, and as a part of these, new information technology modules will be created. Such modules will be the settlement adaptation barometer module (SABM), the adaptation decision support module for municipalities (ADSMM) and the online adaptation management information system (AMIS). In connection with these, an online calculator for settlements for the assessment of climate vulnerability of buildings will be developed.

Hydrological assessments will be pronounced during the NAGiS further development too, as it is one of the most impacted natural and economic resources by climate change. Extension of the results of climate models to the Danube River basin, integration of hydrological model results into the system will support to explore the vulnerability of surface waters. The climate vulnerability assessment of drinking water supply services and the investigation of direct and indirect impacts of climate change on shallow groundwaters will be continued. Flooding assessment and hydrological modeling of urban areas will be done within the framework of a pilot project for underpinning water management adaptation measures. The results of these will be used for the elaboration of a handbook for settlements on climate resilient water management of urban areas.

Our goal is to create a geo-information and policy support system, which is as user friendly as possible. Therefore, dissemination of the information on new modules and other results; creating easy-to-use interfaces; trainings and education material development on new modules are important parts of the project, too.

All the above mentioned developments can not be carried out without the modernization of the information technology system, increasing information security level, building electronic accesses and protocols, and modernization of the geo-information methodological tools and digital map visualization. Therefore, the project includes the development of the hardware and software system, too.

Acknowledgements:The authors and the Mining and Geological Survey of Hungary would like to thank the financial support of Iceland, Lichtenstein and Norway through the EEA Grants for the NAGiS project; and the help of the Regional Environmental Center for Central and Eastern Europe (REC), and the Norwegian Directorate for Civil Protection and Emergency Planning (DSB) during the implementation of the project.

Furthermore, we would like to thank the project promoters and partners of the EEA Grants Adaptation to Climate Change partner projects: Hungarian Academy of Sciences – Centre for Economic and Regional Studies, Hungarian Academy of Sciences – Centre for Agricultural Research, Research Institute of Agricultural Economics – National Agricultural Research and Innovation Centre, Hungarian Academy of Sciences – Centre for Ecological Research, Hungarian Meteorological Service, National Center of Environmental Health, National Directorate General for Disaster Management, University of Szeged, Hungarian Meteorological Service, Eötvös Loránd University, Department of Meteorology.

Further development of NAGiS is financed by the European Union and the Government of Hungary via the Environmental and Energy Efficiency Operative Programme (EEEOP).

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