NAGiS
National Adaptation
Geo-information System

Climate impact on Drinking Water Protection Areas

Research study

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1 INTRODUCTION

In Hungary, 95% of drinking water is produced from subsurface layers, so the role of groundwater in drinking water supply is crucial. Apart from the shallow groundwater primarily used for irrigation, the significant water supply of the deep porous aquifer beneath the plains provides the majority of our drinking water. Karstic water of our various mountain ranges play important role as well, in some region it is the main drinking water resource. In our country, the bank filtered systems have important role both as current and long-term future water supply.

During operation of drinking water supply attention should be given to short and long-term operational safety, i.e., to continuous operation threatening conditions. The Water Framework Directive (European Parliament and Council 2000/60 / EC (23 October 2000) Article 7, and based on this the 120/1999. (VIII. 6.) and 123/1997. (VII. 18.) Government Decrees requires the increased protection of such water resources, facilities as well as handling, storage, water distribution facilities. According to the development of the water supply system in 147/2010 (IV. 29.) Govt. Decree the operational safety of the water distribution facilities and drinking water quality complying with the drinking water standards must be ensured.

Extreme weather conditions in many cases caused problems in drinking water supply in the past. During summer dry periods, reduced water resources and simultaneous increase of water demand caused water shortage in some areas and often led to water restrictions. In other cases, floods, karst-floods formed due to extreme rainy weather conditions, so some water resources had to be suspended to avoid the risk of infection.

The frequent appearance of extreme weather conditions or in the future prospective further changes necessitated a detailed assessment of the impact of climate change on drinking water supplies. Part of the river basin management plans, required by the Water Framework Directive and reviewed every seven years, is the consideration of climate circumstances, however in-depth data systems aiding the detailed studies and measures have not been available so far.

One part of the NAGiS project is to determine and to characterize the climate vulnerability of water supplies. The effect of climate change spatially differs, depending on local climate, on geology, on hydrology and on hydrogeology. So our task within the project is to characterize the most important climate elements of the expected climate change and those geological environment and hydrogeological conditions determining the vulnerability of drinking water resources. The effect of climate change on water supplies and its reduction and elimination have social and economic consequences. Therefore, our study was complemented with the characterization of adaptation possibilities to the changing environment. During our work a data system containing geospatial elements was built, which aids to improve the adaptability and to mitigate any adverse effects.

The collection of the necessary parameters and indicators to the assessment of adaptation was based on direct consultations with the water supply operator. However, within the frame of NATéR project there was no possibility to carry out this direct contact for the whole country, so the adaptation and climate vulnerability of water supply were determined for the designated area of the Danube Regional Waterworks Co.

2 DEFINITION AND TYPES OF DRINKING WATER SUPPLY

By definition ‘water protected area’ is an area or a three dimensional subsurface body utilised or to be utilised by water abstraction facilities and its water resources available for human consumption or other utilization together with the existing or planned water abstraction facilities.

So under the expression drinking water protection area understand are bodies of surface water or groundwater having drinking water, mineral and medicinal quality water demand for present and future use, providing more water than 10 m^3 a day an average, or at least ensure drinking water for minimum 50 people. This includes also those bodies of water, which intended for such future use.
By the expression ‘drinking water protected area’ bodies of surface water or groundwater are understood which are used or planned to be used, for the abstraction of water intended for human consumption and are providing or planned to provide a total of more than 10 cubic metres of water per day on average, or serving or planned to serve more than 50 people.

Thus, in our work the term ’drinking water protected area’ applies both to the groundwater body contained in the subsurface space and intended to supply drinking water demand and to the necessary water abstraction facilities.

According to the hydrogeological characteristics water resources can be divided into the following types:

- Karst water supply: such a drinking water supply where the used or perspective water is contained in pores, fissures, or caves of karstified rocks (limestone, dolomite); it can be confined or non-confined. The latter is under the direct influence of meteorological conditions.
- Bank-filtration system: groundwater resources in the vicinity of surface water, where more than 50% of the produced water recharged from surface water.
- Confined groundwater supply: groundwater resources where the produced water derived from confined porous aquifers (below the first aquitard or aquiclude layer) or the aquifer layers are situating more than 50 meters below the surface.
- Shallow groundwater supply: groundwater resources where the porous aquifer is unconfined, and its depth is less than 50 meters below the surface.

Our work was based on the Public Water Supply database made by the General Directorate of Water Management. Out of the water supplies of the database 19 are surface water (1 is reserve and 2 are closed), the rest draw water from subsurface layers, 1752 areworking, 74 are perspective, 98 are reserve and 240 are other type of public water supply. Furthermore, there are 32 working public supply with less than 10 m^3/day productions.

Reserve water supply is the non-operating but ready state water resource, while perspective water supply is the technically researched but not involved into production water resource. The perspective water resources, as their name suggests, has long term reserve role.

Considering the Hungarian legislation in 23/1997. (VII. 18.) Government Decree, in accordance with the Water Framework Directive, drinking water protection areas should be delineated in order to safeguard the water supply. Most important aspect of the designation of protection areas is to prevent pollution to reach water resources, so the base of delineation is the "travel time" determined by groundwater flow models.

However, in terms of climate change the recharge processes or their changes are determinative, so the whole recharge area must be considered.

3 APPLIED METHODS

In order to assess the climate sensitivity of the drinking water protected areas we used the CIVAS modell (Climate Impact and Vulnerability Assessment Scheme) established in the CLAVIER international climate research project. The CIVAS modell is based on the mutual assessment of both the impact and the vulnerability of the territory and thus provides unified methodological framework for the quantitative climatic impact assessment. It also enables climate vulnerability assessment, which is carried out for the drinking water protected areas and drinking water supply systems.

The CIVAS modell uses the approach proposed by the 4th Assessment Report of the Intergovernmental Platform for Climate Change (IPCC 2007). The philosophy of the CIVAS modell is similar to the DPSIR2 ('Driving Force — Pressure –State — Impact — Response') modell, which is established and widely used in environmental status assessment in the European Union (PÁLVÖLGYI et al. 2010).

In the CIVAS modell the influences of climate change on the drinking water supplies are examined in the exposure → sensitivity → impact → adaptive capacity → vulnerability context. Therefore, in addition to the expected environmental changes the resulted, indirect social and economic processes are also considered.

Anthropogenic activity, irrespective of climate change, can result in similar phenomena and when these two are superimposed, distinction is made difficult between them. The changing groundwater levels, due to groundwater withdrawal, as well as, and groundwater quality changes caused by anthropogenic impacts are superimposed on the impacts of climate change and are amplified. Thus, the additional human impacts need to be addressed within the context of climate-vulnerability assessment. For our climate-vulnerability assessment we applied the modified version of the CIVAS modell (Figure 1) with the following elements.

Exposure relates to the climatic change and provides its expected characterisation. It is peculiar only to a geographical location, for which data can be extracted from archived meteorological data series or climatic modells.

Sensitivity is the specificity of the impacted sytem (in this case the drinking water supply) which shows to what extent changes take place in the impacted system as a result of climate change. The sensitivity of the affected system is independent of the climate change, and is primarily determined by the environmental and physical parameters of the impacted system. In case of the drinking water supplies these are related to the geological and hydrogeological characteristics.

Other anthropogen impacts on groundwater quantity and quality, which are independent of climate change represent changes due to anthropogenic impacts.

Potential impact is a combined indicator of exposure, sensitivity and other environmental impact, which is peculiar to both the geographic location and the impacted system under investigation.

The adaptive capacity is a non- climatic factor, which represents the local social and economic answers to the mitigation of the unfavourable effects of climate change. In cases of the drinking water supplies, beside social and economic factors technical factors are also important which maintain the quality and guarantee the security of drinking water services under the changing circumstances.

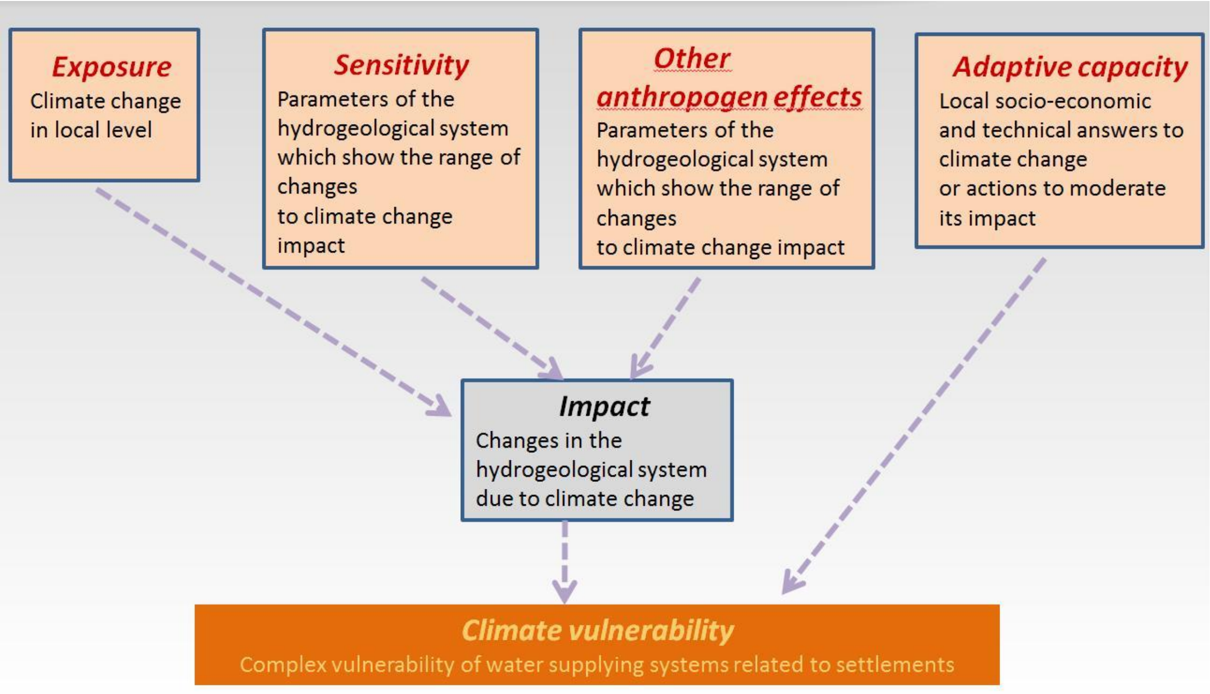


Figure 1. Application of the CIVAS modell for climate sensitivity and vulnerability assessment of the drinking water supply (after Pálvölgyi, Hunyadi 2008)

The *vulnerability* is a complex indicator, which integrates exposure (that is the expected climatic change at a geographic location), climate sensitivity (the physical characteristics of the natural environment affected by climate change at a given geographic location), as well as, the adaptive capacity (the ability of the society and economy to minimise unfavourable changes).

For the climate vulnerability assessment of drinking water supplies, groundwater quality changes resulting from non-climatic, antropogenic effects were not considered due to their complexity. Investigation considered solely the impact of groundwater production, those of groundwater quality changes were beyond the NAGiS project objectives, due to the wide range of groundwater quality changes and limited time frame of the project. Investigation of the impact of climate change on groundwater quality is a further reasearch objective, which is proposed to be investigated in another research project together with groundwater quality changes caused by anthropogenic impacts and contamination flow path modelling for chemical components and parameters (e. g. nitrate, total dissolved solids and organic pollutants).

For the investigation of adaptive capacity and for the definition of adaptive capacity indices information is needed directly from the groundwater supply operator. We did not have the opportunity to consult all of the presently accredited 34 regional waterworks; therefore we selected a pilot area (Figure 2.) where the adaptive capacity and climate vulnerability assessment methodology can be worked out in detail.

We carried out the methodological study of climate sensitivity assessment enhanced with climate vulnerability and adaptive capacity assessment for the drinking water supplies in the study area within the operational area of the Danube River Regional Waterworks Corporation (DMWR Zrt.)

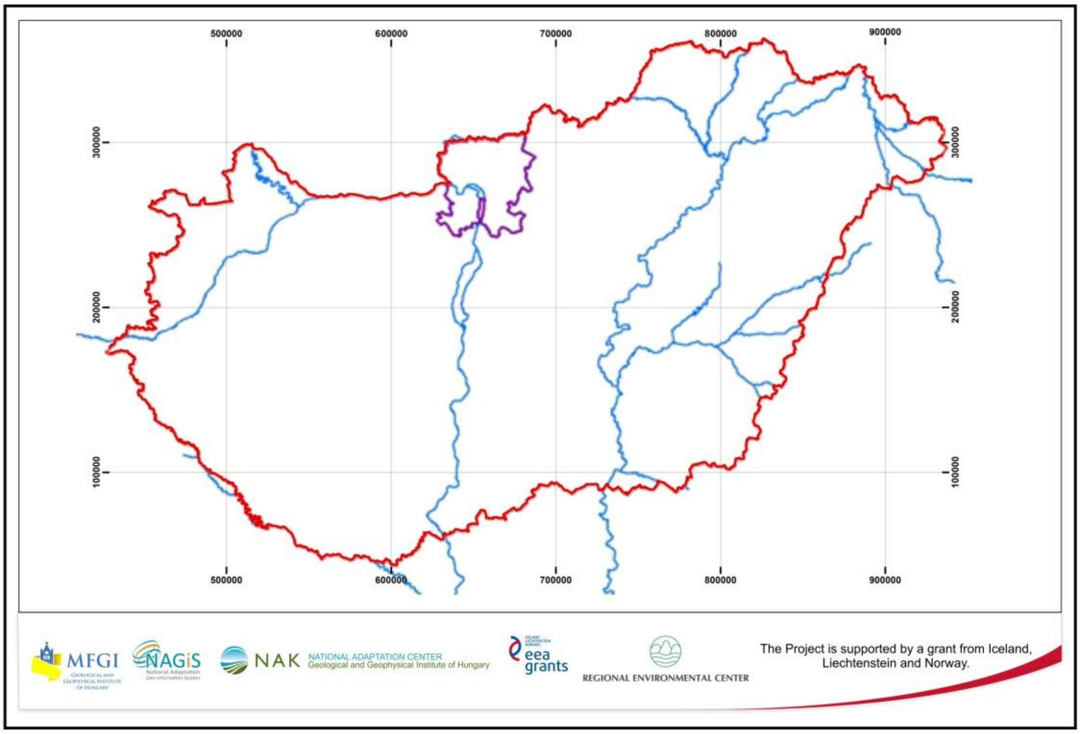


Figure 2. Study area located in the operational area of the DMRV

The climate vulnerability is characterised by the spatial distribution and categorisation of indicators. The results are presented in data tables and are also visualised spatially using GIS tools. The resulting NAGiS system supports decision making and contributes to the establishment of sustainable climate strategies.

4 EXPOSURE ASSESSMENT

Climate changes seldom have direct effect on drinking water protected areas. The subsurface reserves are mostly indirectly related to surface hydrological, climatic and meteorologic processes acting in climate change. Therefore, climate change results in changes in groundwater reserves and groundwater flow parameters. The factor influencing it is related to surface processes, the infiltration and discharge (including evapotranspiration).

Processes at the areas of infiltration are regulated, mainly by the variability of precipitation amount and the extent of evapotranspiration of the given soil horizon, in the period prior to the precipitation event. The latter is mainly the function of temperature change. At the discharge areas of groundwater the effects of both the precipitation and the temperature and the closely related evapotranspiration processes are faster and more direct.

Based on the above considerations, the exposure of drinking water protected areas regarding climate changes can be characterised by the investigation of the meteorological parameters which determine infiltration and discharge.

A unique groundwater system is the bank-filtration system, the exposure of which is regulated primarily by the meteorological conditions and climate change of the catchment area (in many cases having a transboundary character) of the recharging surface water system instead of the nearby area. The exposure of these groundwater systems are characterized mainly by water level fluctuations of surface water systems.

We applied indicators in both cases to assess exposure, which characterise present and future climate variability.

4.1 Exposure to climate

4.1.1 Data and methods

The database for our analyses consists of two types of data. CarpatClim-Hu data are climatological measurements interpolated to a regular grid, while modeled data comprise simulated data of the ALADIN-Climate and the RegCM climate models based on the climate scenario A1B. Grid of the different datasets overlap, therefore the spatial resolution being 10 km is consistent. CarpatClim-Hu covers the time range 1961–2010, while data of the climate models are provided for the periods 1961–1990, 2021–2050 and 2071–2100.

We used four climate indicators that have been chosen according to the aim of the analyses and the availability of the data necessary for the calculations.

4.1.1.1 ARIDITY INDEX

The aridity index is defined as the ratio of precipitation and potential evapotranspiration. Potential evapotranspiration has been calculated using Thornthwaite’s method (ÁCS et al. 2013).

$$\mathrm{AI} = \frac{\mathrm{P}}{\mathrm{PET}}$$

AI in the equation implies the aridity index, P is the annual sum of precipitation and PET indicates the annual sum of potential evapotranspiration.

The aridity index of this certain definition and the related climate classification — summarized in Table 1 — was introduced by UNEP (United Nations Environment Programme) in 1992.

Table 1. Climate classification based on the UNEP aridity index (TSAKIRIS, VANGELIS 2005)

Climate class	Aridity index
Hyperarid	AI < 0.05
Arid	0.05 < AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry subhumid	0.50 < AI < 0.65
Humid	> 0.65

4.1.1.2 PÁLFAI DROUGHT INDEX

The Pálfai drought index (PDI) indicates the severity of droughts in the individual years and shows a strong correlation with the decrease of crop yield (Hungarian Meteorological Service 2012). The modified Pálfai drought index (PaDI) that has been developed in the frames of the DMCSEE project, shares the applicability of PDI, however, data necessity for the index is less and calculation is simpler (Hungarian Meteorological Service 2012).

$$PaDI_0 = \frac{\left[\sum_{i=Apr}^{Aug} T_i\right] / 5 * 100}{c + \sum_{i=Oct}^{Sept}(P_i * w_i)}$$

where

$PaDI_0$ base value of the modified Pálfai drought index [°C/100 mm],

T_i monthly mean temperature from April to August [°C],

P_i monthly sum of precipitation from October to September [mm],

w_i weight factor,

c constant value [10 mm].

The monthly weight factors of precipitation (see in Table 2) express the role of humidity accumulation in the soil and the variance in water needs of vegetation taking the plant structure to be the average in Southeast Europe (Hungarian Meteorological Service, 2012).

Table 2. Monthly weight factors for precipitation

Month	w_i weight factor
October	0.1
November–December	0.4
January–April	0.5
May	0.8
June	1.2
July	1.6
August	0.9
September	0.1

The value of PaDI can be determined according to the

$$\mathrm{PaDI} = \mathrm{PaDI}_0 * \mathrm{k}_1 * \mathrm{k}_2 * \mathrm{k}_3$$

equation, where:

PaDI implies the modified Pálfai drought index [°C/100 mm],

k_1 is the temperature correction factor, that is the relation of the summer mean temperature to the multiyear mean:

$$\mathrm{k}_1 = \frac{(\mathrm{T}_{\mathrm{Jun}} + \mathrm{T}_{\mathrm{Jul}} + \mathrm{T}_{\mathrm{Aug}})/3}{(\overline{\mathrm{T}}_{\mathrm{Jun}} + \overline{\mathrm{T}}_{\mathrm{Jul}} + \overline{\mathrm{T}}_{\mathrm{Aug}})/3}$$

k_2 is the precipitation correction factor, namely the relation of the minimum value of the monthly sums of precipitation in the summer to the multiyear mean:

$$\mathrm{k}_2 = \sqrt[4]{\frac{2 * \overline{\mathrm{P}}_{\mathrm{summer}}^{\mathrm{min}}}{\mathrm{MIN}(\mathrm{P}_{\mathrm{Jun}}, \mathrm{P}_{\mathrm{Jul}}, \mathrm{P}_{\mathrm{Aug}}) + \overline{\mathrm{P}}_{\mathrm{summer}}^{\mathrm{min}}}}$$

$$\overline{\mathrm{P}}_{\mathrm{summer}}^{\mathrm{min}} = \mathrm{MIN}(\overline{\mathrm{P}}_{\mathrm{Jun}}, \overline{\mathrm{P}}_{\mathrm{Jul}}, \overline{\mathrm{P}}_{\mathrm{Aug}})$$

k_3 is a correction factor for the precipitation rates of the previous 36 months, meaning the relation of the mean precipitation of the previous 36 months to the multiyear mean of a long-term period. The long-term period in our analysis was defined as the period of the climate windows, that is 30 years.

$$\mathrm{k}_3 = \sqrt[\mathrm{n}]{\frac{\overline{\mathrm{P}}}{\overline{\mathrm{P}}_{36\mathrm{m}}}}$$

$$\overline{\mathrm{P}}_{36\mathrm{m}} = \sum_{\mathrm{i}=(\mathrm{year}-3)\mathrm{Oct}}^{(\mathrm{year})\mathrm{Sept}} \mathrm{P}_{\mathrm{i}} \Big/ 36$$

The value of the parameter n is dependent on the relief conditions. We differentiated low- and highlands by setting a fixed height of 200 m to be the boundary.

$$\mathrm{n}_{lowland} = 3$$

$$\mathrm{n}_{highland} = 5$$

Intensity of droughts on the basis of the modified Pálfai drought index is defined according to the classification summarized in

Table 3.

Table 3. Climate classification based on the modified Pálfai drought index (Hungarian Meteorological Service, 2012)

PaDI	Description
< 4	year without drought
4–6	mild drought
6–8	moderate drought
8–10	heavy drought
10–15	serious drought
15–30	very serious drought
> 30	extreme drought

As precipitation data of the preceding three years are necessary for the calculation of the PaDI, we only have results of full value from the fourth year of the climate windows: 1964 for the reference period and 2024 and 2074 for the future climate windows. In the course of data process we therefore did not take the first three years into account.

4.1.1.3 THE RATE OF PRECIPITATION SUMS FOR THE HYDROLOGICAL HALF-YEARS

The quantity of water filtrating under ground is strongly influenced by the annual distribution of precipitation. Precipitation of the winter hydrological half-year mainly determines annual infiltration (KESSLER 1954). In order to analyze precipitation trends over the consecutive hydrological half-years, we defined an indicator as the ratio of precipitation sums of the winter and summer half-years, where the summer half-year comprises the months from May to October and the winter half-year is the period between November and the end of April.

$$\mathrm{P}_r = \frac{\mathrm{P}_{winter}}{\mathrm{P}_{summer}}$$

P_{winter} and P_{summer} in the equation imply the precipitation sums for the winter and summer hydrological half-years and P_r is the ratio.

Precipitation rate for the first year of a climate window is calculated as the ratio of precipitation sums for the winter half-year beginning with November and continuing to the next year and the summer half-year of the year in examination and so forth. Since precipitation data are available for finite time periods, the ratio for the last year of a period cannot be calculated. In case the precipitation ratio is below 1, summer precipitation exceeds the sum for the winter half-year, otherwise the relation is reverse.

4.1.1.4 CLIMATIC WATER BALANCE

For the further investigation into water budget we determined the climatic water balances for the different areas of the country and their possible future changes. Climatic water balance in our analysis is defined as the difference between the annual sums of precipitation and potential evapotranspiration, where potential evapotranspiration is calculated according to the method of Thornthwaite (ÁCS et al, 2013).

As the majority of the chosen indicators — except of the water balance — yield one value for a year, we determined all the indices in annual resolution. From the annual values a thirty-year mean is then calculated. The present report summarizes results based on the thirty-year means. To analyze characteristics of past climate periods and tendencies we calculated ten-year means of each indices based on CarpatClim-Hu data for the 1961–2010 term. In this case we considered the long-term period for the calculation of PaDI to be 50 years. Similarly to the case of thirty-year means, due to the limited availability of climate data, PaDI could only be calculated from the year of 1964 and the precipitation rate to 2009. Mean values in these cases were calculated for 7 and 9 years, respectively. In order to demonstrate the extent to which the individual areas are exposed to the variability of dry and humid periods we prepared maps showing the distribution of standard deviation values of the indices for the reference period based on CarpatClim-Hu data.

Possible future changes in the precipitation and temperature conditions were estimated with the analysis of the climate model data available for the NAGiS project. We determined rates and signs of the changes for the 2021–2050 and the 2071–2100 climate windows compared to the reference period.

Data process was carried out by programming in the FORTRAN language and we used the ArcGIS software for the visualization of the results.

4.1.2 Description of aridity conditions in the last decades based on CarpatClim-Hu data

Figure 3., 4**Hiba! A hivatkozási forrás nem található.** show the spatial distribution of the mean values of the aridity index and the PaDI in the 1961–1990 time period for the area of Hungary. The lower a value of the aridity index for a certain region is, the more arid is the region. In case of the PaDI the relation is reverse, lower values are connected to a more humid, while higher values imply a more arid climate.

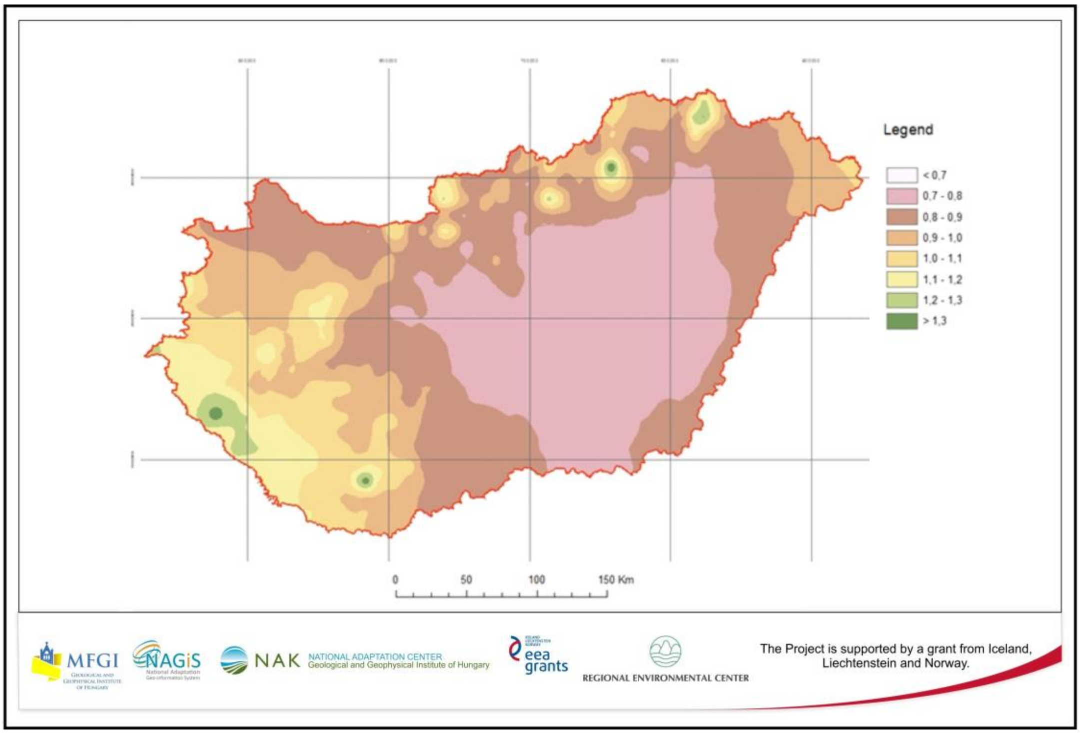


Figure 3. Spatial distribution of the UNEP aridity index in the 1961–1990 period based on CarpatClim-Hu data

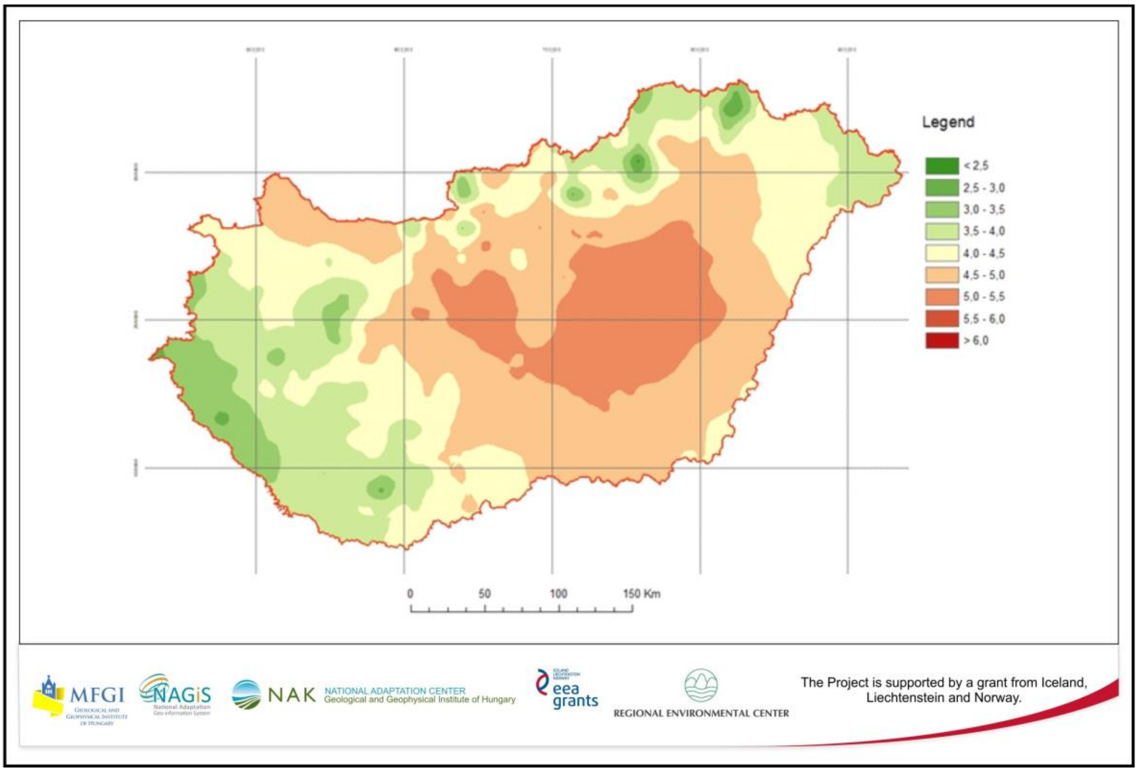


Figure 4. Spatial distribution of the modified Pálfai drought index in the 1961–1990 period based on CarpatClim-Hu data

Relief dependence is well visible on both Figures. According to the results the plain of Alföld proves to be the most susceptible region of the country to dryness, however, indices over hilly areas, where precipitation generally exceeds those typical for lowlands, implies more humid conditions. Regions around hills with higher altitudes, including the hills of Zemplén, Visegrád, Mátra, Bükk, Börzsöny and Buda on the north, Bakony on the west, the hills in Transdanubia and the Mecsek, appear to be outstandingly humid compared to other parts of the country.

Division of precipitation sums for the hydrological half-years yields a ratio without dimension that represents the relation of precipitation sums for the consecutive hydrological half-years to each other. Provided that the ratio is under 1, precipitation sum of the summer half-year in a certain year exceeds precipitation of the subsequent winter half-year. Accordingly, the ratio with a value over 1 means precipitation surplus in the winter half-year. The greater the absolute value of the difference between the ratio and 1 is, the greater is the difference in the precipitation sums of the consecutive half-years. Figure 5 shows the spatial distribution of mean precipitation rate values calculated from CarpatClim-Hu data in the period between 1961 and 1989.

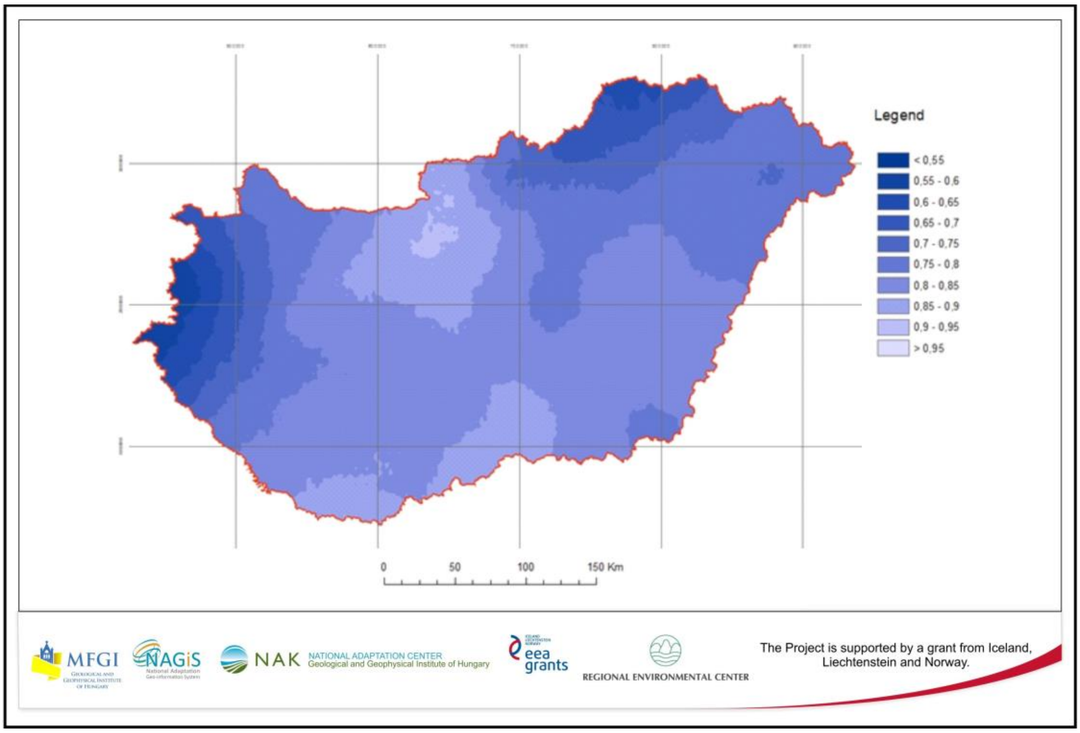


Figure 5. Spatial distribution of the precipitation rate values in the 1961–1989 period based on CarpatClim-Hu data

Figure indicates that precipitation in most cases is more abundant in the summer half-year, only a few areas — around the capital city in the period in examination — show winter precipitation surplus. According to the results precipitation sums of the consecutive hydrological half-years differ the most in the middle parts of the country; in regions towards the western and northeastern borders summer precipitation exceeds winter sums to a larger and larger extent.

Standard deviation of the indices for a period of time refers to their variability and therefore suggests information indirectly on the exposure to climate. Figure 6–8 show the standard deviations of the annual values of the aridity index, PaDI and the precipitation rate for the period between 1961 and 1990.

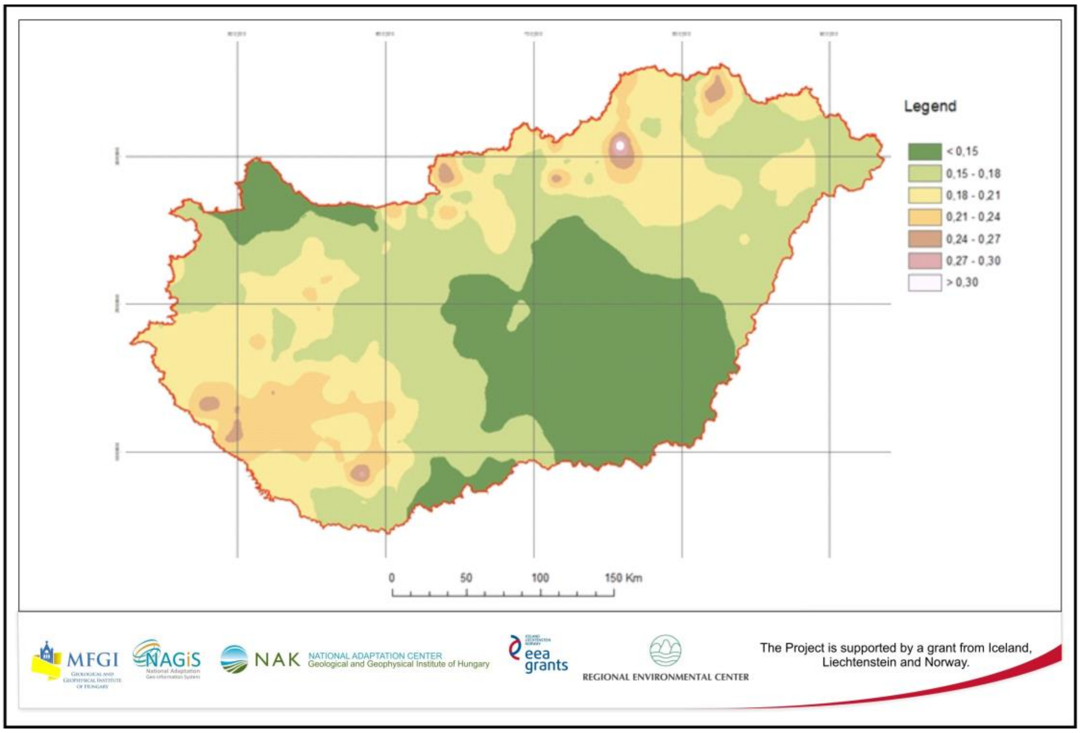


Figure 6. Spatial distribution of the standard deviation values for the aridity index in the 1961–1990 period based on CarpatClim-Hu data

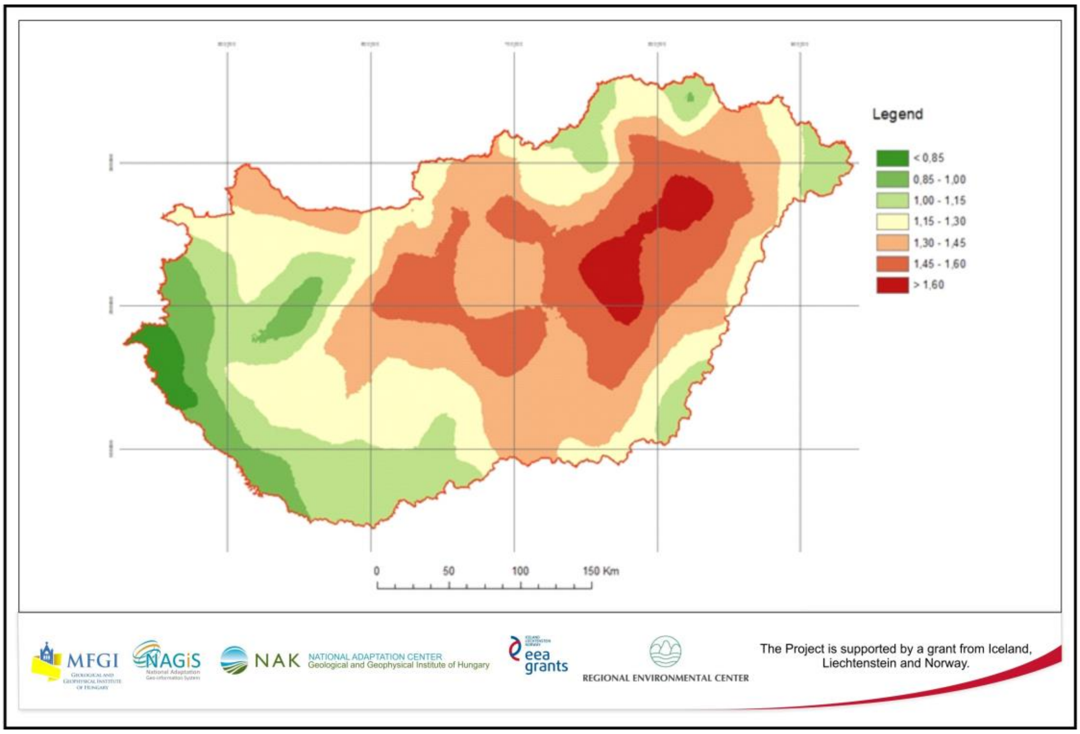


Figure 7. Spatial distribution of the standard deviation values for the modified Pálfai drought index in the 1964–1990 period based on CarpatClim-Hu data

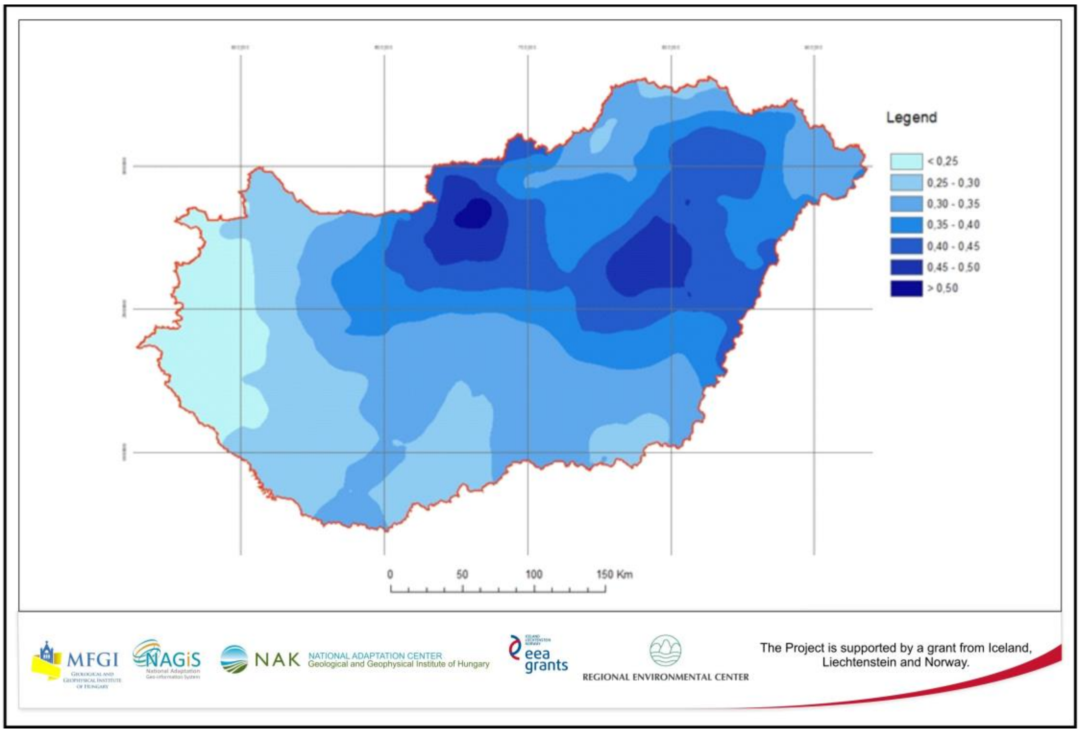


Figure 8. Spatial distribution of the standard deviation values for the precipitation rate in the 1961–1989 period based on CarpatClim-Hu data

According to results highest variability in the value of the aridity index is connected to hilly regions in the reference period. As the aridity index is defined to be the ratio of precipitation and potential evapotranspiration, variability of the index is dependent directly on the changes in precipitation amounts that vary more with higher altitudes.

Based on results concerning the modified Pálfai drought index lowlands appear to be the most exposed to drought conditions with the highest values of variability. Exposure of regions where precipitation is more abundant — such as the Mátra, the Bükk, the hills of Zemplén and Bakony — is lower. It is though important to note that the definition of the index is such that it takes the effects of relief in a simpler manner into account, therefore results are more appropriate around lowland areas.

Precipitation amounts of the consecutive hydrological half-years deviates the most in the northern parts of the Danube–Tisza Interfluve and the middle regions of Transtisza, while variability decreases towards the western and northeastern areas of the country.

In order to analyze trends in past climate we calculated ten-year means of the indices based on CarpatClim-Hu data. Due to the fact that precipitation data of the preceding three years are necessary for the calculation of PaDI for a certain year, results — as suggested before — are appropriate from the year 1964, therefore mean values for the first decade were calculated based only on seven years (1964–1970). Similarly, as the rate of precipitation of consecutive hydrological half-years is determined with the winter half-year spreading into the following year, the rate value for the last year cannot be calculated, leaving results for the last decade to be determined from nine-year data (2000–2009).

Different indices for the consecutive decades show slightly different tendencies, however, the main characteristics of results for past climate are similar. In general, climate in the area of Hungary had gradually become dryer from 1960 until around the turn of the century when a more humid period began. A significant decrease in the intensity of aridity occurred in the first decade of the 21st century.

Analysis of the climatic water balance provides information on the water budget of various regions in the country. Figure 9 shows the spatial distribution of the mean annual climatic water balance values for the reference period, based on CarpatClim-Hu data.

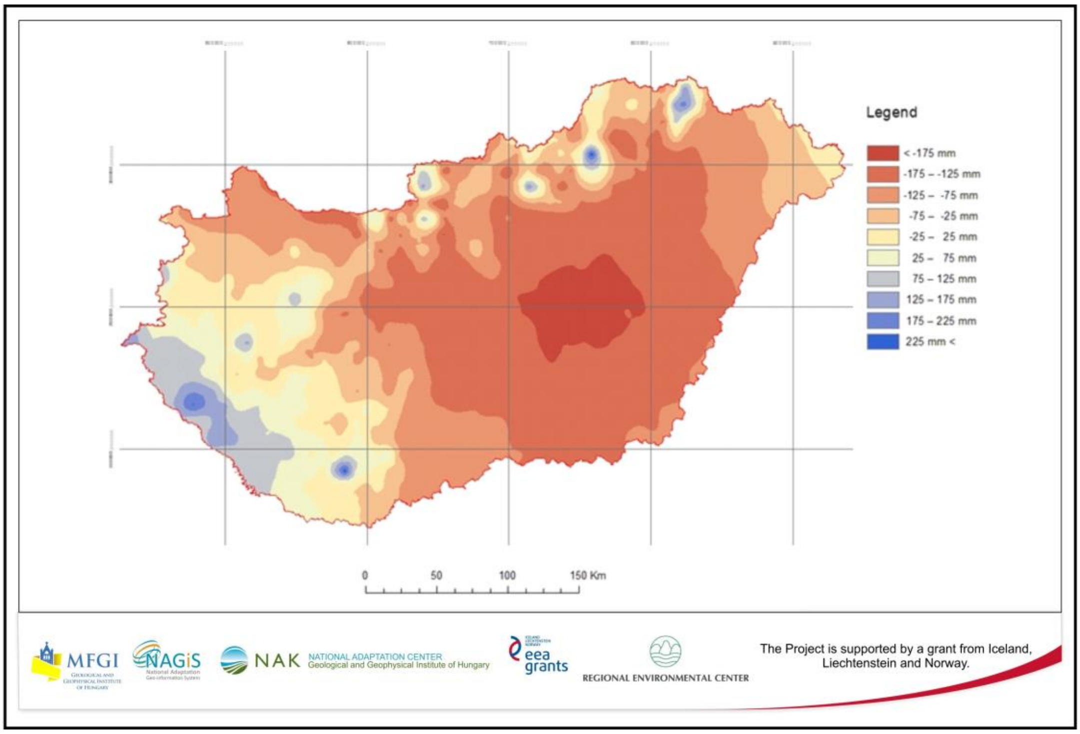


Figure 9. Spatial distribution of the annual mean climatic water balance in the reference period based on CarpatClim-Hu data

Figure 9 indicates which areas of Hungary abound in precipitation and where is water shortage more general. In accordance with results demonstrated previously, lowland areas appear to be the most arid regions on the basis of water balance analysis. Annual water balance is negative for the largest part of the country meaning that the amount of water that the area is capable of evaporating under the specific climate conditions exceeds precipitation. The largest extent of water shortage is present in the middle areas of Alföld. Along with the increase in altitude water balance gradually increases and turns into positive, reaching a maximum over 200 mm in hilly areas and the south-western part of Transdanubia.

4.1.3 Expected future tendencies on the basis of ALADIN-Climate and RegCM climate model projections

Analyses of climate model data lead us to estimations of possible future changes in the climate conditions of Hungary. Data of two climate models — ALADIN-Climate and RegCM — are available for our investigation in the frames of NAGiS, which are based on the SRES A1B climate scenario. For the demonstration of the results we chose to visualize the changes in the values of climatic indices compared to the 1961–1990 reference period. Maps showing the spatial distributions of the calculated difference values are presented in Figure 10 – Figure 12. the upper two of which represent results for the 2021–2050 period, the lower two refer to the 2071–2100 period, based on the data of climate models RegCM on the left and ALADIN-Climate on the right side maps.

It is necessary to note that climate model simulations naturally contain a set of uncertainties that often lead to differences or even contradictions in data calculated by different models (SZÉPSZÓ et al. 2015). The purpose of climate models is to describe the behavior of the climate system as a whole that is only possible in an approximate way due to the complexity of physical processes. The reason behind the uncertainties lies within the differences in approximations, calculation methods and parametrizations. When investigating future climate, analyses are therefore suggested to be carried out with data of several climate models or simulations.

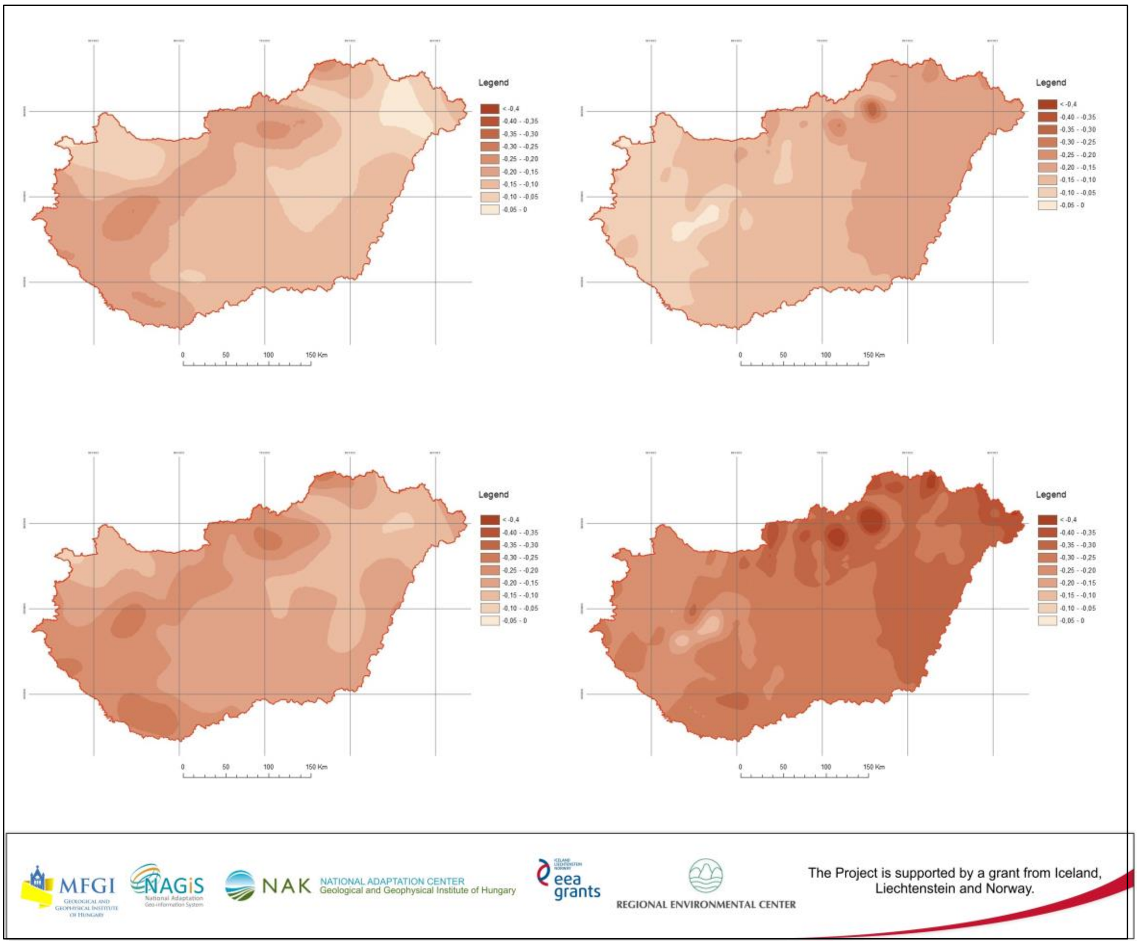


Figure 10. Spatial distribution of the changes in the UNEP aridity index for the 2021–2050 (upper figures) and the 2071–2100 (lower figures) periods on the basis of RegCM (a, c) and ALADIN-Climate (b, d) data

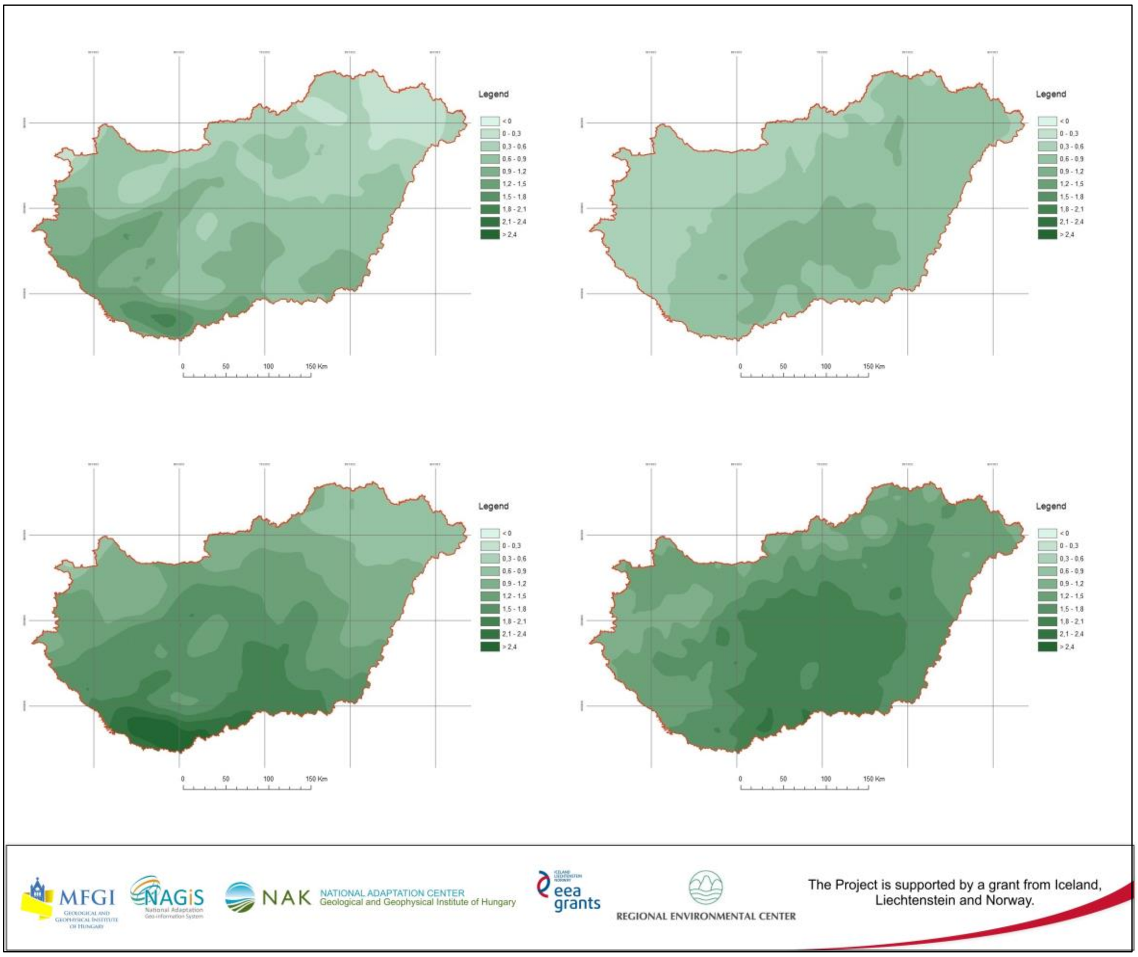


Figure 11. Spatial distribution of the changes in the modified Pálfai drought index for the 2021–2050 (upper figures) and the 2071–2100 (c, d) periods on the basis of RegCM (lower figures) and ALADIN-Climate (b, d) data

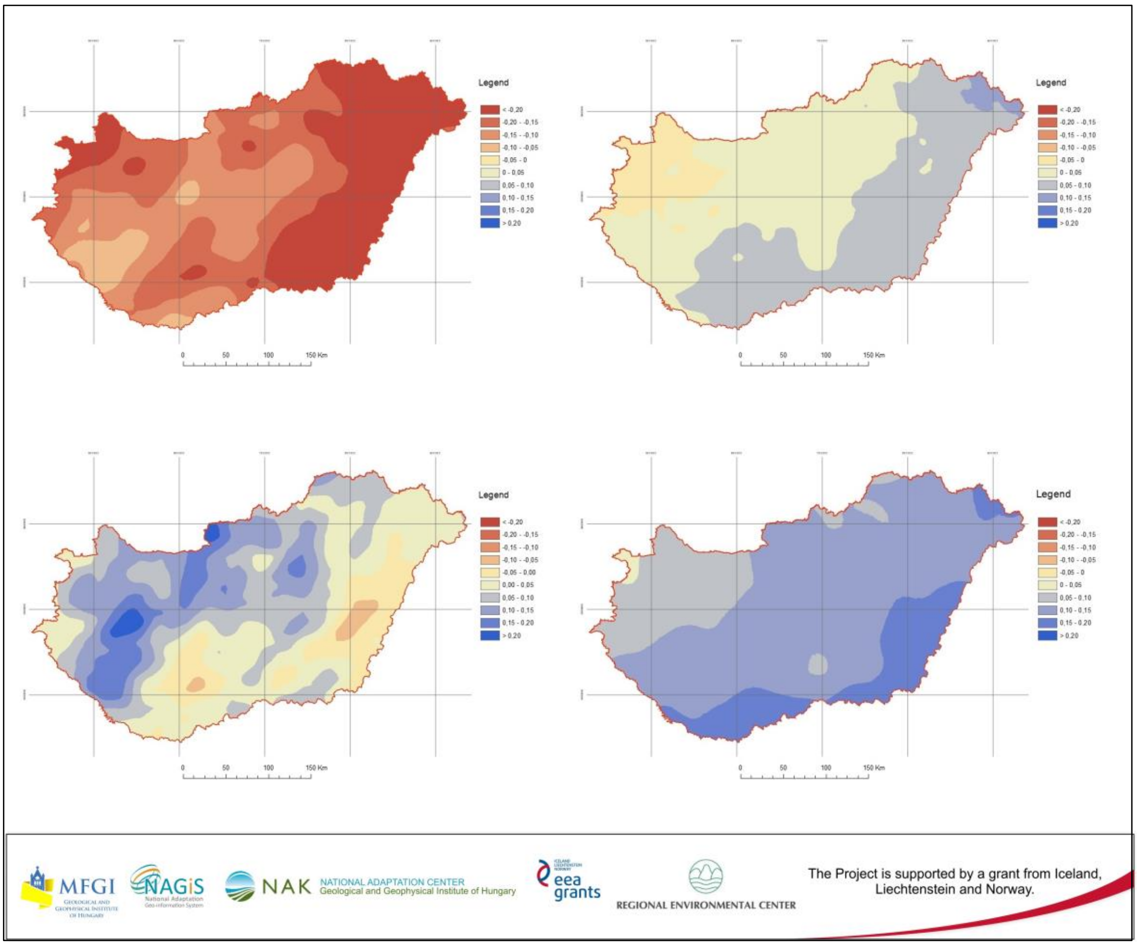


Figure 12. Spatial distribution of the changes in the precipitation rates of consecutive hydrological half-years for the 2021–2050 (upper figures) and the 2071–2100 (lower figures) periods on the basis of RegCM (upper left, and lower right map) and ALADIN-Climate (upper right and lower left maps) data

The values of the future changes in the aridity index based on ALADIN-Climate data shows a continuous decrease from the western parts of Hungary towards the eastern areas, suggesting the climate to get dryer in the whole country but to a different extent regionally. Aridity is likely to intensify by the end of the 21th century. The most extensive change concerns the northern hills, such as the hills of Zemplén, Cserehát, Bükk, Mátra and Börzsöny. We can draw a similar conclusion from the calculations using the data of RegCM. Aridity is expected to intensify generally in the future, although the spatial distribution of the changes — due to the differences in climate models (SZÉPSZÓ et al. 2015) — differ from the one based on ALADIN data. RegCM places the regions affected by the changes the least to northeast and northwest and assumes more intensive drying to the middle, the western and the southwestern parts of Hungary. Most of the hills, such as Mátra, Bükk, Bakony and the Mecsek are perceptible also on the maps generated from RegCM data, suggesting more intensive drying. The two models estimate mainly similar future changes concerning the modified Pálfai drought index. According to results, intensification of aridity is most probable in the middle and southern parts of the country and less affected are the northern, the northwestern and the northeastern regions. According to RegCM PaDI at some places — mostly in the northeastern parts — might decrease for the 2021–2050 period, by the end of the century, however, the whole of the country is likely to be affected by the intensification of aridity to a higher extent.

The models yield different estimations for the changes in the rate of precipitation sums for the winter and the summer hydrological half-years for the 2021–2050 period. The reason behind the uncertainties lies within the differences in climate models (SZÉPSZÓ et al. 2015). ALADIN data suggest slight changes in precipitation rates being negative in most areas and positive in the southern and eastern parts. RegCM indicates negative changes for the whole country, the largest extent concerning the eastern regions. An unambiguous increase in the values of precipitation rates is expected for the end of the 21th century on the basis of both model projections which means an increase in winter and a decrease in summer precipitation. The most extensive increase in the values of the precipitation rate is likely to occur in the south and southwest according to ALADIN and in Central Transdanubia and some parts of the northern area according to RegCM. RegCM sparsely — in the south and southeast — estimates a decrease in the precipitation rate even for the end of the century. Based on the results we draw the conclusion that projections of climate models suggest a shift in precipitation amounts toward the winter half-years for the most parts of Hungary, which tendency means that the summer half-years are probable to get more arid in the future.

The researches carried out in the frames of the CLAVIER (CLimate ChAnge and Variability: Impact on Central and Eastern EuRope) project provided results in accordance with our conclusions. Analyses based on data provided by the REMO climate model indicate a widespread decrease in summer precipitation for the middle areas of Europe, while winter precipitation is expected to increase.

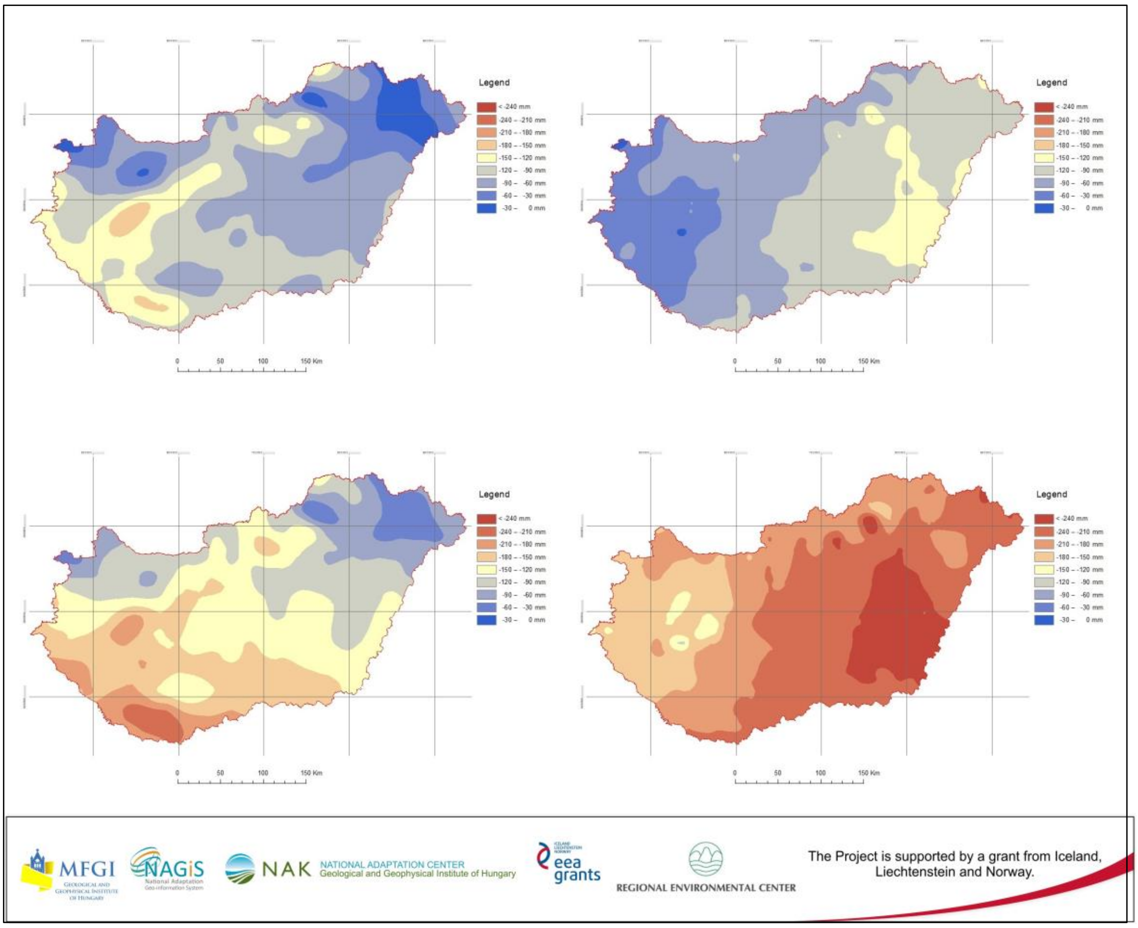


Figure 13. Spatial distribution of the changes in the climatic water balance for the 2021–2050 (upper figures) and the 2071–2100 (c, d) periods on the basis of RegCM (lower figures) and ALADIN-Climate (b, d) data

The projected changes in the mean annual climalic water balance are summarized in Figure 13. Both of the climate models estimate the water balance to shift to the negative side of the spectrum throughout the whole area of Hungary. ALADIN places the largest decrease in the water budget to the eastern parts of Alföld, while RegCM estimates it to occur in the southwest regions. Less affected areas are expected to be the western, northern and northwestern regions. Drying tendencies are likely to intensify with time till the end of the 21th century, when the decrease in water balance might exceed 200 mm.

4.2 Exposure of bank-filtration systems

The bank-filtration systems of Hungary are located along the rivers Danube, Tisza, Rába, Dráva and Hernád. The security of water supplies is endangered by the more and more frequent low-flow conditions and floods as a result of the extreme weather conditions.

We characterized the exposure of water courses due to water level fluctuation by assessing time series of gauge data of the General Directorate of Water Management (OVF) in the period between 1960–2013. In the assessment we used measurement data of daily and monthly average yields and monthly minimum and maximum yields at locations in the different segments of the water course, as close as possible to the bank-filtered drinking water supplies. We did not use data at those measurement localities, where gauge data is apparently influenced by anthropogenic activity. Data on the measurement sites selected for exposure assessment are summarized in (Table 4).

Table 4. Summary data of measurement sites used for the derivation of exposure indicators in bank-filtration systems

Identification of measurement site	Water-course	Name of measurement site	EOV X	EOV Y	Water gauge "0" level (mBf)
000005	Duna	Komárom	267810	579960	103.88
000547	Duna	Dunaújváros	181880	642362	90.295
001021	Duna	Vác	270611	655530	98.115
001026	Duna	Budapest	238946	648561	94.97
000831	Duna	Mohács	72070	622654	79.2
000011	Rába	Árpás	242212	526018	113.13
000344	Rába	Sárvár	213634	491535	149.86
001515	Tisza	Tivadar	308128	908829	105.4
001722	Tisza	Tiszapalkonya	285238	800352	87.28
002046	Tisza	Szolnok	204000	737000	78.78
002275	Tisza	Szeged	101000	735000	73.70
000835	Dráva	Barcs	68688	525528	98.14
000836	Dráva	Drávaszabolcs	49181	584216	86.76
001734	Hernád	Gesztely	308886	792475	108.06

For the characterisation of exposure we investigated the unfavourable situations regarding the operation of the bank-filtration systems, which are the mean low-water and mean high-water time series calculated for the different time periods.

The time series of monthly minimum yields showed a downward trend in the low-water time series, in general (Figure 14).

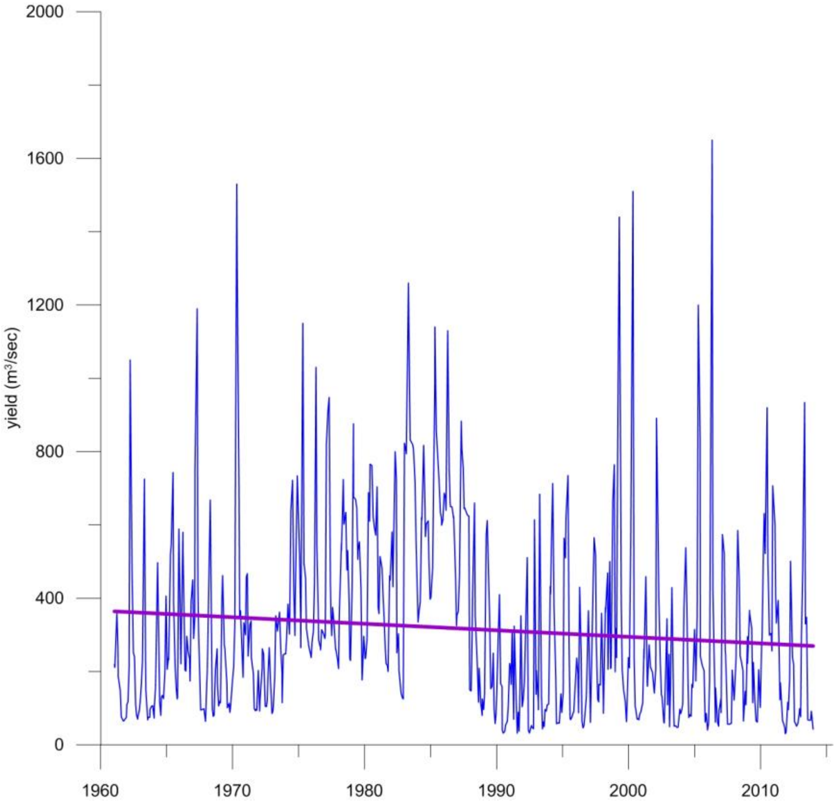


Figure 14. Monthly minimum yields in the period between 1960–2010 for the River Tisza at the Tiszapalkonya No. 1722 gauging station

Evaluation of the mean high-water yields time series is less unified. Mean high-water yields time series of the rivers Danube and Hernád show upward trends. There is also a slight upward trend in the time series of the River Tisza, but the rivers Rába and Dráva are characterised by downward trends (Figure 15).

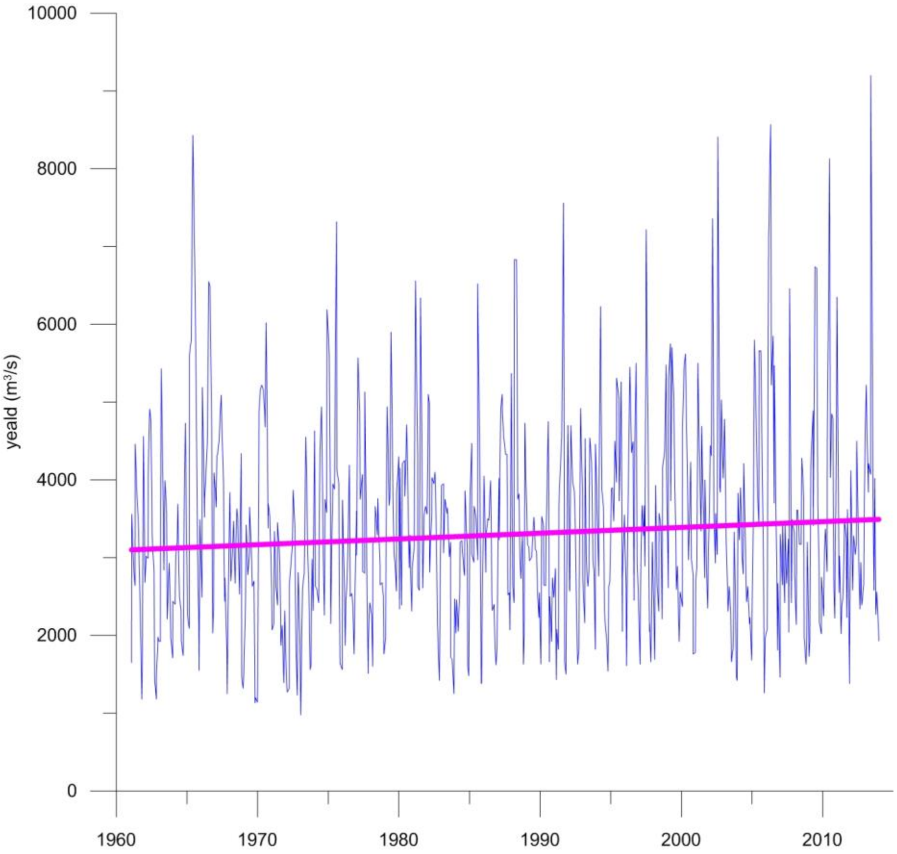


Figure 15. Monthly maximum yields in the period between 1960–2010 for the River Duna at the Budapest No. 1026 gauging station

In order to characterise exposure due to low- and high-water cases, we also compiled duration curves based on daily data of the period between 1961–2013. On the duration curves we highlighted values representing monthly mean low-water and mean high-water. In Figure 16 a semilogarithmic scale is used as yield values vary in wide range in the different rivers.

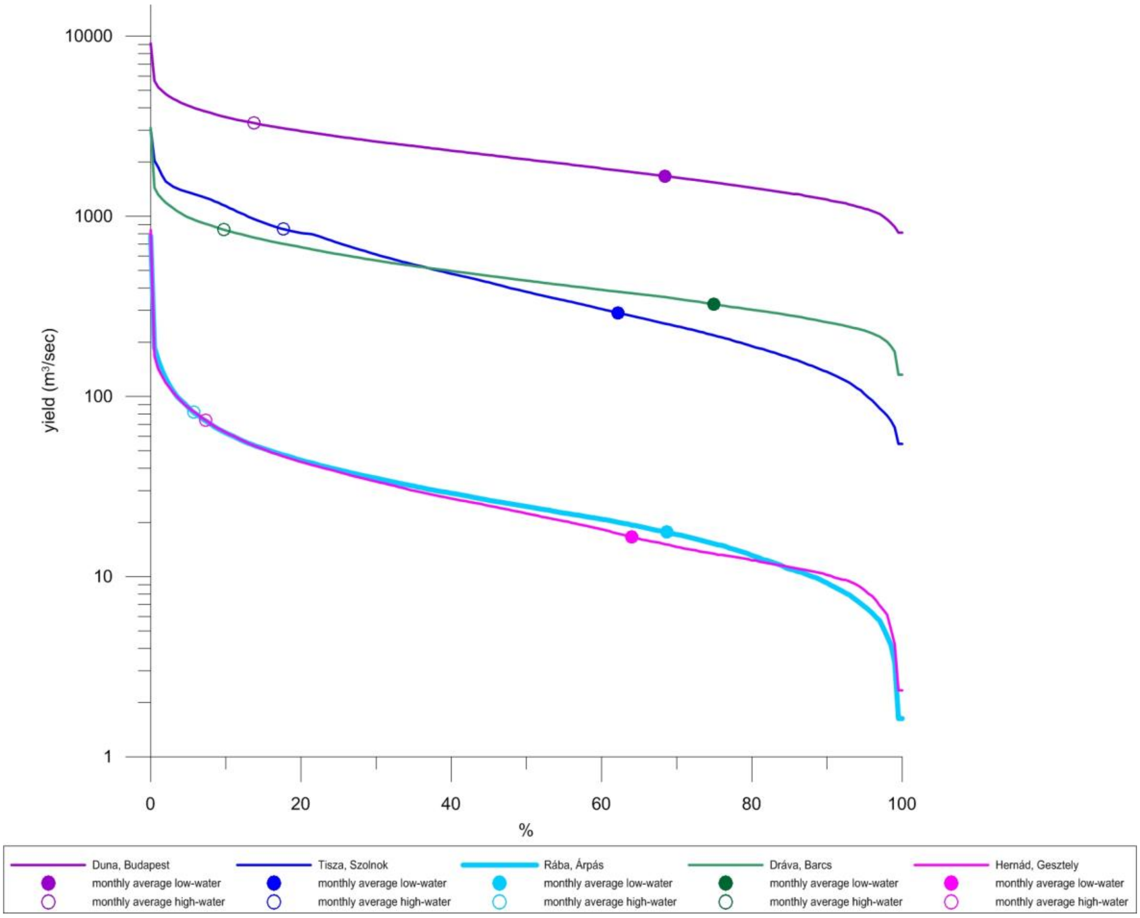


Figure 16. Duration curves related to the period between 1960–2010

In rivers having bank-filtration systems no significant differences are found in the exposures. Altogether, the River Tisza has the highest degree of exposure. In case of the River Tisza both low-water and high-water cases occur in greater percentage than for the rest of the rivers. Based on the assessment of duration curves, the water flow of the River Dráva can be considered the most stable among the selected rivers.

It is difficult to forecast the climatic exposure and its expected change for the bank-filtration systems. The difficulty arises mainly from the uncertainty of the amount of precipitation derived from the regional climatic modells. The ALADIN and RegCM modells used in our assessment result in contradicting outcomes for specific time periods (SZÉPSZÓ et al. 2015). Further difficulties arise, as signiificant amount of the precipitation influencing water level fluctuation of rivers has transboundary origin and is not included in the CarpatClim-Hu data system used in the NAGiS project.

It has to be considered that the river flows can be influenced by anthropogenic activity, such as land use changes in the catchment area of the upstream river and water regulations, in addition to climate change.

Therefore, clarifications in the exposure assessment of the bank-filtration systems need further research.

5 CLIMATE-SENSITIVITY OF DRINKING WATER PROTECTION AREAS

The effect of climate change on groundwater is not as direct and intense as in case of the surface water system. Often, what we observe is the result of changes acting for several years. As the changes are acting in most cases for several years, upon termination of the unfavourable effect, the original status can be achieved slowly.

The infiltrating water is transported either through the available subsurface pore space or fissure network of the karst system. Due to the subsurface conditions the movement of groundwater is significantly slowed down and processes are acting on a longer time scale. The degree of porosity regulated by geological processes, therefore the climate-sensitivity of the drinking water supply is determined by the geological and hydrogeological properties of the recharge and drinking water protected areas.

5.1 Factors influencing climate-sensitivity

Hydrogeological systems representing the different geographical and geological environments are sensitive to climate change factors in a different manner. The hydrogeological systems typical to the greater geographical and geological units of Hungary can be classified based on the expected effects of climate change (ROTÁRNÉ, TÓTH 2008) according to the followings:

- Karstic and mountaneous areas.
- Areas of deep sedimantary basins.
    1. Hilly loess land.
    2. Sand ridges.
    3. Lowlands with elevated groundwater table.
- Interaction zone of surface and groundwater flow systems.

5.1.1 Karstic areas

The water balance of the karstic areas is sensitive to climatic changes and responds quickly. In case of sustained decrease in precipitation, the dynamic reserves of the karst system can be deplenished. Even if recharge is to increase, the static groundwater reserve is recovering slowly on a longer time scale to reach the original level.

In cases of increase in precipitation and unpredictable climate, sudden showers of rain and thunderstorms are expected to lead to significant flood discharges at springs especially in karstic areas with conduit flow channels. Karstic floods typically appear suddenly, within few hours after the precipitation event and may transport pollutants from the surface into the karstwater systems.

In the Bükk Mts., primarily, uncovered karstic areas dominate the landscape which are characterised by conduit flow channels. Due to the drinking water production from the karst water system, it is also very sensitive to the precipitation deficient periods caused by the extreme climate. The extent of karst water withdrawal has exceeded the recharge of dynamic reserves for shorter-longer periods (LÉNÁRT 2006). This causes problems mainly during the longer, dry (precipitation deficient) periods.

Due to the different hydrogeological situation the karst system of the Transdanubian Mountain Ranges is less sensitive to climate extremes then that of the Bükk Mts. However, according to the instrumental measurements of the past decades, the effects of sustained climate change and extreme events are apparent in the water budget of the region. In the area of the Transdanubian Midmountains the different, karsticfied carbonate formations are well connected hydraulically, therefore can be considered a hydrogeologically homogenous unit. Regarding its spatial distribution, it extends in the deep subsurface, covered by younger sedimantary bedrock, to the Slovenian border in the W and SW and in the E and NE it can be traced over the line of the Danube. The effects of climate change are observable in the recharge areas of uncovered karst areas immediately and in the directly connected sediment covered karst systems slightly delayed. The effects of climate change are even more subtle and delayed substantially in karst systems situated in the deeper zones of the regional groundwater flow system. Similar observations can be made in the karstic areas of the Mecsek and Villány Mts.

5.1.2 Areas of deep sedimentary basisns

In the porous Neogene sedimentary basins the influence of climate change is dependent of depth and the effects are observable primarily in the shallow depth horizons. In the greater depths, the indirect effects of sustained climate change can be evidenced, such as changes in hydraulic potentials, due to changes in the flow and recharge conditions, manifested by pressure transmission. These effects are difficult to be distinguished from changes caused by other anthropogenic activity.

Changes taking place in the shallower zones are influenced not only by the geological conditions, but also by the location in the hydrogeological flow system. As a consequence, climate sensitivity of the hilly loess land, the sand ridges and the lowlands with elevated water table are different.

5.1.2.1 HILLY LOESS LAND

The hilly loess land of the Transdanubian Hills is characterised by a deeper groundwater table (in general 10 m or locally even 30 m deep) within the lower horizons of loess-, clayey-loess strata (occassionally in horizons bellow the loess sequence). In the loess soil horizons of low conductivity, but high water retention capacity, infiltration is low, and unsaturated flow downward to the water table is slow and uniform process. Due to this, variability of the water table is small, and follows slightly the multiannual infiltration tendency, only.

Therefore, in these areas the effect of extreme climate conditions on the groundwater system is less spectacular. In the time periods determining infiltration (primarily the winter half-year) precipitation is decreased and thus the recharge too. However, this is shown in the declining groundwater levels, only by several years or even decades delay. Periods with increasing precipitation can result in similarly slow and gradual increase in groundwater level.

5.1.2.2 SAND RIDGES

Sand ridges of the Danube-Tisza Interregion, as well as, of the Nyírség area are also having peculiar hydrogeological characteristics; these represent the local recharge areas of the Great Hungarian Plain. In the surface, there are sandy layers of several meters thickness, characterised by good hydraulic conductivity, which allow the infiltration of precipitation into the shallow groundwater aquifer. The sandy layers moisture content is only moderately decreased by evaporation, thus small amount of precipitation is enough to reach saturation and induce infiltration. Groundwater level is very sensitive to changes in the amount of precipitation. Thus, the effect of climate change is primarily dependent on changes in the amount of precipitation and changes in temperature and subsequent evaporation processes are less significant. The humid, and dry periods result in changes primarily connected to groundwater level, therefore the amount of infiltrating precipitation, which influence significantly local flow patterns. The sustained downward trend in precipitation, together with the effects of groundwater withdrawal from the shallow and deeper aquifer horizons, may result in the decline of groundwater level on a regional scale.

As a result of the decreasing recharge the groundwater flowpaths may change, flow fluxes may decrease. At locations, where groundwater flow has diluting effect on pollution propagation this is unfavourable, where groundwater flow is a major factor of pollution transport this results in favourable changes in water quality. Water quality changes occur also, when changes occur in the groundwater flow system by the decrease of the number of the local flow system, as a result of changing (presumably decreasing) recharge. In such cases, polluted and ocassionally evaporated groundwater formerly discharged locally may become part of the regional flow system.

The increasing recharge peculiar to a more humid climate can result in the enhanced transport and propagation of pollutants into the groundwater system (on lowland areas these are primarily chemicals used by agriculture).

The groundwater of sand ridges is thus sensitive to changes of climate elements (regarding especially the amount of precipitation) sustained for several years.

5.1.2.3 LOWLANDS WITH ELEVATED GROUNDWATER TABLE

In the discharge areas of the groundwater system, where the groundwater table is situated close to the topographic surface — such as under natural conditions, the significant extent of the the Great Hungarian Plain and the wide valley bottom areas of the hilly and mountaneous regions — the ascending groundwater is affected by evapotranspiration or evaporation. In Hungary, evapotranspiration is significant at locations with elevated groundwater level. Since evapotranspiration is directly influenced by humidity and temperature, it is foreseeable that lowlands and wet areas of higher topographic position are very sensitive to climatic change. In the low lying areas of the lowlands which have constant high groundwater table, evaporation and evapotranspiration processes become more intense, as a result of the increase in temperature, and an increased evapotranspiration value is expected, as compared to the present one. Due to this, water budget is changing and significant evaporation and concentration of dissolved solid (ocassionally pollutant) is prognosted in the groundwater bellow the water table and at discharge zones.

According to climate scenarios so far, decrease in temperature and subsequent decrease in evaporation is a less likely scenario. In case, this should occur, water drainage problems are expected.

A more likely scenario is that the late autumn - winter months are becoming more humid. In this case, lowland areas may develope inland water more frequently which may endanger ecosystems, mitigate pollution propagation and create problems to the agriculture and the settlements.

5.1.3 Interaction zone of surface and groundwater flow systems

The relation of surface and groundwater systems is determined by the relative position of the gauge level and the groundwater table. At high-water and floods surface water is leaking into the groundwater from the water course. In case of low-water, leakage is reversed and is towards the water course from the subsurface groundwater regime. As a result, groundwater is discharging into the surface water course. Therefore, in dry periods the base-flow of the watercourse is maintained by the groundwater. The amount of base-flow is not constant, and shows a slow downward tendency parallel to the deplenishing of the subsurface water reservoir. It is interrupted by the increased flow caused by the subsequent wet period. At this stage the groundwater reserves are recovered and saturated and the cyclic process restarts.

The connection of the surface and the subsurface groundwater system is also sensitive to climate change, although this can be different for small watercourses and larger rivers.

Alongside the larger rivers, the typical exploitation of the connection of surface and subsurface water is the bank-filtered groundwater reserve. This type of groundwater reserve forms the most important elements of the perspective drinking water reservoir of the country. By definition the bank-filtered groundwater reserve is recharged mainly by the surface water. Therefore these systems are sensitive to surface water flow changes induced by climate change, and influence the quantity and quality of produced water (SPRENGER et al. 2011). At low water, the amount of producable water is diminished, and in the meanwhile the ratio of water related indirectly to the surface water is reduced. Consequently, this means that the ratio of the water originating from the surrounding areas, the so-called background area, with potential pollutant concentrations, is increased. The quality of bank-filtered water is influenced by the modified travel-time of water particles and the changing redox conditions.

Extreme weather conditions are expected to result in flood event more frequently. During these floods pollutants in the surface water can pose a direct hazard on those wells in the bank-filtered drinking water system where the filtering riverbed sediments are missing. It is noted, however that bank-filtered sediments have substantial reservoir capacity, therefore moderate the direct effects caused by extreme climatic conditions as well as, seasonal changes. This moderating effect is proportional to the extent of the water course and its alluvial fan.

According to the aboves, in cases of smaller watercourses, as well as, groundwater systems, where recharge originates from the surface water system only in smaller proportion, we define the alluvial aquifer affected by watercourse.

5.2 Climate-sensitivity categories

Based on the above, the climate-sensitivity of the groundwater systems are different and based on the hydrological constraints climate-sensitivity categories can be established. For the determination of the categories we defined the following types of groundwater systems based on the hydrogeological character of their major aquifers:

- groundwater systems of porous aquifers,
- groundwater systems of karstic aquifers,
- groundwater systems of fractured aquifers,
- bank-filtered systems,
- surface waters.

According to the character of the hydrogeological system the groundwater systems are further subdivided. The porous aquifers are sudivided as a function of depth into three categories:

- 0 to 30 m depth,
- 30 to 100 m depth,
- greater than 100 m depth,

The karstic aquifers are categorized according to the character of the flow channels, the thickness of the top cover sediment and hydraulic connection to uncovered karstic areas with direct recharge, as follows:

- karstic aquifer with well developed channel network,
- open (unconfined) karst system,
- confined karst system connected to recharge area,
- deep karst system, part of regional groundwater flow system.

The intensity of climate-sensitivity is divided into four categories:

- very sensitive,
- sensitive,
- moderately sensitive,
- having no direct effect.

The climate-sensitivity categories and the degree of climate-sensitivity of the drinking water systems defined in the above manner are summarised in Table 5.

Table 5. Climate-sensitivity categories of drinking water systems

Type of aquifer	Climate-sensitivity category	Code of the climate-sensitivity category	Intensity of climate-sensitivity
porous aquifer	porous aquifer <30 m	ps	very sensitive
	porous aquifer 30-100 m	p30	moderately sensitive
	porous aquifer >100 m	p100	no direct effect
karst system	karstic aquifer with well developed channel network	kj	very sensitive
	open karst system	kny	sensitive
	confined karst system connected to recharge area	kf	moderately sensitive
	deep karst system, part of regional groundwater flow system	km	no direct effect
bank filtration system	bank-filtration system	asz	sensitive
	alluvial aquifer affected by watercourse	ar	sensitive
fractured aquifer	fractured aquifer	r	moderately sensitive
surface water	surface water	fev	very sensitive

5.3 Categorisation of drinking water system climate-sensitivity

The cooperation between OVF and MFGI made available for us the database of drinking water protected areas, which contains information on all the operating, standby and to be abandoned resources. In the NAGiS Project we completed and corrected the existing database with the climate-sensitivity parameters.

We carried out the categorisation of all the 2018 drinking water protected areas into the climate sensitivity categories listed in Table 2. We reviewed the data of individual wells in each drinking water protected areas with particular attention to the character of the aquifer and depth. We compared well data with that of the MFGI *Geological Borehole Database*, and the available regional, in case of necessity, local geological maps and thematic layers. We reviewed the available aquifer diagnostic measurements and the related results of numerical hydrogeological modelling, in order to better differentiate between sub-types of karstic groundwater resources, bank-filtered groundwater reserves and alluvial aquifer affected by watercourse.

The categorisation of drinking water protected area climate-sensitivity is not clear in all cases. If the aquifer can not be categorised unambigously into one of the categories, first the dominant character is considered as a basis and indication is made to the secondary aquifer type. An example for this is the discrimination among the confined karstic aquifers, as these are hydraulically connected to the unconfined karstic aquifers and in case of the confined karstic aquifers climate-sensitivity is determined by the travel-time of water particles. There are no sharp boundaries among the bank-filtration water system, the alluvial aquifer affected by watercourse; the transitions are related to the similarity of the environments. In our consideration, the drinking water protected area is considered as a bank-filtration system when the contribution of the surface water component is more than 50%. In order to define the percentage of contributing sources we used the values determined by numerical flow modelling of the diagnostic measurements in the "National Groundwater Protection Programme".

In porous aquifers, it is frequently the case, that wells are penetrating to different depths. In this case, according to a "worst-case-scenario" the depth of the shallowest well gives the basis of the climate-sensitivity qualification. Due to this reason, in the dominantly shallow porous aquifers there are wells often taping deeper aquifer horizons (30 to 100 m, rarely greater than 100 m) and based on their secondary character belong to the less climate-sensitive category.

The created database contains the following drinking water resource related data:

- code of drinking water protected area,
- name of drinking water protected area,
- operator,
- operational status of the drinking water protected area,
- type of drinking water protected area determined based on aquifer character,
- code of the Regional Water Directorate,
- centroid coordinates of the drinking water protected area (EOV coordinates),
- assignment to the climate-sensitivity category,
- qualification of the climate-sensitivity,
- related groundwater body.

Map display is made using centroid coordinates of each drinking water protected area (

Figure 17. Climate-sensitivity of the drinking water protected area

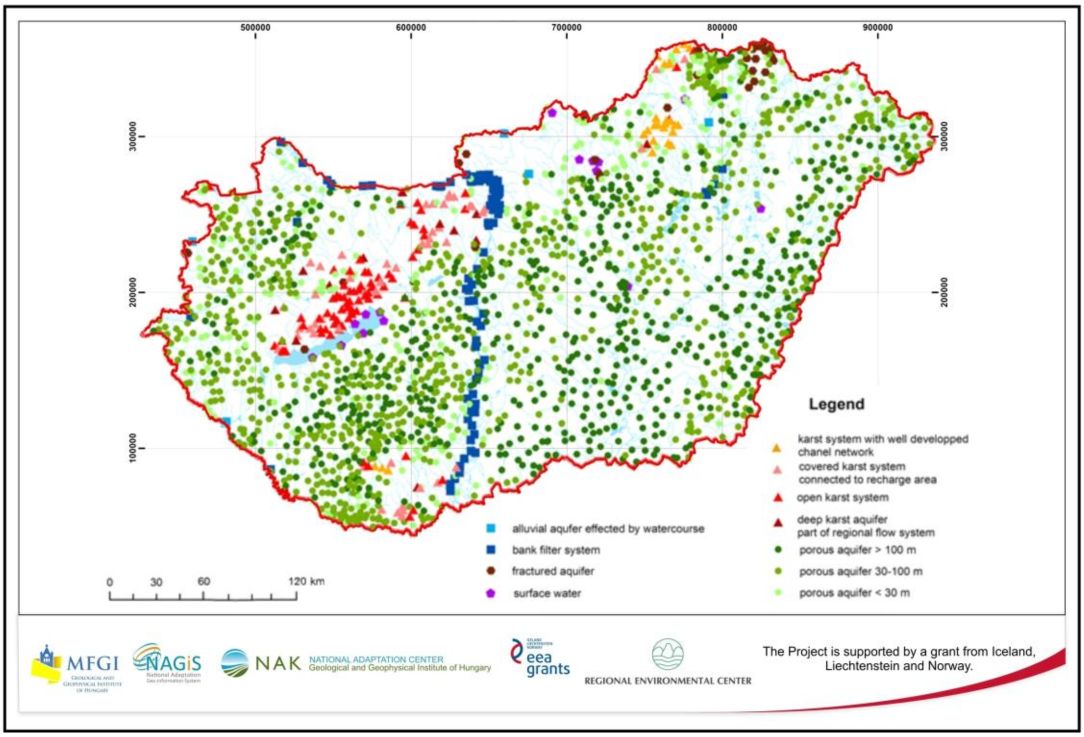


Figure 17. Climate-sensitivity of the drinking water protected area

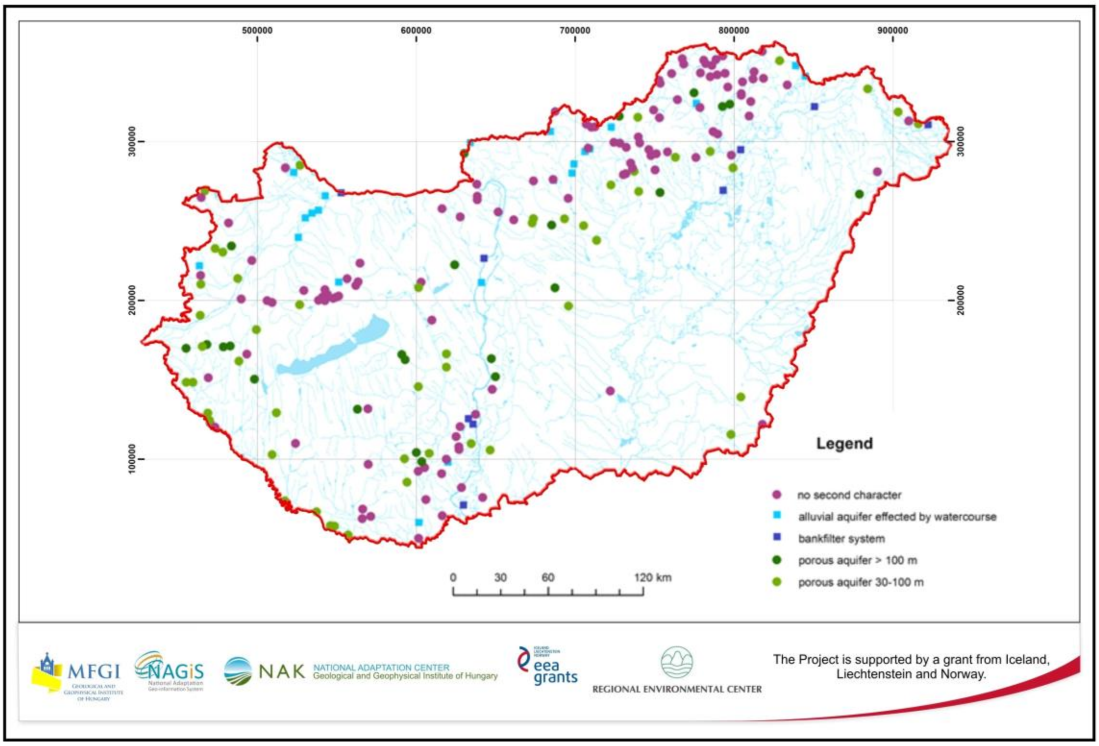


Figure 18. Secondary climate-sensitivity classification of shallow (0 to 30 m depth) porous drinking water protected area

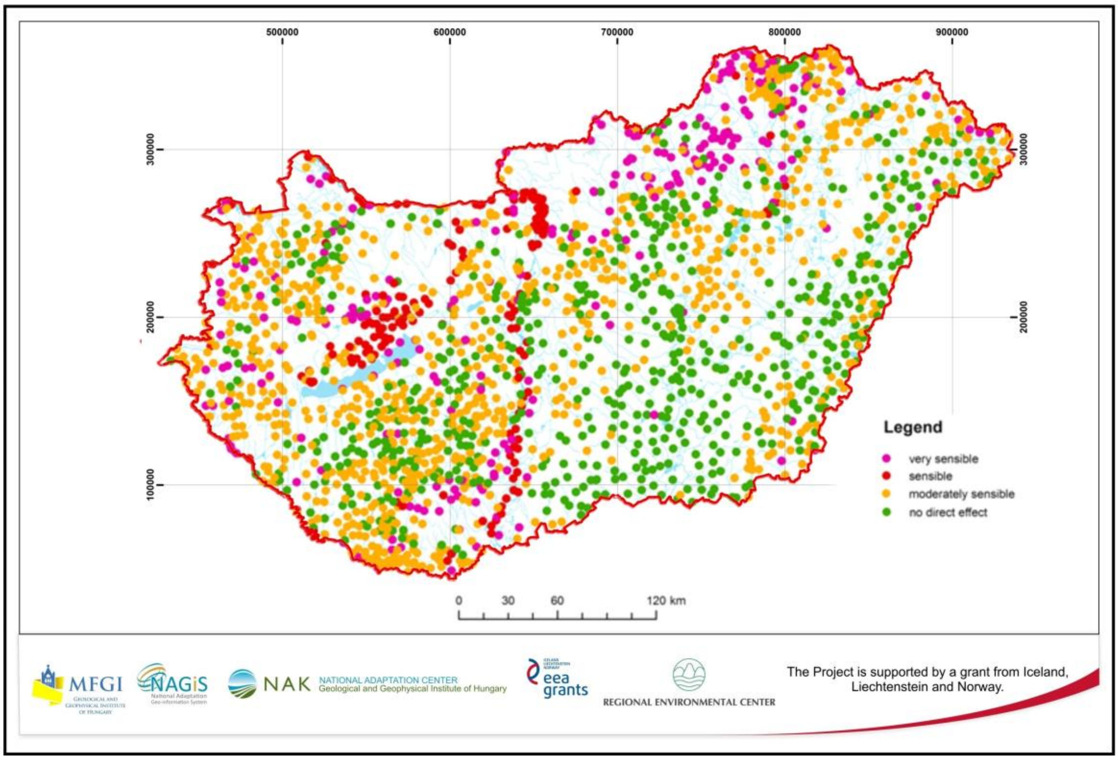
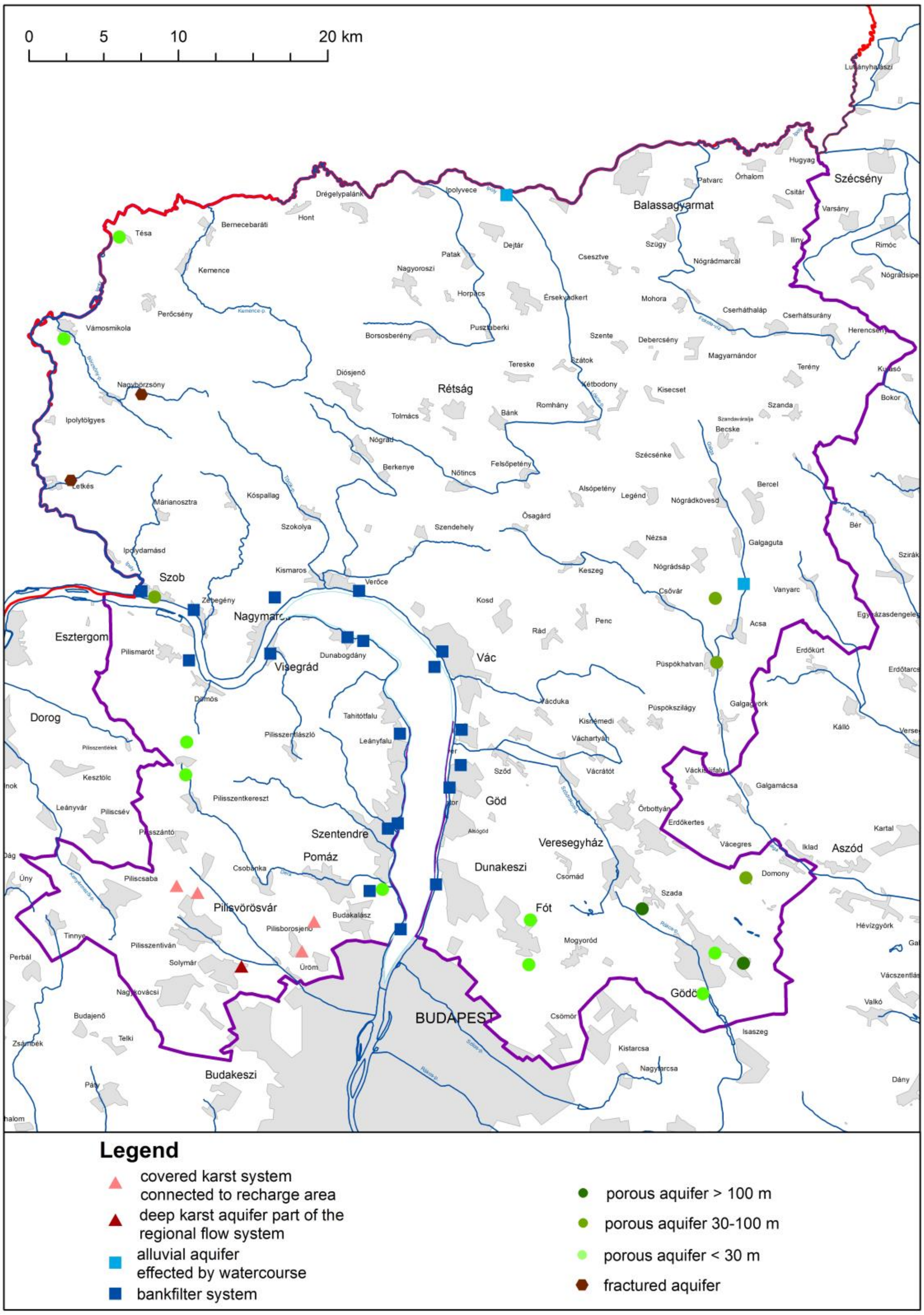


Figure 19. Intensity of drinking water protected area climate-sensitivity

5.4 Drinking water protected area climate-sensitivity in the pilot area

The pilot area (operation territory of DMRV) situated at the Danube Bend is mainly of mountainous character. As a result of the geological settings the drinking water resources are located in a concentrated way. There are only a few drinking water protected areas situated in the distribution area of volcanic formations with limited groundwater potential. The bank-filtration systems of greater volume drinking water potential and of prognostic supply potential are located alongside the River Danube.

Similarly to the country-wide characterisation, we carried out the thematic categorisation for the selected pilot area according to the climate-sensitivity and the intensity of climate-sensitivity, and displayed the results on maps representing the drinking water protected areas with their centroid point coordinates (Figure 20 and Figure 21).



MFGI Geological and Geophysical Institute of Hungary
NAGiS National Adaptation Geo-information System
NAK National Adaptation Center Geological and Geophysical Institute of Hungary
eea grants
Regional Environmental Center
The Project is supported by a grant from Iceland, Liechtenstein and Norway.

Figure 20. Drinking water protected area climate-sensitivity in the operational area of the DMRV

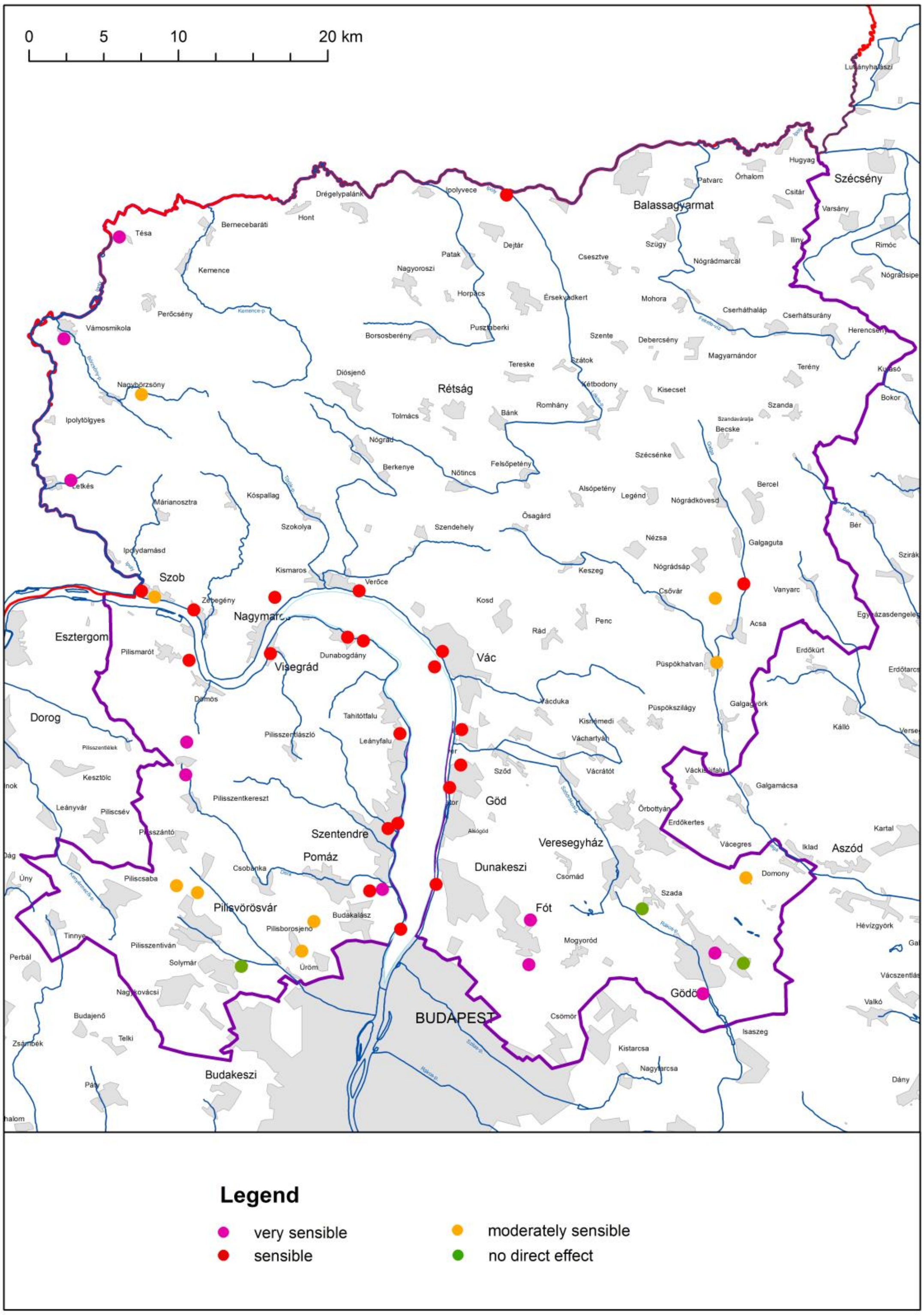


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Figure 21. Drinking water protected area degree of climate-sensitivity in the operational area of the DMRV

As it is illustrated in Figure 20 the spatial distribution of the drinking water protected areas are not homogenous in the operational area of the DMRV, which is primarily due to the geological structure.

Among these are the bank-filtration systems, which are sensitive to climate change and have major importance in securing public water supply. The drinking water resources situated between 0 to 30 metres have also important contribution. The water resources which are less affected by climate change (karst and porous aquifers of the deeper flow regime) represent a smaller proportion (Figure 22).

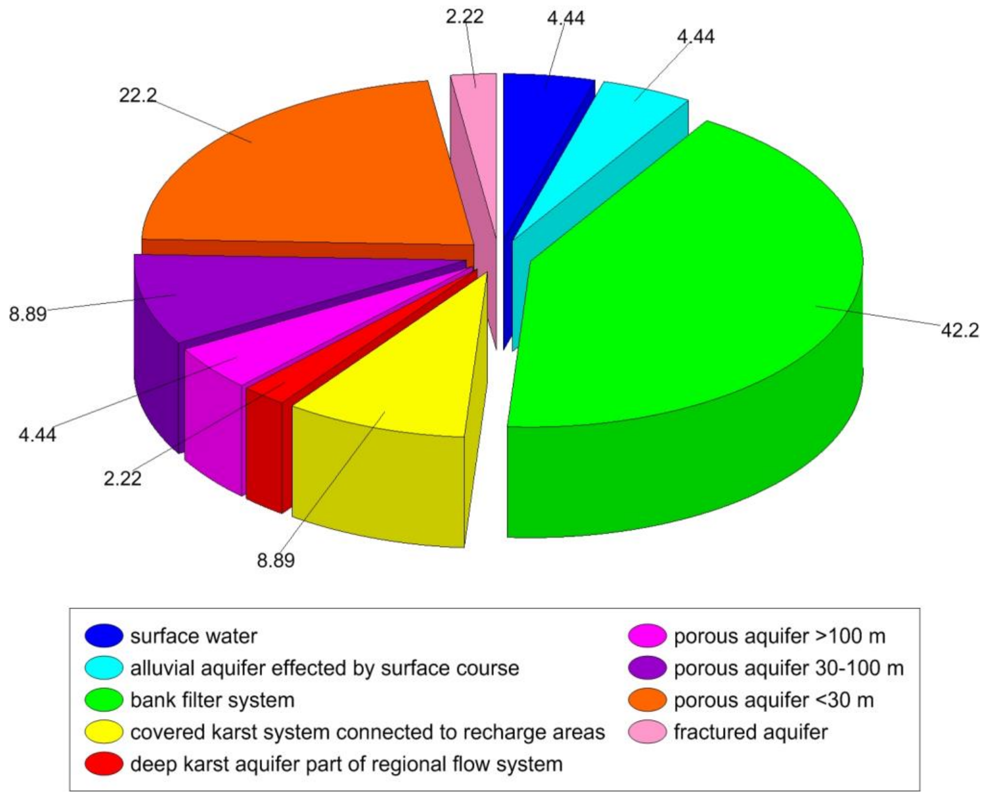
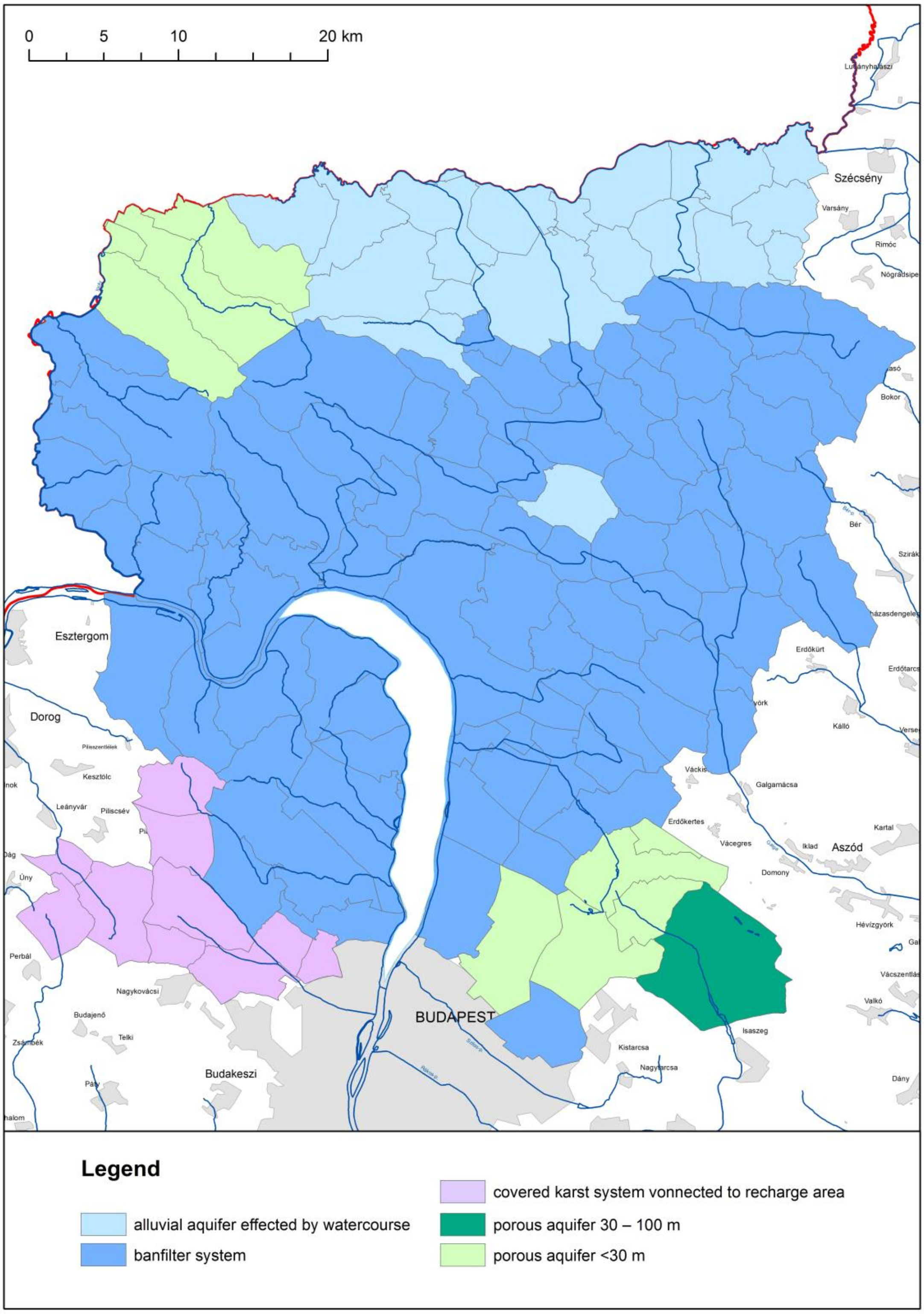


Figure 22. Pie chart (as percentage) of drinking water protected area climate-sensitivity type

In addition to the display of drinking water protected area centroids on the thematic climate-sensitivity category map, we also assigned these to the settlements, in order to provide a basis for the climate-vulnerability assessment. For the assignment we identified the settlements directly supplied by the respective drinking water protected areas. However, for emergency cases DMRV has the technological capacity within its operational area, which enables that any regional water supply can be governed to secure water supply of another region. As drinking water supply of a settlement is often provided by more than one drinking water protected areas, the climate sensitivity categorisation is implemented on the basis of the least sensitive drinking water protected area (Figure 23 and Figure 24).



MFGI Geological and Geophysical Institute of Hungary NAGiS National Adaptation Geo-information System NAK NATIONAL ADAPTATION CENTER Geological and Geophysical Institute of Hungary eea grants REGIONAL ENVIRONMENTAL CENTER The Project is supported by a grant from Iceland, Liechtenstein and Norway.

Figure 23. Drinking water protected area climate-sensitivity of the settlements based on the least sensitive direct water supply type, within the operational area of the DMRV

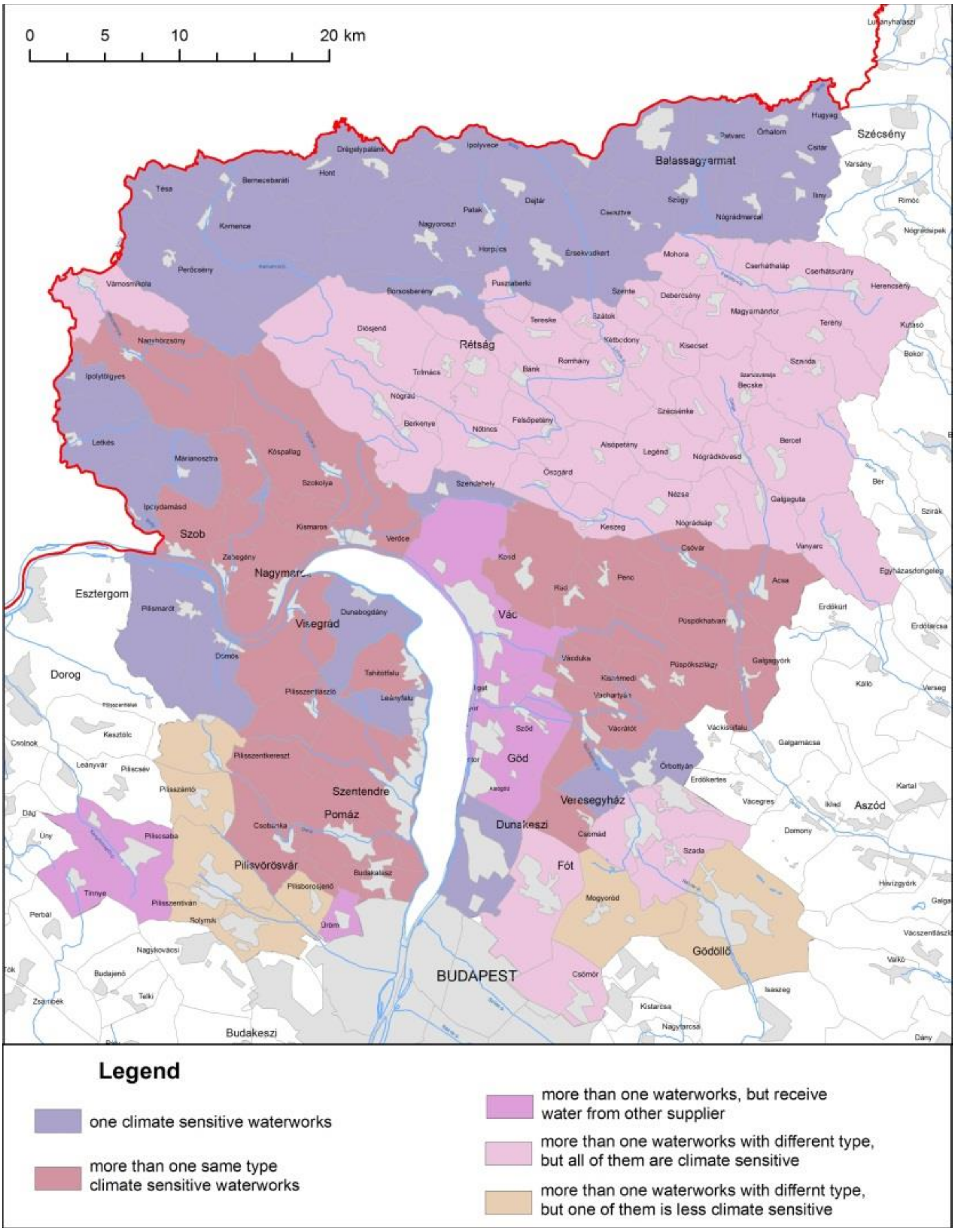


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Figure 24. Drinking water protected area climate-sensitivity of the settlements based on the number and climate-sensitivity of the direct water supply, within the operational area of the DMRV

6 CURRENT DEMAND ON GROUNDWATER RESOURCES

It is difficult in all aspects to differentiate between the effects of climate change and other anthropogenic activities. In groundwater systems these are superimposed and amplify each other. For this reason, it is essential to consider the water production data of the past decades for the investigation of climate change. The effect of overexploitation of water resources is now a global pressure on water resources (GREEN et al. 2011). The production of groundwater, primarily for drinking water purposes has increased significantly since the 50s, in Hungary. As well as, in specific regions of the planet Earth, we can observe sustained downward tendency in water levels related to groundwater production in several aquifers, also in Hungary. In case of increasing temperature the drinking water demand of the population and that of the agriculture can be increased significantly. The increased water exploitation can result in further significant water level decline and in specific regions it can even reach the limits of the exploitable quantities.

We carried out the investigation of groundwater level decline due to exploitations so far, using monitoring data of our groundwater monitoring network and by the interpretation of simulation results of numerical groundwater flow modells.

6.1 Assessment of groundwater level changes in the monitoring wells

There are altogether 844 monitoring wells for which we assessed groundwater level changes. We carried out the trend assessment of time series for all the monitoring wells with an automated method. Than we checked visually that trends identified by the automated method are characteristic for the whole length of the time series, and that the data series are not biased by errors. In the assessment we investigated the River Basin Management Monitoring Network data for the period between 1991–2014, the monitoring network data of MFGI for the period between 1970–2015. In the analysis of time series we investigated whether the time series can be characterised with a single trend curve or there is a change in trend with time. In the trend analysis first we considered the whole length of the time series, than the time series of the past eight years only.

We compared our results with the results of the groundwater budget tests of the River Basin Management Plan prepared in 2015, taking into account that the latter examined primarily the data series of the past eight years.

6.2 Assessment of groundwater flow modell results

We corrected the assessment of groundwater level changes in the monitoring wells and completed it with the results of country-wide water budget updates evaluated by experts of the MFGI for the 2nd River Basin Management Plan. It included the results of numerical hydrogeological modelling developed to study water budget of the shallow porous, porous and porous thermal groundwater bodies.

Recently, the numerical hydrogeological modell developments were carried out at MFGI, in the porous sedimentary basin particularly due to the thermal water and geothermal resources management problems. The further development of the “XL-Pannon modell” was considered useful for the water budget calculations by the update and reform of the geometry, the hydraulic parameters and the recharge boundary conditions in the shallow porous parts. The modell construction simulates constant, permanent conditions. Additional simulations are made considering situations without and with groundwater production (in addition to drinking water production the agricultural, industrial and geothermal productions). Groundwater depressions caused by water production could be derived using the results of the two investigations. Figure 25 shows the depression values calculated for the undermost horizon of the most significant porous drinking water bearing Pleistocene aquifer.

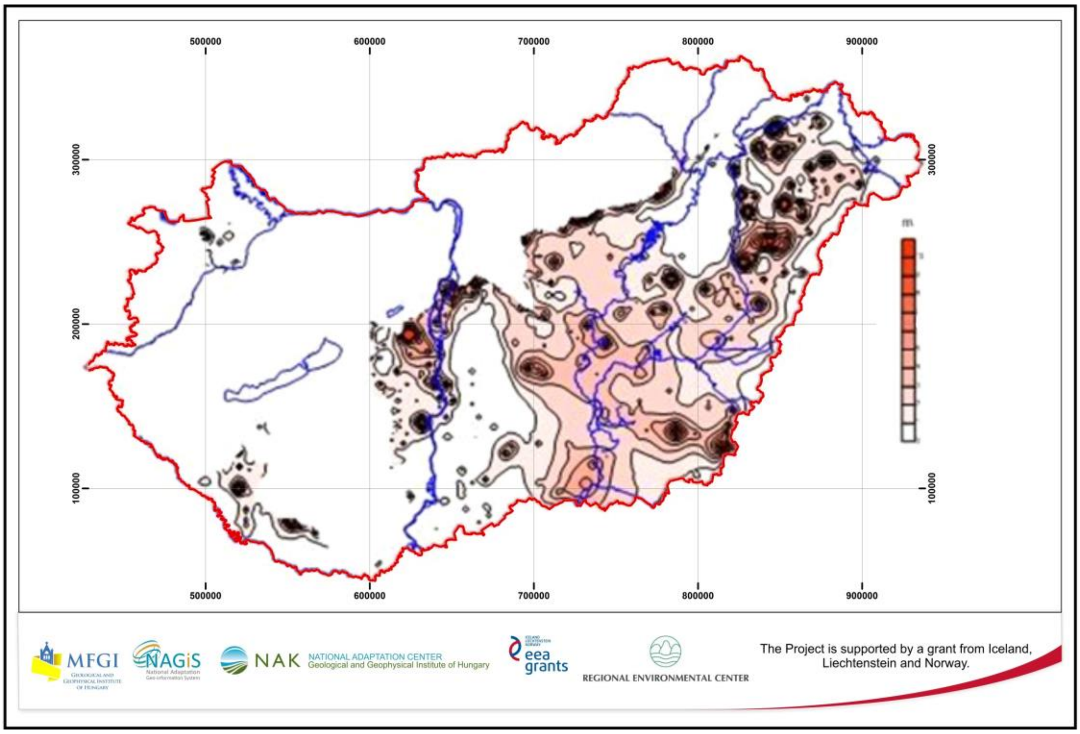

Figure 25. Calculated value of groundwater level decline caused by water production in the lower part of the Quaternary formations

6.3 Evaluation of the groundwater level changes

Groundwater level time series of monitoring wells and water budget simulation results of porous aquifers are evaluated together, in order to characterize the depressions caused by abstractions on groundwater bodies (Figures 25, 26).

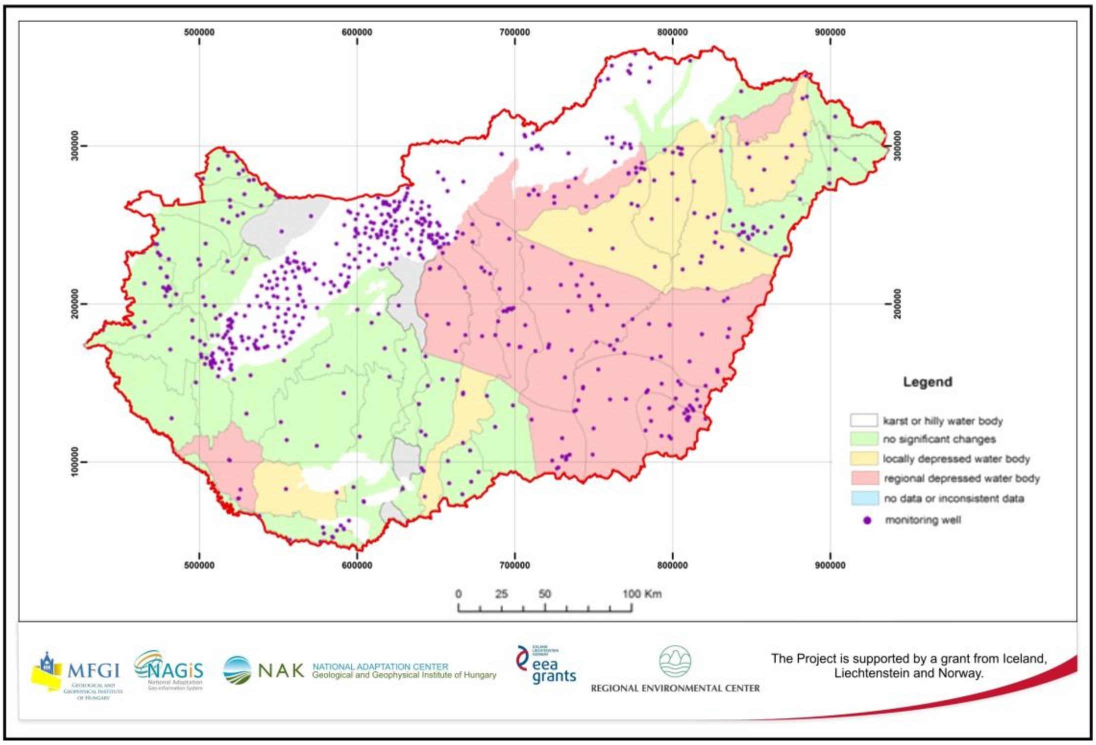

Figure 26. Groundwater level decline caused by water production in the porous groundwater bodies

In general, we can conclude that the effect of depression caused by groundwater abstraction is characteristic mainly, as regional groundwater level decline, in the central region of the Great Hungarian Plain and the extent of which is increasing with depth. In the mid-90s, the decline of groundwater level is ceased in several regions and no significant change could have been observed since than. The present groundwater levels are, however several meters below the original levels in these areas (Figure 26).

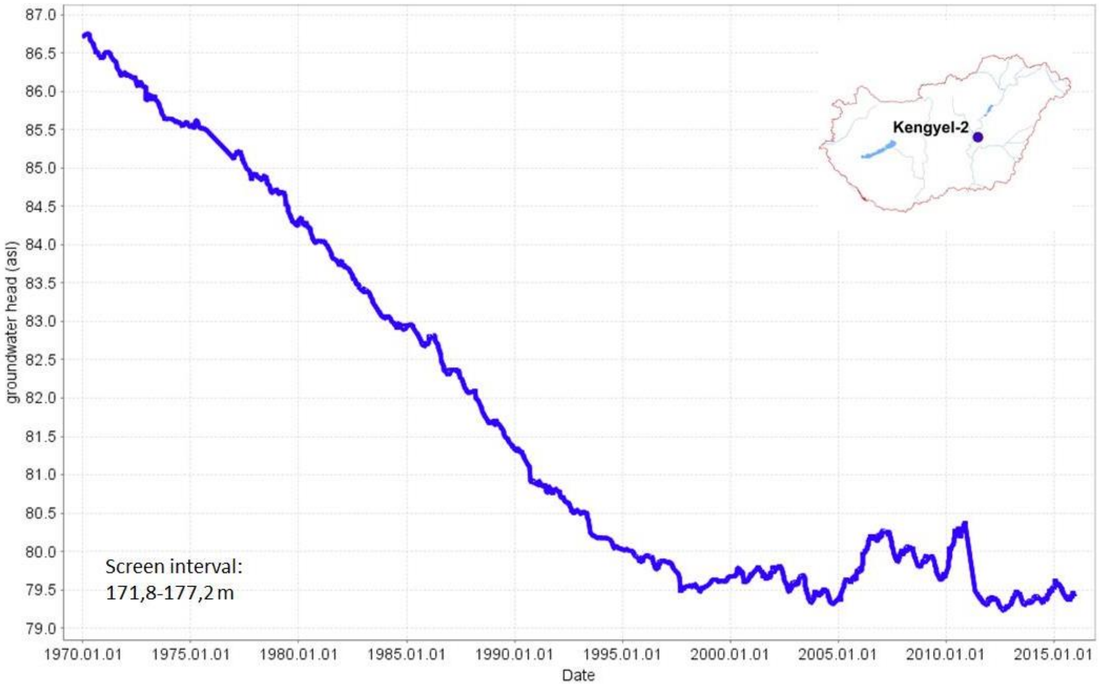

Figure 27. Groundwater level time series of Kengyel–2 monitoring well of the MFGI

The great demand on groundwater in the Northern part of the Great Hungarian Plain can be related to the open pit lignite mining at Bükkábrány.

In general there is no large volume groundwater production in the mountaneous areas.

In the distributional area of karst, present water production is much less than that of the 90s due to recovery of the system after the clousure of mines. In the region of the Transdanubian Mountain Ranges the declining groundwater levels caused by former mining activity are now characterised by increasing groundwater level trends, despite of the current drinking water withdrawal.

7 CLIMATE ADAPTATION OF SETTLEMENTS REGARDING WATER SUPPLY

As a result of climate change the extent and frequency of summer heat wave periods are expected to increase significantly and also changes in the distribution of precipitation are expected to take place. In the winter semester precipitation is expected to increase, while in the summer semester, which is the vegetation growing season, it is expected to decrease. As a result, water demand of the population is anticipated to increase, partly, due to domestic water use, as well as, water used for irrigation in the private sector. Therefore, regarding climate adaptation the current status and upgradeability of the infrastructure and the water demand of population are the main factors.

7.1 Methodology

In addition to climate exposure and climate-sensitivity we need to define climate adaptation, in the climate-vulnerability assesssment of the settlements regarding drinking water supply. For the investigation of these we used the social-economic indices of the National Settlement Development and Planning Information System (TeIR) of the KSH-T-STAR and NAV SZJA databases and data relevant to the status of the water supply system infrastructure in the pilot area provided by DMRV.

In the first stage of the investigation we delineated data needs and classified data specifities, in cooperation with the DMRV. The important tasks of this stage were the screening of data for errors, checking and correction of outlying values.

It was an important aspect in the assessment that data possibly represent a single, specific year however, this could be satisfied only partially. Data related to the status of the infrastructure is up-to-date, that is representative of the present conditions, while the social-economic indices are available uniformly for the year 2013.

With regards to the aboves we used the following specific indices for the determination of climate adaptation:

1) The infrastructure factors of climate adaptation,
    a) The number of drinking water protected areas directly supplying a given settlement,
    b) The expandability of the drinking water protected area (category),
    c) The potential to increase drinking water supply capacity (category).

2) The social-economic factors of climate adaptation,
    a) Drinking water consumption per inhabitant, 2013 (m^3/per capita),
    b) All domestic income per inhabitant, 2013 (HUF/per capita/year).

In the further stages of the investigation, we related category values to each indices then by summing up the category values we determined the intensity of climate adaptation for each settlement.

7.2 The infrasrtructure factors of climate adaptation

Regarding water supply, the intensity of climate adaptation is fundamentally influenced by the number of drinking water protected areas directly supplying a settlement, as well as, the upgradeability of the water supply system infrastructure. Using data obtained from the DMRV, we could define the number of opearting drinking water protected areas supplying each settlement (Figure 28). We also investigated whether drinking water protected areas can be extended or water supply system infrastructure supplying a settlement can be increased. In the meanwhile, it is important, to emphasize that as a result of water supply network established, the drinking water supply can always be secured by approppriate water governance.

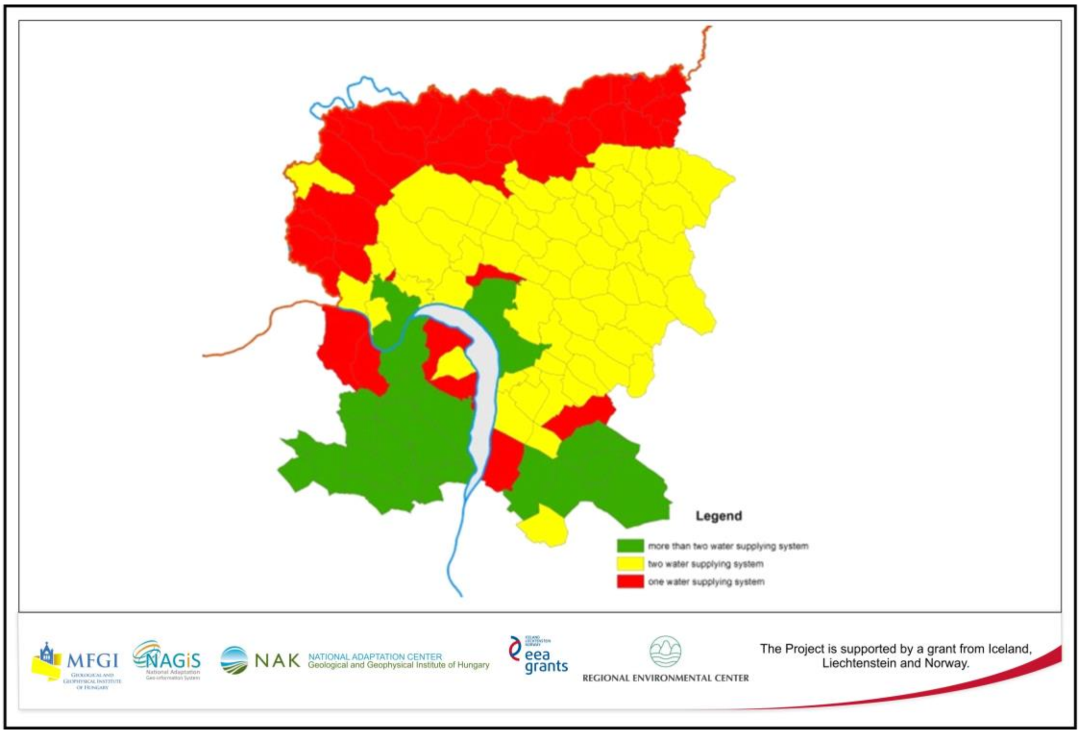

Figure 28. Number of drinking water protected areas supplying settlements in the operational area of DMRV, 2015 (Source of data: DMRV)

We defined three categories regarding water supply security in climate adaptation (Figure 29). Regarding climate adaptation we considered conditions the least favourable when a settlement is supplied solely by a single drinking water protected area. Consequently, the most favourable case is when more than two drinking water protected areas supply the given settlement. In this respect, there are significant differences throughout the operational area of DMRV. Along the River Ipoly, settlements are usually supplied only by a single drinking water protected area, but in the Budapest area most of the settlements are supplied by more than one drinking water protected areas.

Regarding the upgradeability of the drinking water protected area the situation is more uniform. Within the pilot area, for the majority of the settlements, there are drinking water protected areas where both the extension and the capacity increases are possible, according to the data provided by DMRV. By the extension of the drinking water protected area the possibility to establish a new production well is meant by. While the increase of capacity means the increase of existing production capacities, the exchange or modernisation of existing production wells. The development of the drinking water protected areas can be hindered mainly by the built-up of the area, or the contamination of the water resources, however, the development requires great financial investment, in general. There are two significant, connected areas in the southern section along the River Ipoly and the Danube Bend where related problems arise.

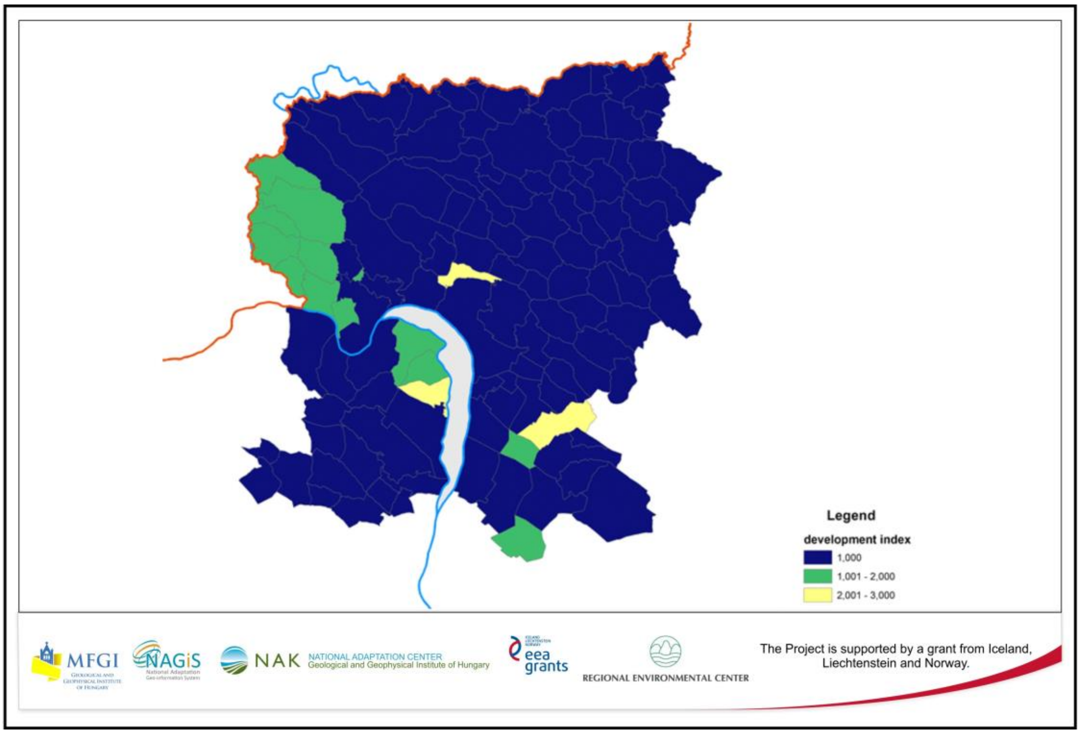

Figure 29. Development possibilities of drinking water protected areas in the operational area of DMRV, 2015 (Soure of data: DMRV)

7.3 Social –economic factors of climate adaptation

The fundamental objective of climate adaptation investigation is to determine the capability of the society to respond to challenges caused by climate change. In case of drinking water supply the most important socio-economic questions are the water demand of the population and the ability of the individuals and communities to tackle the problems. The public water demand can be defined simply based on the water consumption per person indices, the situation is, however more complex, regarding capabilities to tackle the problems. The main issue in this context is that the individual or the local community has the capability to take necessary measures in tackling the problems. To answer this question the figure of all domestic income per person, which is representative of the public income ratio is well suited, since development of a region is primarily determined by the income of the population (FALUVÉGI 2000). With the investigation of population income we gain information on the differences in development status. Based on the research carried out by BÍRÓ, MOLNÁR (2004) it can be stated that that there is a strong, direct relationship between the economic and infrastructure developments of the regions, therefore it is justified to investigate income ratio in the study of climate adaptation.

This relationship is well indicated by the strong correlation of public income ratio and water consumption figures (Figure 30), as well. There is a clear positive, linear correlation between population income ratio and water consumption with the exception of certain outlying values. These outlying values are related to unique impacts. The highest amount of water consumption per person is observed for Visegrád in 2013, which is primarily due to tourism.

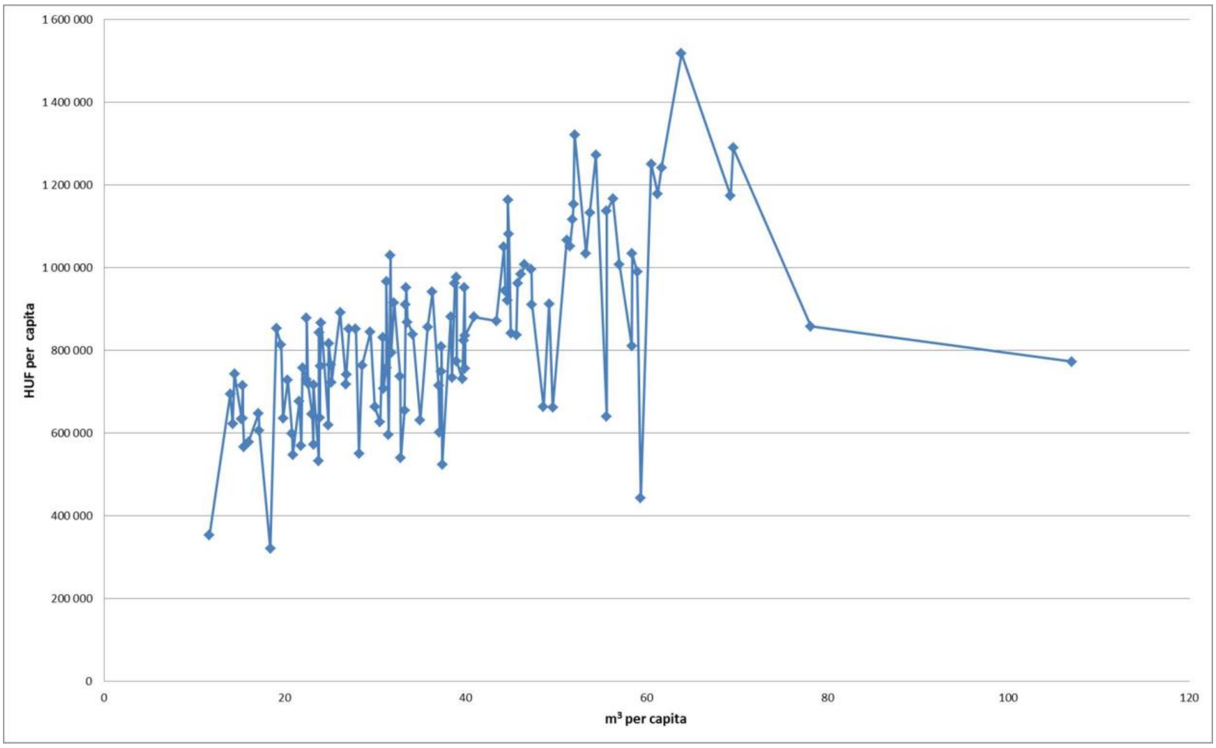

Figure 30. Public income and water consumption relationship based on all domestic income per inhabitant (HUF/per capita/ year, 2013) and water consumption per inhabitant (m^3/per capita, 2013).

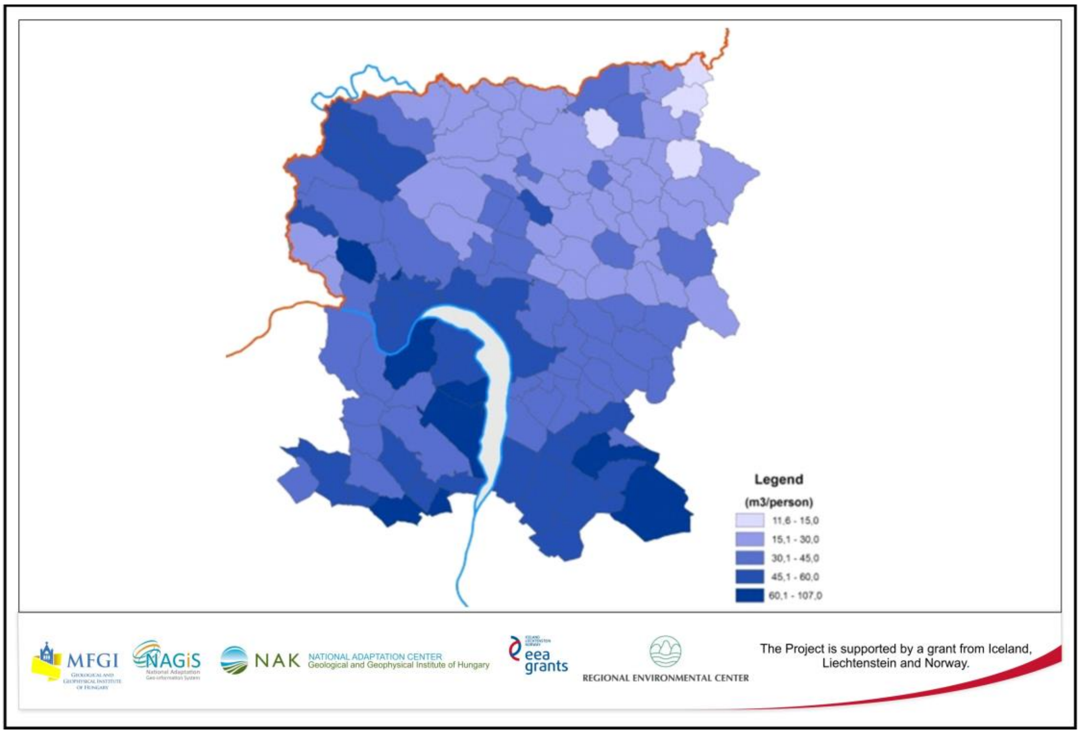

Figure 31. The specific water consumption of settlements in the operational area of the DMRV, 2013 (Source of data: DMRV, KSH T-STAR)

Regarding the territorial difference of water consumption (Figure 31), there is a significant duality in the region. Settlements of the Budapest agglomeration, the area of the Danube Bend, as well as, the Lower-Ipoly Valley are characterised by higher water consumption, while the settlements of Nógrád County have mostly lower (30 m^3/per capita) consumption figures.

There are also significant regional differences in the income ratios of the area (Figure 32). The income ratio is the highest in the area of Budapest, in the settlements of the agglomeration. There are average values in the area of the Danube Bend, in the area of Vác and Balassagyarmat. In the remaining part of the pilot area the income ratio per inhabitant is low.

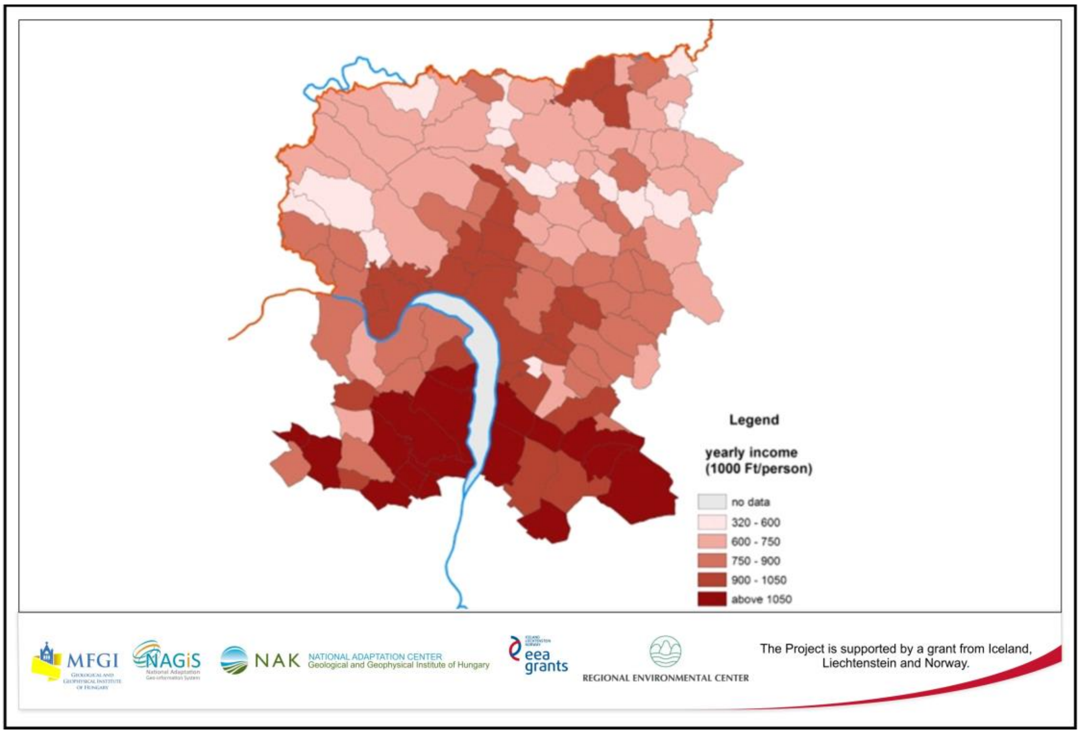

Figure 32. Income ratio of the population in the operational area of the DMRV, 2013 (Source of data: NAV SZJA statistics, KSH T-STAR)

7.4 Determination of climate adaptation of the settlements in the operational area of DMRV

As a result of the detailed investigation on the individual impact factors we determined the climate adatptation of the settlements rearding water supply (Figure 33). In the investigation we considered the number of drinking water protected areas responsible directly for water supply, the potential to develope water supply, the public water demand, and the indices related to income ratio of the population with equal weights. With respect to climate adaptation it can be judged positively if there are more than one drinking water protected areas which supply a settlement, or there is a potential to extend the drinking water protected area and develope its capacity, and if population has low water demand and favourable income ratio.

We classified climate adaptation into four categories on this basis: extreme, high, moderate and weak adaptations. Regarding climate adaptation, the least favourable region is proved to be the Lower-Ipoly Valley area. In this area all of the investigated indices are poor. The majority of the settlements are supplied by only one drinking water protected area, and the potential to develope the water supply system is limited, but water consumption is high and income ratio of the population is low.

The settlements in the right bank of the Danube River Bend are also in poor conditions, regarding climate adaptation. Problems are mainly due to deficiencies in the infrastructure and high water consumption of the population.

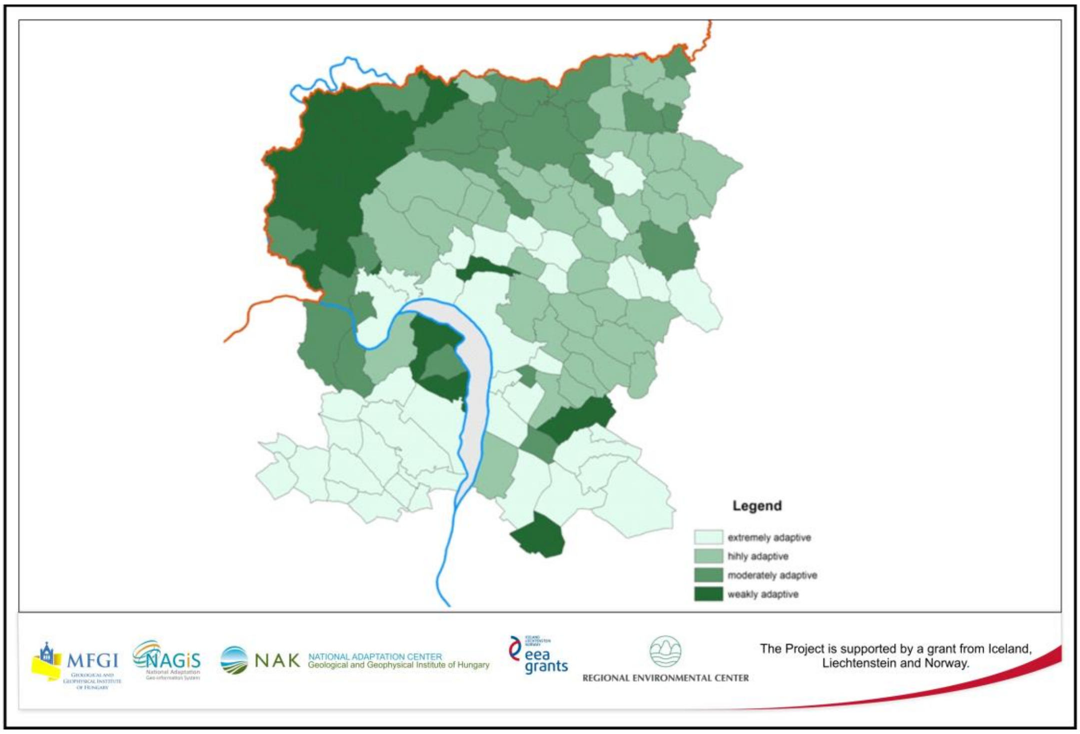

Figure 33. Climate adaptation of the settlements regarding water supply

8 CLIMATE-VULNERABILITY ASSESSMENT OF DRINKING WATER PROTECTED AREAS

The climate-vulnerability of drinking water protected areas is derived from the combined assessment of exposure, climate-sensitivity and adaptation according to the introduced methodology. By definition, climate-vulnerability is related to the administrative areas of the settlements. As indicators of adaptation could be given only for the operational region of DMRV, we carried out the climate-vulnerability assessment also in this region.

We identified categories in order to characterise the intensity of climate-vulnerability. In deriving the categories, exposure, climate-sensitivity, pressure and adaptation factors are considered with uniform weights for the derivation of the combined indicator. Indicator values and climate vulnerability categories are defined in a way that they could be applicable country-wide, following the same methodology.

In the calculation of the combined indicator we did not consider the modified Pálfai-aridity index, applied formerly in the characterisation. Although, this index represents drought approppriately, meteorological data of the summer months obtains greater weights in the calculation. Conversely, meteorological parameters of the winter period have greater significance in the infiltration. It is apparent, that in the recharge of the drinking water protection areas the annual distribution of precipitation and its expected amount is extremely important. Despite of all, we did not make use of the index calculated from precipitation ratios, due to the large uncertainty of climate modells and the conflicting forecasts of the two modells (SZÉPSZÓ et al. 2015). The combined exposure indicator is thus calculated on the basis of UNEP aridity index and the meteorological water balance value.

The climate-vulnerability of drinking water protected areas was determined by both of the two climate modells for the two predicted climate windows (Figure 34–37).

The figures well indicate areas with different intensity of climate-vulnerability, already encountered in the period between 2021–2050, in both modells. As time progresses, the intensity of climate-vulnerability is increasing, in the period between 2050–2100.

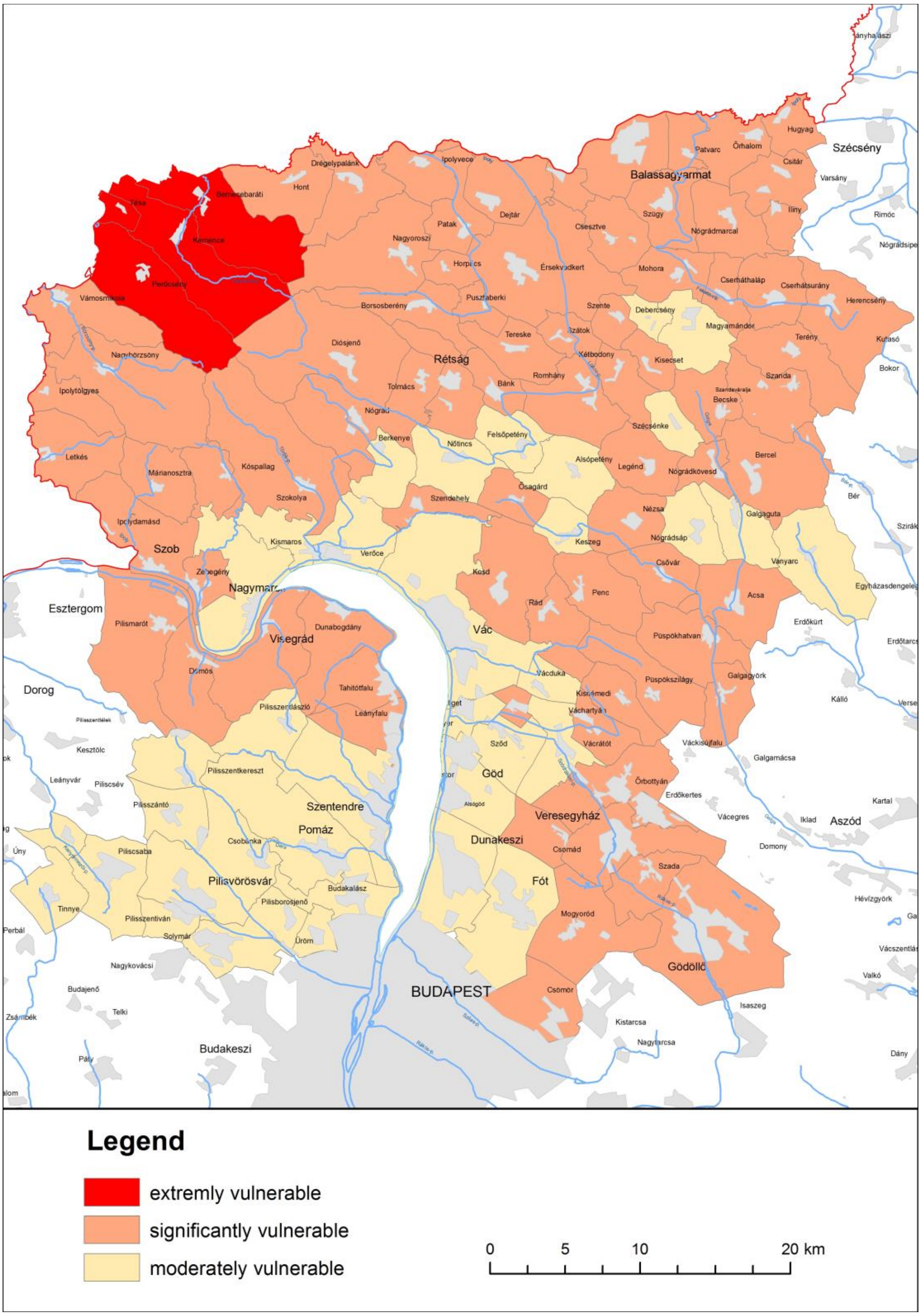

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Figure 34. Climate-vulnerability of drinking water protected areas using the ALADIN modell for the period between 2021–2050

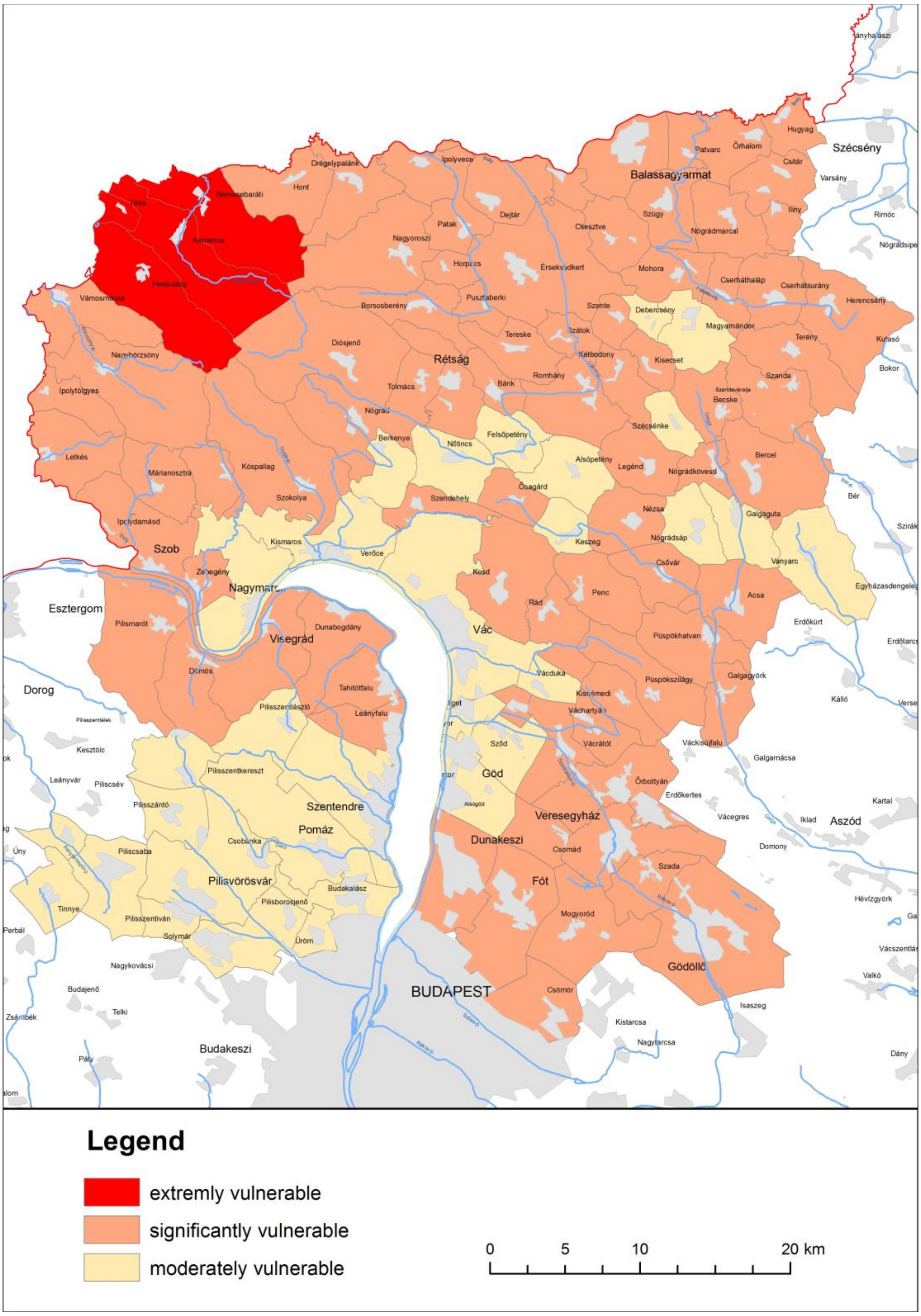

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Figure 35. Climate-vulnerability of drinking water protected areas using the RegCM modell for the period between 2021–2050

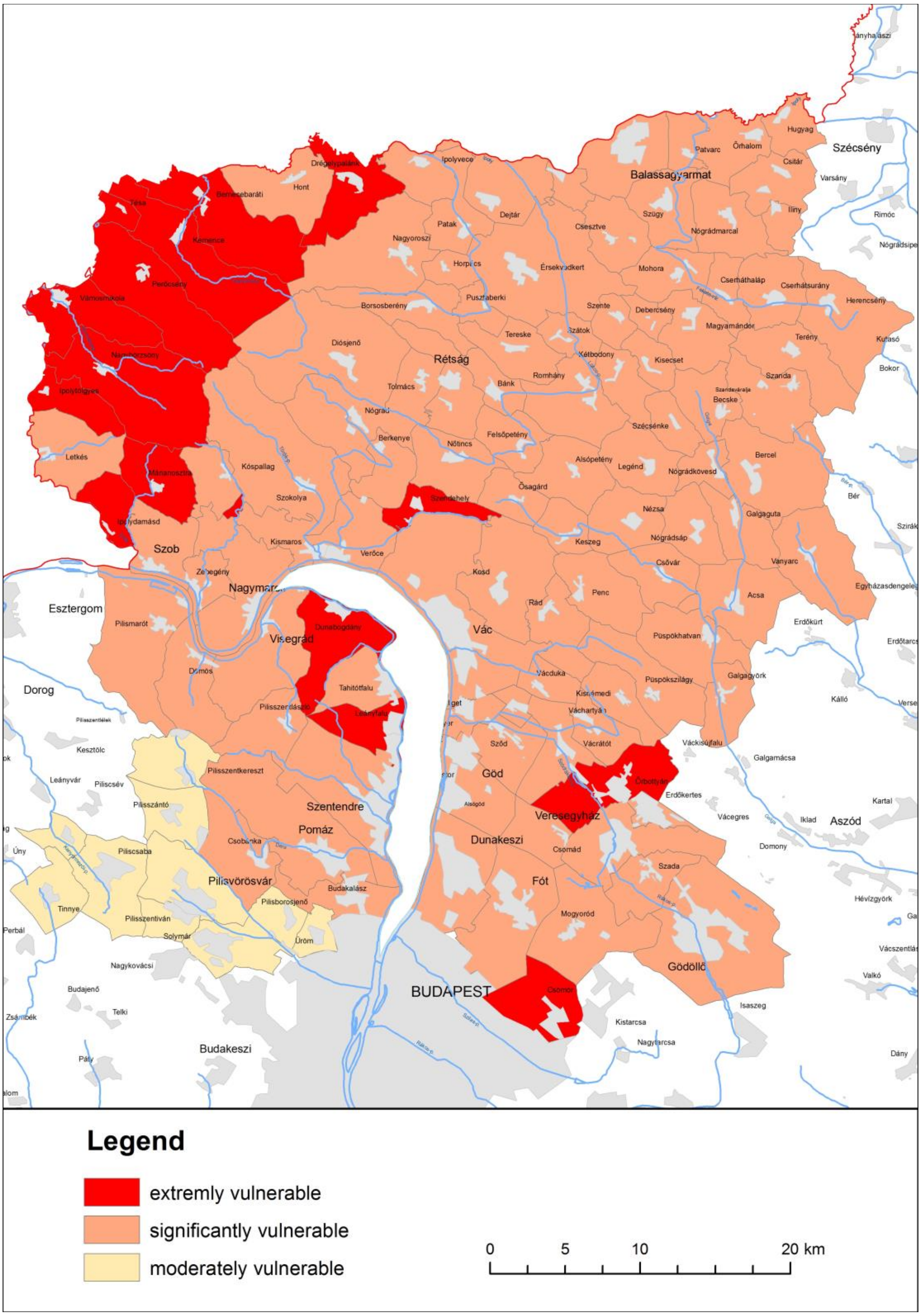

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Figure 36. Climate-vulnerability of drinking water protected areas using the ALADIN modell for the period between 2071–2100

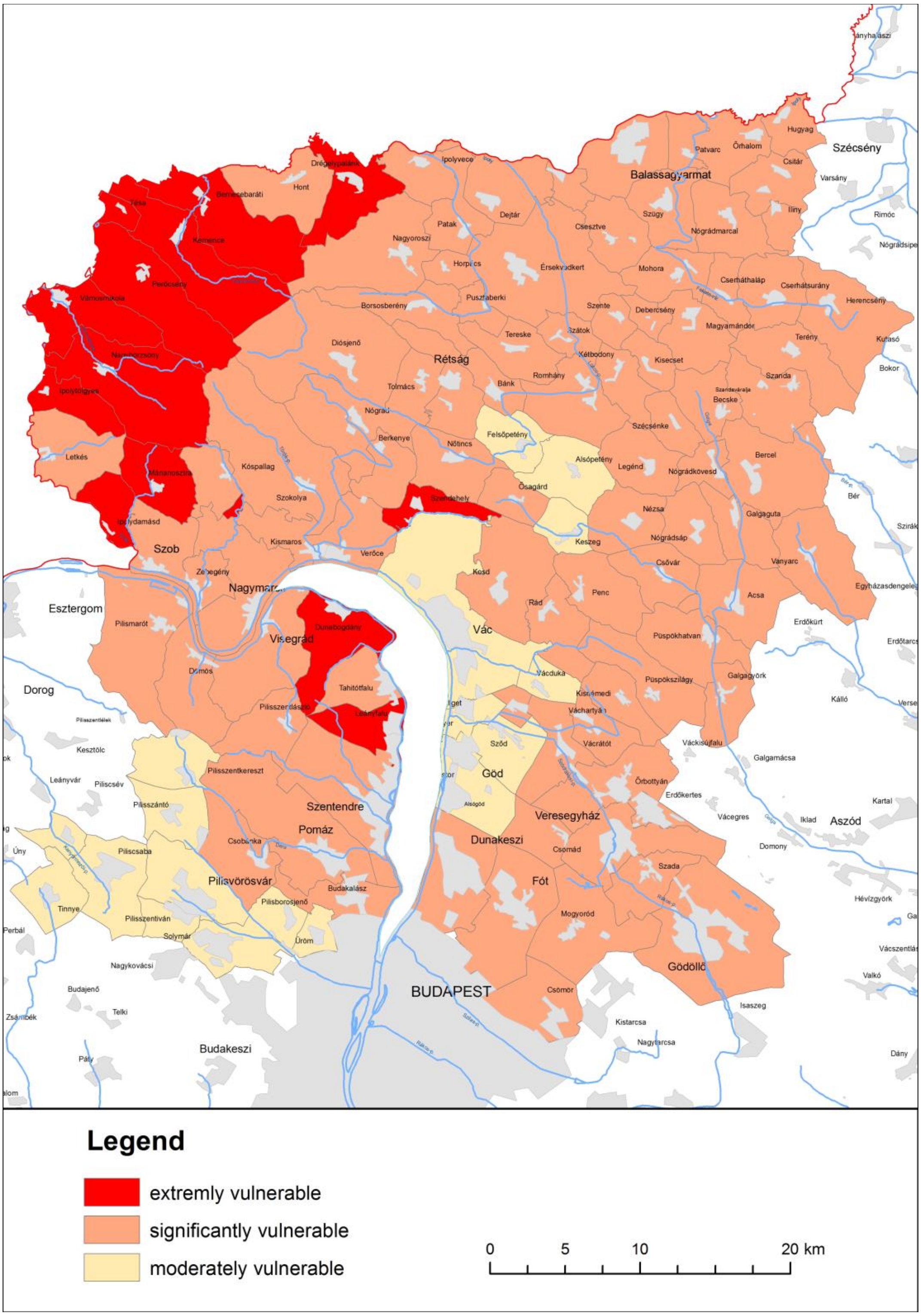

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Figure 37. Climate-vulnerability of drinking water protected areas using the RegCM modell for the period between 2071–2100

9 CONCLUSIONS, RECOMMENDATIONS

We can conclude from the result of the above investigation, that the climate exposure of the drinking water protected areas is not uniform in the different regions of the country. However, regarding the European scale it is within a relative narrow range. As a result of climate change the amount of infiltration responsible for groundwater recharge is expected to decrease. This process is somewhat balanced by changes in the annual distribution of precipitation, that is by the expected increase in the amount of winter-precipitation.

The current climatic modells are characterised by large uncertainties, therefore in future research it is important to reduce this uncertainty with the use of new, high-resolution climate modell results. In addition to the clarification of climate-exposure, further investigation is needed for the characterisation of the exposure of bank-filtration systems.

The drinking water protected areas have different climate-sensitivity due to their different geological and hydrogeological settings. In supplying drinking water, drinking water protected areas of less climate-sensitivity need to have greater role. Despite of their sensitivity to climate change, bank-filtration systems are of major importance and can be the basis of perspective water supplies, as they have great reservoir capacities and constantly renewable reserves. It is advisable to replace the karstic and shallow-porous drinking water protected areas of increased climate vulnerability by new drinking water protected areas of greater security. In case of limited possibilities, due to the geologic and hydrogeologic conditions, the importance of perspective drinking water protected areas are increased.

The status of groundwater, the effects of climate change and groundwater pressures need to be monitored on a regular basis. Similarly, it is necesssary to register water consumption, typical consumer habits and underlying social and economic factors. By the regular, periodic evaluation of these observations, the identification and characterization of changes it is possible to develope the appropriate climate adaptation measures.

In order to reduce the effects of climate change we need greater emphasis on adaptation. Regarding the supply of water, regional supply systems can provide greater security, due to the importance of groundwater governance, the trans-regional redirection of water, as applied successfully already, nowadays.

As a part of the climate adaptation strategy water consumption habits need to be changed, towards a conscious and economic water use.

The constant drinking water supply can be guaranteed by the utilisation of the drinking water reserves exclusively for drinking purposes, and the supply of other uses from different reserves, thus by the separation of the two systems.

In the regional developments we need to take into consideration the climate-vulnerability of the drinking water protected areas, as well as, the underlying social and economic factors.

The investigation of the climate-vulnerability of drinking water protected areas needs further research. It is necessary to extend the methodology of climate-vulnerability assessment to a nationwide scale, with the detailed assessment of climate exposure, climate-sensitivity, water demand and climate-adaptation by the participation of the other regional public waterworks.

It is necessary to clarify the importance of each element in the climate-vulnerability assessment.

As a result of climate change there might be changes in the chemical composition of groundwater. It is of the utmost importance to consider these changes in the bank-filtration systems and changes in the processes determining pollution propagation, as a result of climate change. These processes are expected to change according to the different climate scenarios and their detailed examintaion is needed, for preventive purposes.

10 ACKNOWLEDGEMENTS

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