

**THE IMPACT OF CLIMATE CHANGE ON THE HYDROPOWER POTENTIAL:
A CASE STUDY FROM TOPEĽA RIVER BASIN**

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The contribution presents the impact of climate change on the hydropower potential in the Topľa River basin. There are various methodological approaches for determining the impact of climate change on the hydrological regime. One of them is the assessment of the impact of climate change on the hydropower potential. Changed climatic conditions, characterized mainly by changes in precipitation, potential evapotranspiration, and air temperature in future decades were predicted by recent outputs of the KNMI and MPI regional climate change models and the A1B emission scenario. To specify changes in long-term mean monthly runoff in comparison with the reference period 1981-2010 and future time horizons, the physically based WetSpa rainfall-runoff model was used. As a basic indicator of the potential for water energy utilization, hydropower potential (HPP) was calculated. An assessment of possible adaptation strategies for water management with respect to the hydropower potential and its utilization for energy production in Slovakia was attempted. The hydropower potential of small, run-of-river and storage hydropower plants is strongly related to the distribution of runoff over the year and can therefore affect not only the total change in runoff but also changes in its distribution in the future.

KEY WORDS: hydropower potential, the WetSpa model, climate change

Introduction

The utilization of water flows is an indispensable source of energy. Hydropower plants were also one of the first power plants to produce electricity in Slovakia. The hydropower potential used in hydropower plants is one of the natural resources of every country. Particularly, they determine in particular the natural conditions and the degree of economic, technical and social development of the country concerned. Hydropower is a dominant renewable source of energy production and has received significant worldwide attention for further development (Resch et al., 2008; Liu et al., 2011; Stickler et al., 2013).

Climate change caused by rising concentrations of greenhouse gases in the atmosphere may affect the hydrological cycle and the availability of water to humans, there-by affecting agriculture, forestry and other industries.

Reduced hydropower generation has been reported to be associated with climate change (Qiu, 2010; Bahadori et al., 2013), and significant progress has been made in assessing the impacts of climate change on hydropower elsewhere in the world. For example, it was reported that a future decrease in climate-change-induced runoff would reduce energy generation and revenues of hydropower plants under current regulations in

the Columbia River and California hydropower systems in the United States (Hamlet et al., 2010; Vicuña et al., 2011). Considerable impact of climate change on hydropower was reported in the Swiss and Italian Alps regions, but the impacts varied for different locations, hydropower systems, and projections of climate change (Maran et al., 2014). Most studies suggested that new adaptive management may mitigate projected losses of hydropower in the Alps regions (Majone et al., 2016).

Few studies perform a broad analysis of climate change impacts on the energy system, from the effects on climate parameters (e.g. temperature and precipitation) to the resulting technological structure, inherent financial costs and GHG emissions. Climate change impacts on natural resources, and also on hydropower, are often analysed through climate and hydrological models (whose character is eminently biophysical) and/or electrical grid models (Tarroja et al., 2016; Van Vliet et al., 2016). Economic impacts of climate change on the energy sector are mainly assessed through bottom-up technological models that rely on techno-economic data, but disregard the biophysical component. An exception is the study from Seljom et al. (2011) that use ten climate experiments and a bottom-up energy model to analyse the impacts of climate change on energy demand and supply, considering the effects on hydro- and wind power potential for Norway by 2050. They find that climate

change will increase precipitation and hydropower potential.

In Slovakia, few researches deal with different hydrologically - distributed models, which have been used to simulate runoff processes under climate change conditions. Good examples of such models include: WetSpa (Valent et al. 2016; Rončák et al., 2016; 2017). This article builds on previously published papers and uses several older outputs of global and regional models, climate change scenarios, and various conceptual or distributed hydrological models in Slovakia (see, e.g., Štefunková et al. 2013; Hlavčová et al., 2015).

This study presents a model-based approach for analysing the possible effects of climate change on hydropower potential at a basin scale. By comparing current conditions of climate and water use with future scenarios, an overview is provided of today's potential for hydropower potential and its and long-term prospects.

Material and methods

Study area

The Topľa is a river in eastern Slovakia which is the right tributary of the Ondava River. It rises in the Čergov mountain under Minčol peak. The Topľa catchment (1062.24 km²) is situated in eastern Slovakia (Fig. 1). The catchment is in a flysch mountain area of Nízke Beskydy on Slovakia's border with Poland; it is characterised by numerous springs, bogs and streams. Prolonged rainfall has a great influence on the runoff regime, especially during the growing season and periods of melting snow. The climate is warm and moderately humid with cool winters. The potential natural vegetation

is characterized by submontane beech forests in the north, while the lowlands are covered by Carpathian oak-hornbeam forests (Maglocký, 2002).

The climate change scenarios

The KNMI and MPI regional climate change models (with A1B emission scenario) were used for this research. They were downscaled for the territory of Slovakia in a daily time step. These regional circulation models (RCMs) belong to newest category of so-called coupled atmosphere-ocean models with more than 10 atmospheric levels and 20 oceanic depths of model equations and the integration of variables in a network of grid points. The KNMI and MPI models represent a more detailed integration of the atmospheric and oceanic dynamic equations with a grid point resolution of about 25x25 km, while the boundary conditions are taken from the outputs of ECHAM5 global model. The KNMI and MPI RCMs have 19x10 grid points (190) in Slovakia and its surroundings with a detailed topography and an appropriate expression of all topographic elements larger than 25 km. Scenarios for the variables have mainly been prepared: the daily means, maximum and minimum of the air temperature, the daily means of the relative air humidity, daily precipitation total, daily means of the wind speed, and daily totals of the global radiation. (Hlavčová et al., 2016).

The latest climate change scenarios for the territory of Slovakia were processed on the basis of outputs from climatic atmospheric models at the Department of Astronomy, Earth Physics and Meteorology at the Faculty of Mathematics, Physics and Informatics of Comenius University (Lapin et al., 2012).

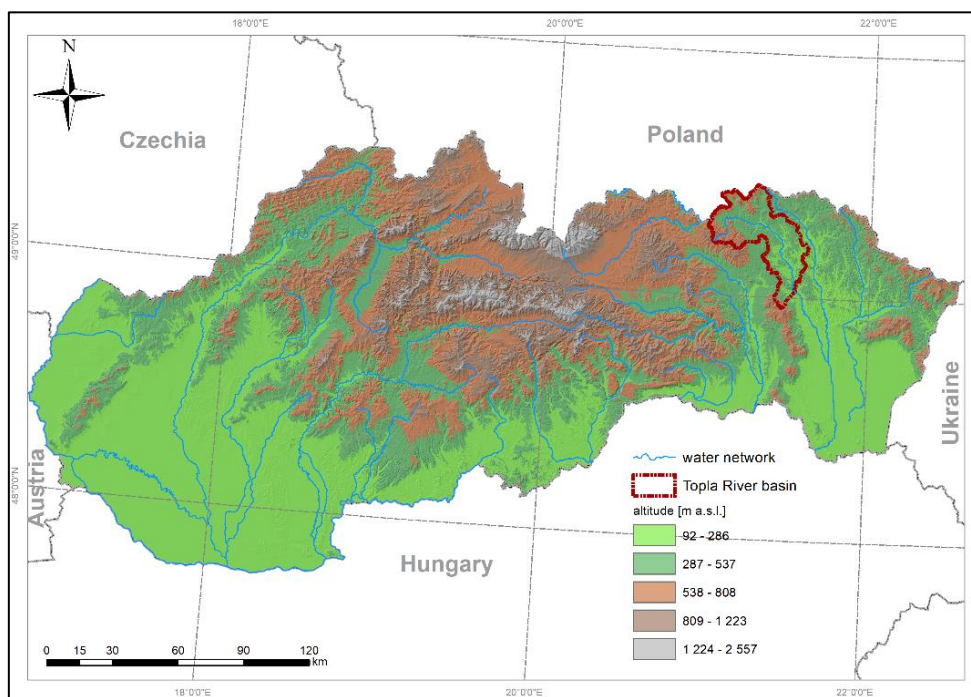


Fig. 1. Location of the Topľa River basin.

Table 1 shows a comparison of the long-term mean monthly air temperature in °C between the period 1951–1980 and the climate change scenarios (KNMI and MPI) in the period 2071–2100 for all of Slovakia. We can observe an increase in the average air temperature in the winter months by 3°C and in the summer season by 4°C in the future horizon.

Figure 2 shows the differences in the long-term mean monthly values of the air temperature in the Topľa River basin in

the 2071–2100 horizon. The air temperature has a rising trend. The mean monthly air temperature will rise, without any exception, in the river basin at about the same rate.

Table 2 presents the long-term mean monthly values of the precipitation for the 1981–2010 reference period in the selected river basins and the changes in their values for three future time horizons till 2100 according to the KNMI and MPI regional climate change scenarios.

Table 1. Long-term mean monthly values of the air temperature [°C] during the period 1951–1980 and for the future time horizon of 2071–2100 in Slovakia

Scenario	horizon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	1951–1980	-3.8	-1.8	2.2	7.7	12.5	16.1	17.5	16.8	13	8	3	-1.5
KNMI [°C]	2071–2100	-0.6	1.6	4.9	9.8	15.6	20	21.7	20.6	15.9	11.4	6.4	2.3
MPI [°C]		-0.1	2.2	4.6	9.5	15	19.5	20.8	20.8	16.6	11.6	6.7	2.4

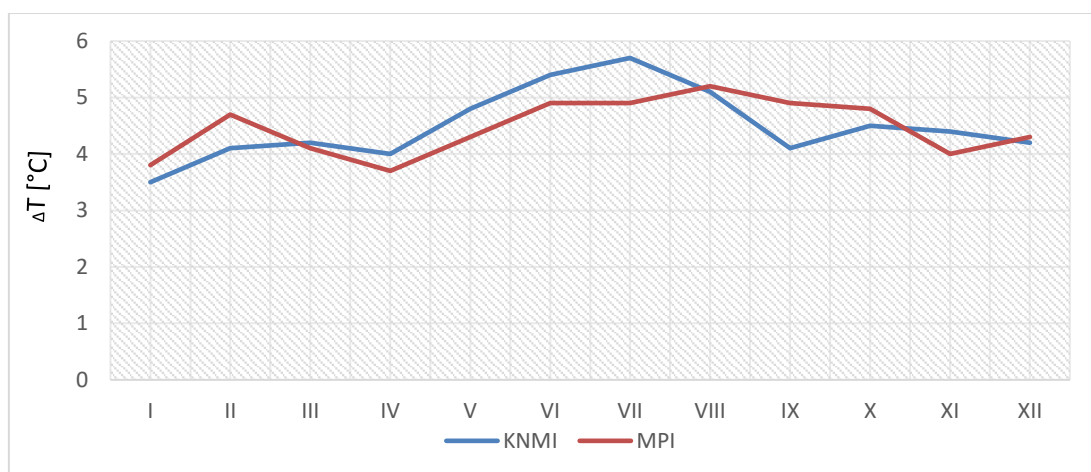


Fig. 2. Differences in the long-term mean monthly values of the air temperature in the Topľa River basin in the 2071–2100 horizon.

Table 2. Long-term mean monthly values of the areal mean monthly precipitation of the reference period (1981–2010) and the changes in their values in [%] for the future time horizons of 30 years from 2010–2100 in the Topľa River basin

precipitation [mm]		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
	1981–2010	35.8	33.8	33.5	51.7	84.1	96.4	96.1	74.9	64.1	44.1	38.1	43	
Topľa	KNMI [%]	2010–2040	-8.4	-0.7	-4.4	-7.8	-6	6.1	-3.5	-0.5	27.9	1.7	2.4	3.1
		2041–2070	-1	-0.2	4.6	12.4	-6	2.5	-9	-6.1	14.7	10.4	-2	15.3
		2071–2100	7.3	11.5	11.4	7.9	-13.4	-25.6	-19.6	0.9	50.8	10.9	4.6	17.8
Topľa	MPI [%]	2010–2040	-1.3	9.2	-2.1	-5.6	-1.2	12.7	-4.9	12.9	6.9	1.4	1.3	1.3
		2041–2070	4.7	0.2	11.4	12.9	-8.6	10.3	-0.3	10.7	16.1	13.1	-2.1	10.2
		2071–2100	13.3	10.2	12.6	10.8	-2.1	-15.9	-19.7	5.6	12.5	9.5	4.9	8.2

According to the individual climatic models as seen in Table 2 and Fig. 3, a decrease in the mean monthly precipitation in the summer period can be expected. On the other hand, the winter period should be more humid in comparison with the current conditions.

Both the KNMI and MPI scenarios gave similar seasonality change prognoses. They predict a general increase in precipitation amounts, with the highest precipitation amounts from September to winter period and less precipitation from May to July. The air temperature should increase, mainly during the winter period, and this could result in less snow accumulation and increased winter snow-melt runoff. While the onset or dry periods should be more frequent, with low precipitation, low runoff and less water storage, the most pronounced seasonality change is expected to be evapotranspiration.

The rainfall-runoff model

The WetSpa model simulates runoff and river flow in a watershed on a daily time step (Wang et al., 1996; Bahremand and De Smedt, 2006). Availability of spatially distributed data sets (digital elevation model, landuse, soil and radar-based precipitation data) coupled with GIS technology enables the WetSpa to perform spatially distributed calculations. The hydrological processes considered in the model are precipitation, interception, depression storage, surface runoff, infiltration, evapotranspiration, percolation, interflow and ground water drainage. The total water balance for each raster cell is composed of a separate water balance for the vegetated, bare-soil, open water, and impervious part of each cell. The model predicts discharges in any location of the channel network and the spatial distribution of hydrological characteristics (Safari et al., 2012).

Input data in a daily step in the period between January 1981 and December 2010 was used in this study. The following hydro-meteorological data were used in the model: daily precipitation totals from spot measurements at 15 stations and the average daily values for the air temperature at 4 climatological stations. The flow data consisted of the average daily flows at the Topľa – Hanušovce nad Topľou profile.

'Gross' hydropower potential calculation

The 'gross' hydropower potential is analysed, in order to outline the general distribution and trends in hydropower capabilities. According to Eurelectric (1997), the 'gross' hydropower potential is defined as the annual energy that is potentially available if all natural runoff at all locations were to be harnessed down to the sea level (or to the border line of a country) without any energy losses. The share of this highly theoretical value that has been or could be developed under current technology, regardless of economic and other restrictions, forms the 'technical' hydropower potential.

The gross hydropower potential can be directly calculated from water availability and elevation data. The analysis of climate and global change impacts on the gross hydropower potential can provide an overall indication of regional trends, but does not allow for immediate conclusions on changes in the actual hydroelectricity production of a country. For example, a decrease of discharges in a region where only few hydropower plants exist may not significantly alter the overall hydroelectricity supply. A more realistic interpretation of changes in future hydropower production within the existing hydropower park is provided by the developed hydropower potential, i.e. the part of the gross potential which is or will be utilized through power plants. However, the latter approach

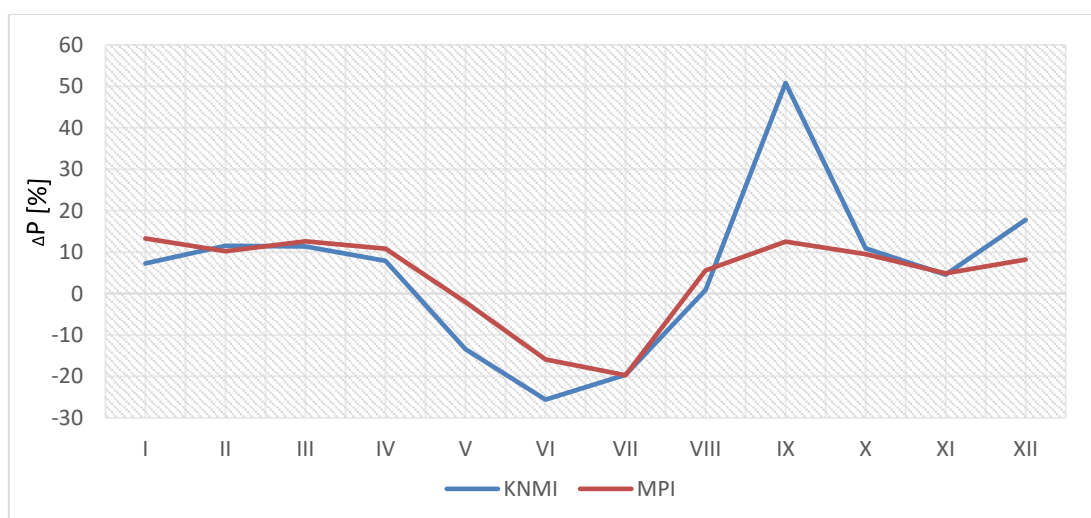


Fig. 3. Differences in the long-term mean monthly values of the precipitation in the Topľa River basin in the 2071–2100 horizon.

requires the reliable identification of plant locations and their installed capacities (Lehner et al., 2005).

For purposes of this study, the ‘gross’ hydropower potential of selected river basis has been calculated based on the relation for theoretical hydraulic power P_i of a river reach (between two profiles)

$$P_i = P_{1-2} = 9,81 \cdot \frac{(Q_1 + Q_2)}{2} \cdot (H_1 - H_2) \cdot \eta \quad [\text{kW}] \quad (1)$$

where

Q_1 – discharge in the upstream profile [$\text{m}^3 \text{s}^{-1}$],

Q_2 – discharge in the downstream profile [$\text{m}^3 \text{s}^{-1}$],

H_1 – altitude of the upstream profile [m a.s.l.],

H_2 – altitude of the downstream profile [m a.s.l.],

η – overall efficiency of energy transformation, $\eta = 1$ for ‘gross’ hydropower.

The ‘gross’ hydropower potential HP_i was then calculated as a theoretical value of energy in river per year

$$HP_i = \sum_{i=1}^n P_i \cdot 8760 \cdot 10^{-6} \quad [\text{GWh}] \quad (2)$$

Calculations were made for:

Q_{50} = medial discharge with 50% probability of exceedance,

Q_{95} = minimal discharge with 95% probability of exceedance.

Results and discussion

Using the parameters of the calibrated WetSpa model and the outputs from the KNMI and MPI climate scenarios, the simulation of flows in the final profile for the future time periods until the year 2100 was made. The 30-year period from 1981 to 2010 was chosen as the reference period.

Based on simulated long-term mean daily discharges, we calculated gross hydropower potential. Then, the comparison between the reference period and the climate

change scenarios was made. The outputs from the WetSpa distributed hydrological model were divided to five 15-years periods.

The future changes in runoff due to climate change were evaluated by comparing the simulated average daily flows and their statistical characteristics for the current state and the modelled scenarios; they are presented in Table 3.

From the results of the scenarios of the long-term mean monthly flows presented in the future horizons and comparing them to the reference period 1981–2010, we can state that change in the monthly discharge regime in Topľa River basin analysed could be expected. Also, the evidence of an increase in the long-term runoff can be seen; it has a linear relationship with the increase in mean precipitation in the future in this catchment.

In the Topľa River basin similar changes in future runoff can be observed, i.e., in the winter period up to a 90% increase according to the KNMI scenario, and in the summer months, e.g., August, up to a 38% decrease according to the MPI scenario in comparison to the reference period.

Changing climatic conditions may also present themselves as a persistent reduction in the potential of surface and water resources, which should also be taken into account in the planning and management of water resources in the future.

It can be seen on the Fig. 4, that the hydropower potential for medial discharge with 50% probability of exceedance slight increase. This phenomenon may be related to increase in the long-term runoff; it has a linear relationship with the increase in mean precipitation.

The opposite situation may occur at the comparison of the theoretical hydropower potential (Q_{95} minimal discharge with 95% probability of exceedance) between the reference period and the climate change scenarios (Fig. 5). The decrease of the hydropower potential can move between 25–70%. At minimum flows, climate change is likely to have negative effects.

Table 3. Simulated long-term mean monthly discharge in [$\text{m}^3 \text{s}^{-1}$] using the parameters from the 1981–1995 calibration period and their changes in [%] for the three future time horizons of 30 years from 2010–2100 in the Topľa River basin

River basin	Scenario	Horizon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Q_{annual} [$\text{m}^3 \text{s}^{-1}$]
		1981–2010 [mm]	196	259	477	413	307.3	258.1	204	151.2	138.9	129.1	147.5	177	2851.5
Topľa	KNMI [%]	2010–2040	8	16	-19	-26	-20	-13	35	21	104	79	20	13	3011.2
		2041–2070	41	46	-18	0	-5	1	-6	-9	29	82	9	23	3134.1
		2071–2100	102	69	4	1	-18	-33	-19	-31	68	93	41	82	3453.7
	MPI [%]	2010–2040	-22	17	-6	19	-7	4	12	35	36	48	14	-11	3085
		2041–2070	32	59	-6	19	9	6	-13	9	64	85	21	28	3429.1
		2071–2100	54	51	4	11	7	-32	-38	-15	-8	41	10	31	3109.6

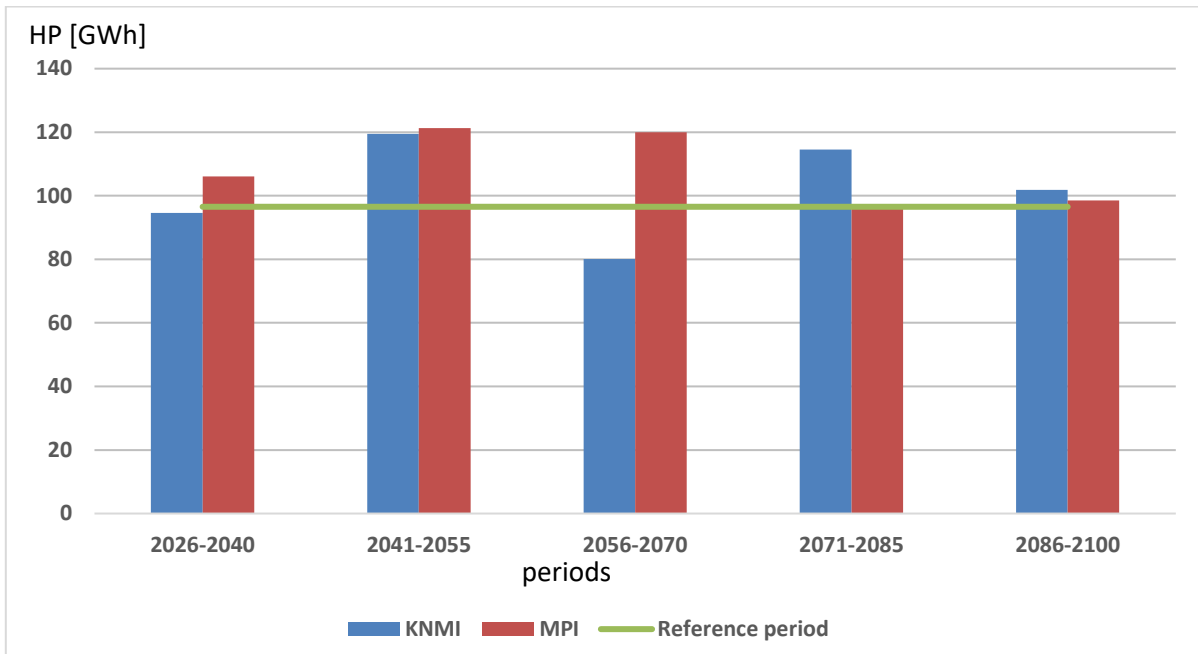


Fig. 4. Comparison of the theoretical hydropower potential (Q_{50} medial discharge with 50% probability of exceedance) between the reference period and the climate change scenarios.

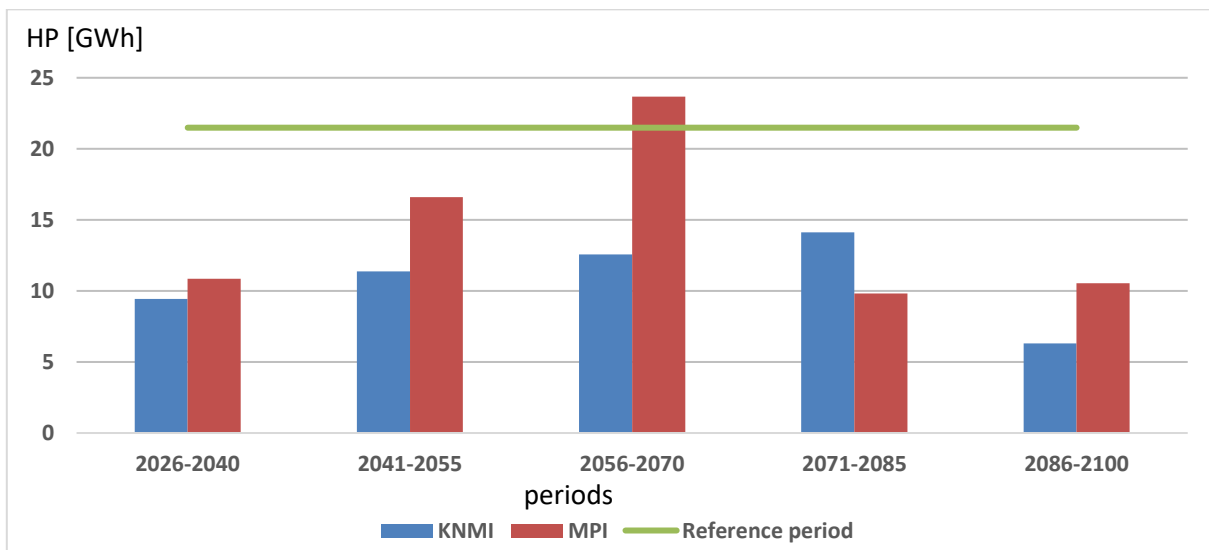


Fig. 5. Comparison of the theoretical hydropower potential (Q_{95} minimal discharge with 95% probability of exceedance) between the reference period and the climate change scenarios.

Conclusion

This paper described a concept of analysing the impacts of climate and global change on future hydropower potentials on a catchment scale. Based on the research results, changes in precipitation and discharges can be expected. The change in these characteristics is related to the development of hydropower potential. The hydropower potential of the Topľa River basin should not be

significantly affected by the impact of climate change. It needs to be mentioned that the KNMI and MPI climate change scenarios represent less extreme changes (the A1B emission scenario). The scenarios considered suggest that practically all the basins analysed could be at risk from summer or early autumn droughts. Prolonged droughts can cause significant water shortages. These dry periods may be interrupted by short episodes of extreme rainfall or severe storm activity with rainfall inducing

the formation of flash floods. According to current developments, it is likely that climate change can have a significant negative impact on local water resources with low water yields, especially in the sub-mountainous regions of the Slovak Republic. On the other hand, it is possible that the long-term mean monthly runoff will increase in the winter. This could be due to higher temperatures and earlier snowmelt in these regions. The lack of water stored as snowpack in the winter could affect the availability of water for the rest of the year. It could also cause earlier snowmelt floods. Based on the results for the five basins from the north, central and eastern parts of Slovakia, it is likely that this effect will apply to the whole territory of Slovakia.

It is generally expected that increased temperature causes stronger water evaporation from the continents and from all water surfaces, also rivers and lakes. The evaporation reduces available river water, but at the same time more evaporated water origins in more precipitation. Therefore, this effect must be investigated in particular for each water basin. Climate change will cause increased variability of precipitation events and will pose significant problems for hydroelectric generation. The increased variability of precipitation will result in more severe and frequent floods and droughts, seasonal offsets, or the altering timing and magnitude of precipitation for traditional rainy and dry seasons and peak snowmelt. Droughts reduce water availability and therefore the amount of the produced energy, but in case of a longer lasting drought (several years) not only the discharge, but also the available head for energy production could be reduced. Seasonal offset will additionally sharpen the situation, especially in case of shorter and more intense precipitation periods and longer lasting and dryer periods.

The Topľa River basin represents the north-eastern part of Slovakia. Climate change will affect hydropower potential in a more significant way in the lowland part of eastern Slovakia. The hydropower potential in this basin may not be dramatically affected by climate change.

The results of the simulation are highly dependent on the availability of the input data. The outputs of the study could be used in an adaptation strategy for integrated river basin management and especially in the organization of the river basin management process and the assessment of the impacts of changes the use of river basin on runoff.

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