Impacts of Future Climate Change on Runoff in Selected Catchments of Slovakia

Peter Rončák, Kamila Hlavčová, Silvia Kohnová and Ján Szolgay

Abstract In this study the authors looked at the impact of climate change on a hydrological regime and catchment runoff in selected catchments of Slovakia. Changed climate conditions, which are characterized in particular by changes in precipitation, air temperature, and potential evapotranspiration in future decades, have been predicted according to the outputs of the KNMI and MPI regional climate change models and the A1B emission scenario. Assuming these scenarios, the hydrological regime characteristics were simulated by a distributed WetSpa rainfall-runoff model parameterized for five selected river basins in a daily step by the year 2100. When compared to the current state, changes in the total runoff and its components, as well as changes in the soil moisture and the actual evapotranspiration, confirm the assumption of an increase in extremes of the runoff regime in the winter period and a decrease during the summer and autumn periods, causing possible droughts. The results of the study indicate a need for re-evaluation of the water demands and the future design of water management structures in Slovakia.

Keywords Climate change · Runoff regime changes · Slovakia

1 Introduction

Environmental changes (including land use changes and climate change) and their impact on water resources are topical issues in recent hydrological studies. The direct or indirect impacts of land use and climate change on a hydrological regime undoubtedly have contributed to problems such as drought and water scarcity, increasingly frequent flash floods, and damage caused by massive deforestation.

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W. Leal Filho et al. (eds.), *Climate Change Adaptation in Eastern Europe*, Climate
Change Management, https://doi.org/10.1007/978-3-030-03383-5_19

Rainfall-runoff models are often used as a tool for assessing the impacts of climate change and land use changes on the hydrological cycle. While climate change modeling can be used in specific conceptual rainfall-runoff models, models with spatially-distributed parameters are needed to simulate the effect of land use changes on runoff in a river basin.

The climate and the hydrological cycle are strongly coupled with land surface and ecosystem processes, both in the sense that modifications of the water cycle significantly affect land surface properties and the functioning of ecosystems, and because vegetation and land surface changes can significantly affect the entire hydrological cycle and the climate (McFarlane et al. 1993).

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 (Misra 2014).

Changes in the hydrological cycle may cause more floods in some areas; on the other hand, droughts can predominate in other areas, with an associated increased pressure on water supplies and irrigation systems (Blauhut et al. 2016; Freire-González et al. 2017). Therefore, it is important to be able to estimate the possible impact of climate change on water resources and develop strategies of sustainability. One of the challenges in predicting the hydrological response affected by climate change is the issue of hydrological non-stationarity (Milly et al. 2008). There are many factors that can affect hydrological stationarity. These include, for example, the response of vegetation to increased CO_2 and changes in land use and precipitation characteristics. It is therefore important to better understand the impact of non-stationarity on hydrological assessments of climate change. The possibilities of estimating or predicting the future development of river basin processes are considerably limited even though there are a number of different complex and accurate hydrological models, as well as databases of climatic, geological and hydrological data and other elements and characteristics.

Distributed hydrological models (models with spatially distributed parameters) take into account the spatial variability of atmospheric processes and the physical-geographic characteristics of river basins that control rainfall-runoff processes (Kulhavý and Kolář 2002). Physically-based and spatially-distributed hydrological models are capable of directly using geospatial information. The intense development of computer programs supports the ability to exploit the rich content of information describing the physical-geographic features of a landscape. The basis for accurate hydrological predictions is also important for access to the relevant data of rainfall and surface characteristics of a basin that transforms precipitation into runoff.

In Central Europe, many different hydrologically—distributed models have been used to simulate runoff processes under changed land use and climate conditions. Good examples of such models include: WetSpa (Valent et al. 2016; Rončák et al. 2016, 2017a, b); SWAT (Arnold et al. 1998); or MIKE SHE (Tegelhoffová 2010). 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., Hlavčová et al. 2008, 2015; Štefunková et al. 2013; Rončák et al. 2017a, b).

The aim of this study is to evaluate the possible impacts of climate change on the runoff regime in selected catchments, where the simulation of future changes in runoff processes are based on the outputs of the KNMI and MPI regional climate models (RCMs).

2 Study Area

For the modelling of runoff and hydrological characteristics, five pilot river basins were selected: the **Hron**—Banská Bystrica [1], **Turiec**—Martin [2], **Váh**—Liptovský Mikuláš [3], **Topľa**—Hanušovce nad Topľou [4], and **Laborec**—Humenné [5]. Their locations on Slovak territory is in Fig. 1. These basins represent rivers without any anthropogenic influences and have been subject to long-term observations of hydrological and climatological characteristics.

The basic spatial input data, such as the digital elevation model, land use map, and map of the soil types, were processed and provided by Esprit s.r.o. The time series of average daily flows, mean daily precipitation, and average daily air temperature data were provided by the Slovak Hydrometeorological Institute (SHMI) for the period 1981–2010 and were used as inputs for the modelling.

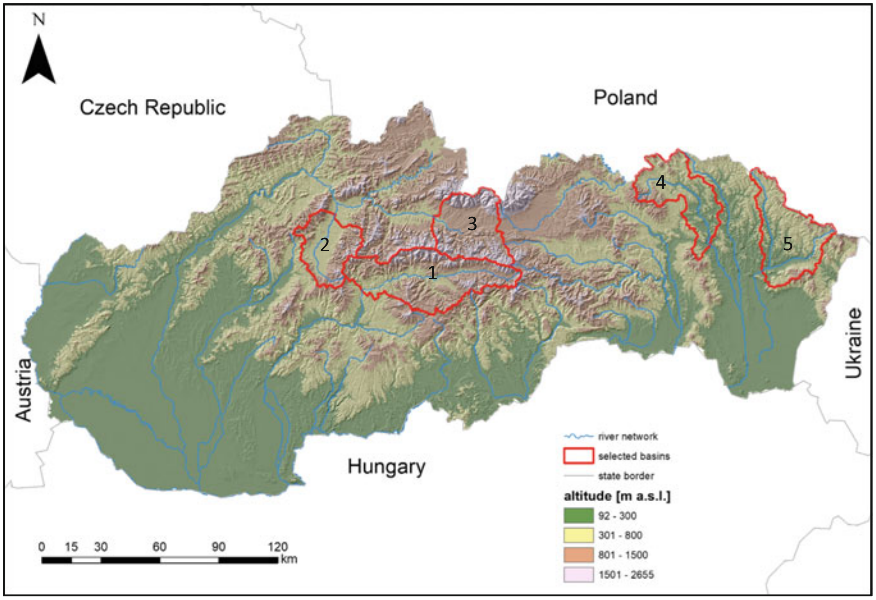

Fig. 1 The location of the selected catchments in Slovakia

3 Climate Change Scenarios

The latest climate change scenarios for the territory of Slovakia were downscaled to the selected precipitation and climate stations 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).

In this study, the KNMI and MPI regional models (Lapin et al. 2012) were used to represent a more detailed integration of the dynamic equations of atmospheric and oceanic circulation in a network of grid points at a distance of 25 × 25 km, while the boundary conditions of the solution to the equation are taken from the outputs of the global ECHAM5 model and the SRES A1B (moderate) emission scenario. The KNMI and MPI RCMs have 19 × 10 grid points (190) in Slovakia and its surroundings with a detailed topography and an appropriate expression of all the topographic elements larger than 25 km. The outputs of the scenarios of the daily temperature and precipitation were available for the period 2010–2100.

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 air temperature in the Laborec and Váh River basins in the 2071–2100 horizon. The air temperature has a rising trend in both basins. The Laborec River basin is characterized as a lowland catchment; therefore, there is a more extreme rise in the air temperature in comparison with the mountainous Váh River basin.

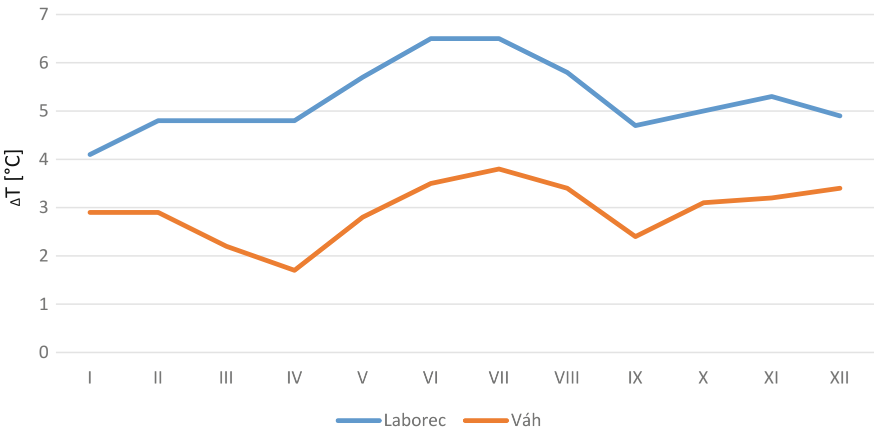

Fig. 2 Differences in the long-term mean monthly values of the air temperature in the Laborec and Váh River basins in the 2071–2100 horizon

Table 1 Long-term mean monthly values of the air temperature during the period 1951–1980 and for the future time horizon of 2071–2100 in Slovakia (Lapin et al. 2012)

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	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		−0.1	2.2	4.6	9.5	15	19.5	20.8	20.8	16.6	11.6	6.7	2.4

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 selected river basins

Precipitation [mm]			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Hron	1981–2010		48.2	45.1	53.6	56.1	94	101.3	93.7	82.2	66	59.3	67.3	62.6
	KNMI	2010–2040	–3.1	3.4	0.4	–4.2	–9.2	0.8	–11.4	3.9	34.3	–2.1	4.2	20.4
		2041–2070	5.2	8.8	11.7	16.4	–0.6	–15.7	–9.5	2.9	19.4	8.5	2.5	19.9
		2071–2100	14.1	21.8	24.9	10.3	–19.9	–32.9	–22.1	–3.1	37.7	14.6	6.8	24.1
	MPI	2010–2040	–0.7	8.8	3.4	–3.6	–8.4	19.7	9.5	–3.3	25.1	–3.9	8.5	13.1
		2041–2070	7.8	6.8	16.7	21.8	–10.5	7.8	–3.7	–8.3	16.4	7.8	1.6	17.1
		2071-2100	15.5	18.1	26.2	18.3	–14.7	0.1	–10.1	–3.8	30.3	18.6	13.9	14.8
Laborec	1981–2010		50.9	45.6	46.9	58.2	83.8	98.5	105.3	76.4	80.2	56.5	58.2	64.1
	KNMI	2010–2040	–9.1	4.9	–4.7	–9.6	–14.8	9	–6.5	–0.4	23	4.9	8.1	9.3
		2041–2070	–0.2	5.4	7.9	11.8	–8.4	8.9	–15.3	–9.7	17.2	13	0	17.1
		2071–2100	9.5	14.1	13.7	5.3	–10.6	–25.3	–19.3	0.3	41.6	10	10.3	16.8
	MPI	2010–2040	–2.6	9.7	–5.7	–4.8	–9.8	–3.3	–10.7	2.8	18.8	4.5	4.7	7.5
		2041–2070	5.8	–0.3	11.2	16.1	–11.8	5.3	–7.3	–1.4	9.9	13.6	–6.6	22
		2071–2100	11.4	9.2	18.9	19.1	–11	–18.1	–29.4	–12.3	16.5	13	7.5	11.7
Topľa	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
	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
	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
Turiec	1981–2010		60.3	51.3	60.2	57.7	92.3	95.5	100.2	87.4	76.2	62.5	69.5	67.4
	KNMI	2010–2040	–3.1	0.2	–4.5	–8.5	–13.4	–4.4	–23.4	–3.9	30.1	–6.3	–1	21.9
		2041–2070	2.1	3.7	9.1	12.9	–4.1	–13.4	–21.4	0.4	14	6.2	–0.5	24.8
		2071–2100	16.5	14.4	23.7	7.8	–20.1	–33.2	–32.9	–5.5	30.1	9.5	5.8	28.6
	MPI	2010–2040	–0.5	7.1	–0.9	–5.6	–14.9	16.3	–0.2	–10.4	22.1	–7.4	1.6	11.1
		2041–2070	2.5	3.7	13.4	19.1	–13.3	9.3	–12	-10.9	13.1	4.3	–7.1	19
		2071–2100	12.7	11.8	22.5	14.1	–17	0.8	–19.5	–10.8	22.6	12.7	4.8	11.6
Váh	1981–2010		47.8	42.7	53.8	54.3	93.5	96	106.2	85.2	69.8	59.3	61.1	55.6
	KNMI	2010–2040	–3.5	0.5	–2.6	–5.5	–12	3	–16.8	5.4	33.4	–3.4	2.8	19.3
		2041–2070	3.9	4.5	8.2	13.6	–5	–12.6	–16.3	2.9	16.6	6.2	0.7	21.9
		2071–2100	13.6	16.6	21.3	8	–22.4	–30.4	–30.8	–3.7	37.3	10.9	3.3	25.7
	MPI	2010–2040	1.2	4.8	–1.7	–2.8	–11.8	17.9	6	–2.9	20	–4.9	5.1	13.2
		2041–2070	8.9	3.3	12.2	20	–14	9.9	–3.6	–5.9	13.4	8.2	–0.6	20
		2071–2100	17.2	13.7	18.8	15.1	–16.3	–2.8	–14.5	–3.9	23	14.1	10.3	17.2

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.

According to the individual climatic models as seen in Table 2, 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. The mean monthly air temperature will rise, without any exception, in the individual river basins at about the same rate. The mean monthly air temperatures will increase with the increasing time horizons.

4 The WetSpa Rainfall-Runoff Model

For simulations of runoff and other components of a hydrological balance under changed conditions, the Water and Energy Transfer between Soil, Plants and Atmosphere (WetSpa) distributed rainfall-runoff model was used. The model uses geospatially referenced data as the input for deriving the model's parameters, which include most data types supported by ArcGIS, such as coverage, shape files, grids and ASCII files. An image can be used for a reference within a view, but is not used directly by the model. The three base maps used in the model are digital maps of the topography, land use and soil types, while other digital data are optional, depending upon the data available and the purpose and accuracy requirements of the project (Wang et al. 1996).

The WetSpa model simulates runoff and river flow in a watershed in a daily time step. The availability of spatially—distributed data sets (a digital elevation model, land use, 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 groundwater 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 parts of each cell, see Fig. 3. The model predicts discharges in any location of the channel network and the spatial distribution of hydrological characteristics.

Digital maps of the topography, land use and soil types are the three base maps used in the model. Daily precipitation totals and the average daily values for the air temperature from spot measurements were used as hydro-meteorological data in the model too. The Thiessen polygon method was used for the interpolation of the rainfall data. The flow data consisted of the average daily flows at the outlet profile.

The use of rainfall-runoff models comes with a few problems which are predominantly linked with the vast simplification of an otherwise complex system of runoff creation, the quality of the input data or the model´s calibration, and the finding of the optimal set of parameters. Therefore, calibration of the parameters is one of the most important parts of hydrological modelling. The calibration of the model requires the identification of a set of parameters which will provide the best possible agreement between the measured and simulated parameters of the hydrological model in accordance with the selected criteria. Various agreement criteria were used during the calibration of the models for expressing any differences between the observed and

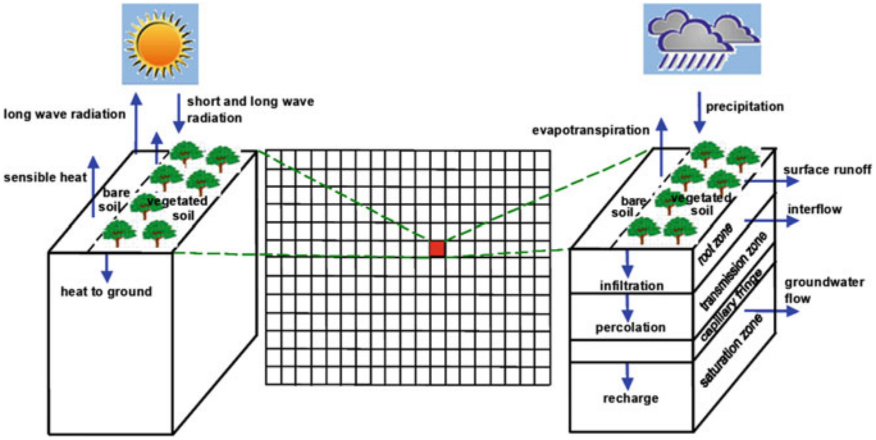

Fig. 3 WetSpa model structure

modelled data. The calibration period was from 1981–1995. Twelve parameters for which a range of admissible values were set were optimized. The Nash—Sutcliffe coefficient was chosen as the dominant criterion in this work.

5 Impacts of Climate Change on a Runoff Regime

Using the parameters of the calibrated WetSpa model and the outputs from the KNMI and MPI climate scenarios, the simulation of flows in the selected basins outlets 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.

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 all the catchments 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 these catchments. The Hron River basin will manifest an increase in average monthly discharges, especially during the autumn and winter months. This will be valid for both scenarios and all the horizons (except for the horizon 2025 in the MPI climate scenario). According to the KNMI scenario, the runoff may achieve a 100% increase in January and February in the last horizon. This could be due to higher temperatures and earlier snowmelt in this region. But we can see that due to climate change, the runoff will react in the opposite way in the summer period. According

Table 3 Simulated long-term mean monthly runoff in [mm] 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 selected river basins

River basins	Scenario	Horizon	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Q annual [mm]
Hron	1981–2010 [mm]		26.7	26.3	54.0	71.7	50.2	38.9	29.3	24.0	21.5	25.3	31.6	29.6	429
	KNMI [%]	2010–2040	27	56	2	−11	−7	−19	−2	0	42	39	11	26	462
		2041–2070	77	90	20	0	3	−12	−26	−7	16	41	4	52	501
		2071–2100	104	112	36	1	−23	−38	−40	−40	2	32	28	86	501
	MPI [%]	2010–2040	−22	−5	−2	27	31	27	43	19	53	42	12	−4	508
		2041–2070	67	95	14	1	−5	−5	−14	−26	−10	14	4	38	479
		2071–2100	65	81	24	28	5	−8	−14	−30	1	69	39	62	537
Laborec	1981–2010 [mm]		30.0	34.9	57.0	50.2	31.6	22.6	21.7	13.7	16.8	19.5	26.3	30.7	355
	KNMI [%]	2010–2040	14	24	−15	−27	−26	−13	13	12	60	48	15	17	367
		2041–2070	42	42	−11	−13	−9	30	−17	−14	36	39	−13	28	386
		2071–2100	63	49	−2	−13	−19	−24	−24	−27	36	28	15	52	394
	MPI [%]	2010–2040	−10	11	−10	9	−7	−18	−21	14	41	49	7	−3	362
		2041–2070	30	46	−4	3	0	−1	−22	−8	14	50	−16	11	384
		2071–2100	45	33	−3	7	−1	−32	−45	−41	−29	13	0	22	363
Topľa	1981–2010 [mm]		16.0	21.1	38.8	33.6	25.0	21.0	16.6	12.3	11.3	10.5	12.0	14.4	232
	KNMI [%]	2010-2040	8	16	−19	−26	−20	−13	35	21	104	79	20	13	245
		2041-2070	41	46	−18	0	−5	1	−6	−9	29	82	9	23	255
		2071-2100	102	69	4	1	−18	−33	−19	−31	68	93	41	82	281
	MPI [%]	2010–2040	−22	17	−6	19	−7	4	12	35	36	48	14	−11	251
		2041–2070	32	59	−6	19	9	6	−13	9	64	85	21	28	279
		2071–2100	54	51	4	11	7	−32	−38	−15	−8	41	10	31	253
Turiec	1981–2010 [mm]		29.4	31.0	62.2	77.3	49.9	34.9	27.7	23.1	26.4	27.2	30.3	28.5	448
	KNMI [%]	2010–2040	40	66	1	−34	−32	−37	−27	−36	−4	8	−4	33	419
		2041–2070	80	84	4	−24	−19	−26	−40	−30	−23	8	−9	51	452
		2071–2100	105	98	18	−18	−33	−44	−56	−59	−36	−5	7	78	458
	MPI [%]	2010–2040	−11	34	−1	−8	−12	−9	3	−18	6	12	−1	2	441
		2041–2070	44	75	2	−11	−12	−9	−23	−37	−27	−1	−11	24	449
		2071–2100	75	71	8	−12	−21	−25	−32	−46	−35	19	11	52	462
Váh	1981–2010 [mm]		16.3	14.7	32.8	76.4	84.1	53.6	40.6	32.8	29.7	30.3	28.7	20.7	461
	KNMI [%]	2010–2040	43	69	28	−13	−17	−16	−10	−7	36	31	5	24	474
		2041–2070	165	241	76	−28	−54	−50	−56	−38	−20	8	2	96	435
		2071–2100	155	195	84	−2	−36	−47	−48	−50	−7	17	22	101	479
	MPI [%]	2010–2040	−7	11	2	−8	8	15	21	−3	26	15	1	−4	489
		2041–2070	49	113	31	3	3	2	−6	−22	-4	15	4	30	502
		2071–2100	97	147	56	4	−10	−22	−30	−36	−15	34	30	69	504

to the KNMI scenario, the monthly flow will gradually decrease by 2% up to 40% in the months of May to August. A similar situation may be expected under the MPI climate scenario; the only difference can be seen in the horizon of 2025, where there would be an increase in the runoff compared to the reference period. In the autumn term an increase in runoff in both scenarios may be expected when compared with the values of the runoff in the reference period with the current climate conditions.

The eastern part of Slovakia is represented by the Laborec—Humenné and Topl̆a —Hanušovce river basins. A similar feature for both basins is a decrease in runoff from March to August. The maximum increases in monthly runoff are in the winter months of December and January in the Laborec River basin; i.e., according to the KNMI scenario, up to 63%, and according to the MPI, up to 45%. For the vegetation period a decrease in discharges can be expected for both basins, i.e., in the Laborec River basin to −45%. In the Topla River basin similar changes in future runoff can be observed, i.e., in the winter period up to a 100% 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.

We can see the decreasing runoff in the Turiec River basin starting from the spring (April) to the late summer (August) from i.e., −45 to −60% for the KNMI. The MPI scenario also presents a decrease but a little bit lower, i.e. (−18 to −46%), which is the highest decrease for the 2071–2100 scenario. Similar to the other basins, an increase in runoff from December to March can be seen; the highest is in January from 40 to 105% in comparison to the reference period.

The northern part of central Slovakia is represented by the Váh River basin (Table 3) with its outlet at the Liptovský Mikuláš stream gauging station. For this river basin, the maximum increases in the long-term mean monthly runoff may mainly occur in February (according to the KNMI scenario for the 2071–2100 horizon; the increase will be up to 200%). A decline in the long-term average monthly runoff may be expected in the months of April to September.

The scenarios considered suggest that practically all the simulated basins could be at risk from summer or autumn droughts. Based on the simulated catchments in this study, it is likely that this effect will also apply to the whole territory of Slovakia. On the other hand, it is possible that the runoff will increase in the winter. A lack of water stored as snowpack in the winter could affect the availability of water for the rest of the year. In the summer months rising demands for water for irrigation, household and industrial use can be observed.

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.

From the results presented, we can conclude for the whole territory of Slovakia that 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 July to September 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.

Climate models indicate a change in the distribution of atmospheric precipitation on earth and a change in the frequency and intensity of extreme weather events. According to the climate change models described in the Seventh National Report on Climate Change, the total rainfall in Slovakia will be about 10% lower than now; the utilizable water resources will decrease by 30–50% over the horizon of 2075–2100 in Slovakia. It is assumed that there will be a much more uneven distribution of precipitation totals over the year and in the individual regions of Slovakia. This will also be in line with the evolution of the runoff regime in Slovakia.

Dry periods could be interrupted by heavy rainfall or strong storms with intense precipitation, while the number of days with storms compared to the current amount (15–30 in the summer) should not change, but very strong storms are likely to be up to 50% more.

There is a visible moderate linear increase in long-term annual precipitation in Slovakia. The runoff coefficient is calculated as the ratio between runoff and precipitation depths, and this highlights a decreasing trend. While the long-term runoff coefficient value approximates the 32.3% value established for 1961–2000, this decreased to 29.8% for 1981–2015 and 27.9% between 2001 and 2015. The decreasing runoff depth coefficient value is an explicit consequence of greater losses in the hydrological balance caused by increased evapotranspiration from rising air temperatures (Fendeková et al. 2018).

6 Adaptation Measures

Adaptation measures in the water sector in Slovakia could be divided into two parts (7th NC SK 2017). The first is the elimination consequences of droughts, e.g., a decrease in the flow rates and water yields, and the second is to minimize the impact of floods, especially flash floods in mountainous areas. It is necessary to prepare and implement proper adaptation measures to eliminate the adverse impacts of climate change. A lot of attention is paid to water resources and their protection and efficient use in all sectors. Water is becoming a critical strategic resource in our country. This resource has to be protected and its effective and efficient use managed to ensure its sustainable use and sustainable development in general. Adaptation to climate change in the area of water management should therefore be focused on the implementation of measures for better management of runoff in individual catchments.

To complete the system of water reservoirs for the purpose of water supply and public drinking, flood protection and water for agriculture and industry, should be carried out: the following main strategies (7th NC SK 2017)

- Continuing with the flood protection system of selected river basins in high flood risk areas, such as levees, polders, etc.

- Revitalization of structures and the gradual implementation of hydromelioration measures in forestry and agriculture to increase flood protection, especially in headwaters.

The following additional measures are suggested on the national level for adaptations to climate change in accordance with the Water Plan of the Slovak Republic:

- Re-evaluate the safety of water structures according to the actual estimations of design maximum discharges
- Review future water needs in all sectors.
- Assess water abstractions for the water supply, electrical generation, and the augmentation of minimum flows.
- Develop a methodology for drought assessments.
- Re-evaluate droughts and their impact on the ecological status of water bodies.
- Support and increase research on the impacts of climate change.

7 Conclusion

The aim of this study was to detect the impact of climate change on flood regimes in selected catchments of Slovakia. An evaluation of the scenarios of the long-term mean discharges and comparing them with the reference period of 1981–2010 shows that changes in the long-term mean monthly flows can be expected in the future. These changes may be reflected differently, depending on the land use and climate scenarios.

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.

The results of the simulation are highly dependent on the availability of the input data, the parameterization of the land uses, the different types of vegetation in the model, and the schematization of the simulated processes; therefore, they need to be interpreted with a sufficient degree of caution and confronted with other results from the literature and experimental measurements. 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 and the size of erosion-accumulation processes.

Acknowledgements This work was supported by the Slovak Research and Development Agency under Contract Nos. APVV-15-0497, APVV 15-0425 and VEGA Grant No. 1/0891/17.

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