Impact of climate change on runoff and development of forest composition in the coming decades in a selected river basin in Slovakia

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Keywords: forest composition — climate change — hydrological modelling

SUMMARY

In this study, the authors dealt with the impact of climate change on the hydrological regime and runoff in a selected river basin in Slovakia. The research also aimed to estimate changes in forest communities during climate change to runoff processes in the river basin. Two scenarios of change of land use with forest communities and two global climate change scenarios were used. Land use change scenarios were created for the entire territory of the Slovak Republic at the Technical University in Zvolen. Outputs from the Koninklijk Nederlands Meteorologisch Instituut (KNMI) and Max-Planck-Institut (MPI) regional climate change models – both with the A1B emission scenario – were also used for this research. Assuming these scenarios, the characteristics of the hydrological regime were simulated by the distributed WetSpa rainfall-runoff model. Based on the research results, it can be estimated that the air temperature will increase, especially in winter, which could result in less snow accumulation and increased runoff in the basin. The Hron river basin will manifest itself in an increase in mean monthly flows, especially during the autumn and winter months. This may be due to higher temperatures and earlier snowmelt in the area. However, we see that due to climate change, runoff will react in the opposite way in the summer. Compared to the current situation, we assume that there will be an increase in the extremes of the runoff regime in the winter and a decrease in the summer and autumn. Climate models suggest a change in the distribution of atmospheric precipitation, which may result in an increase in floods, droughts, and other extreme weather events.

INTRODUCTION

Environmental change (including land use change and climate change) and its impact on water resources are current topics in recent scientific studies [1–3]. The direct or indirect effects of land use and climate change on the hydrological regime have undoubtedly contributed to issues such as drought and water scarcity, increasing flash floods, and damage caused by massive deforestation.

Rainfall-runoff models are often used as a tool to assess the effects of climate change and land use change on the hydrological cycle. While the outputs of climate change models can be used in conceptual rainfall-runoff models, models with spatially disaggregated parameters are needed to simulate the impact of land use change on runoff in a river basin.

Climate change caused by rising concentrations of greenhouse gases in the atmosphere may affect the hydrological cycle and the development of forest composition. The expected increase in greenhouse gases means a change in the minimum and maximum values of air temperature, potential evapotranspiration, and the amount of total precipitation [4].

In Central Europe, many different hydrological models have been used to simulate runoff processes in changing conditions of land use and climate change, such as the WetSpa model [5–7]; SWAT [8]; MIKE SHE [9, 10]; TUW [11]. This article builds on already published articles [7, 12] and also uses outputs from global and regional models, climate change scenarios, and various conceptual or distributed hydrological models in Slovakia [7, 12–15].

The aim of this paper is to evaluate the impact of climate change and land use change on the runoff regime in a selected river basin, where the simulation of future changes in runoff processes is based on outputs from regional climate models (RCMs) KNMI and MPI. For the purpose of this research, the Hron river basin was selected as a pilot river basin.

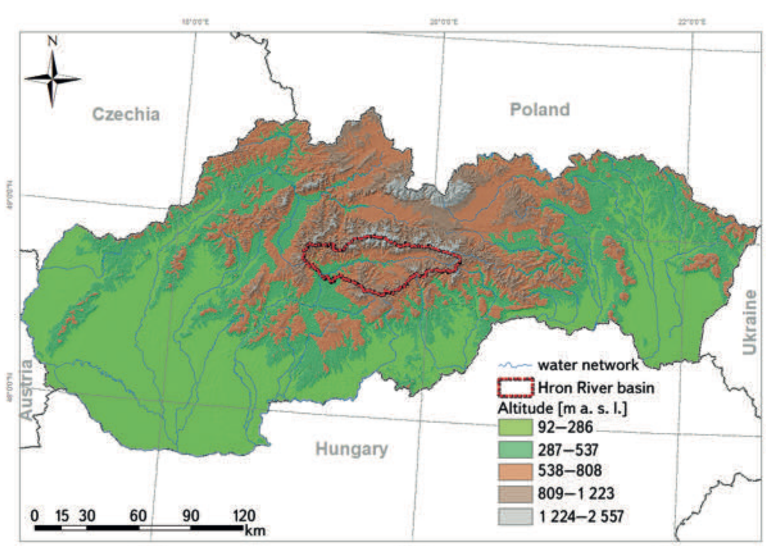

Fig. 1. Location of the Upper Hron river basin in Slovakia

Photo: 123RF.com

AREA OF INTEREST

The Hron is a left tributary of the Danube, with its basin located in central Slovakia. The basin stretches along a long main river with numerous shorter tributaries. The upper part of the river basin, with the final profile in the Banská Bystrica gauging station, was selected for this study as a representative river basin for mountain regions in Slovakia. The basin has an area of 1,775 km^2, the minimum altitude of the basin is 332 m a.s.l., the maximum altitude is 2,042 m a.s.l.,, and the average altitude is 842 m a.s.l., The location of the Upper Hron basin is shown in *Fig. 1.*

The Upper Hron basin is located in a cool, humid to very humid climate area; the average annual air temperature is between 4 °C and 5 °C. July is the warmest month, with the average monthly air temperature oscillating between 14 °C and 16° C. January, on the other hand, is the coldest month; the average monthly temperature ranges from -4 °C to -6° C. The Upper Hron basin shows a relatively well-preserved natural runoff regime.

MATERIAL AND METHODS

Land use change and climate change scenarios

Land use scenarios were created for the entire territory of the Slovak Republic by the Technical University in Zvolen and published in Atlas krajiny SR [16]. Subsequently, they were modified and categorized by ArcGIS for the needs of the WetSpa rainfall-runoff model. Land use scenarios (changes in forest composition) for the 2075 time horizon were created based on the assumption of climate change according to global circulation models (GCM) and incremental models created within the NCP (National Climate Programme).

In the case of climate change scenarios, outputs from general atmospheric circulation models, the Dutch KNMI and the German MPI were used (both with the A1B emission scenario). The KNMI and MPI regional models represent a more detailed integration of the dynamic equations of atmospheric and oceanic circulation in a network of nodal points at a distance of 25 x 25 km, while taking the boundary conditions for solving the equations from the outputs of the ECHAM5 global model. In Slovakia, the KNMI and MPI models have up to 19 x 10 nodal points (190 in total) and quite realistic orography with a good expression of all mountains with a horizontal dimension greater than 25 km. Selected regional models have daily values of several climatological elements in their outputs from 1951, with prediction until 2100. These models and their outputs were selected based on a detailed analysis of 20 different models, of which 15 were RCMs and 5 GCMs.

RCM outputs characterizing climate change for the coming decades have been divided into 30-year time horizons (2011–2040, 2041–2070, 2071–2100), wherein horizons 2025, 2055, and 2085 represent the midpoints of these periods.

Rainfall-runoff model

The WetSpa model is a rainfall-runoff model that simulates both flow and inputs in a river basin, in this case in a daily time step [17]. The availability of a spatially distributed data set (digital relief model, soil types, and land use) in conjunction with GIS allows the WetSpa model to perform spatially distributed calculations. In this study, daily step input data from 1981–2010 were used. The following hydrometeorological data were used in the model: daily precipitation totals from point measurements at 15 stations and average daily air temperature values from 5 climatological stations. Hydrological data consisted of mean daily flows in the final profile Hron-Banská Bystrica.

In this case, the calibration period ranges between 1981–1995. The aim of the WetSpa rainfall-runoff model was to determine global parameters for

Tab. 1. Long-term mean monthly values of an areal air temperature and precipitation of the reference period (1981–2010) and the changes in their values [in °C, mm] for the future time horizons of 30 years from 2010–2100 in the Hron river basin

Temperature [°C]			**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
	1981–2010		**−4.1**	**−3.1**	**0.5**	**5.9**	**11.1**	**14**	**16**	**15.4**	**11**	**6.4**	**1.1**	**−3.1**
Hron	KNMI	2025	0	0.8	1	0.4	0.9	0.9	0.9	0.9	0.9	1.6	0.5	0.1
		2055	1.3	2.6	1.4	1	1.6	2	1.9	1.9	1.5	2	1.5	1.8
		2085	2.8	2.8	2.3	1.7	2.7	3.5	3.7	3.3	2.4	3	3.1	3.4
	MPI	2025	0.1	0.8	0.4	0.1	0.6	0.7	0.6	1	0.9	1.5	0.9	0.3
		2055	1.9	2.9	1.3	0.7	1.3	1.3	1.5	2.2	1.7	1.9	1.9	1.6
		2085	3.3	3.4	2	1.4	2.1	2.9	2.8	3.5	3.2	3.2	3.3	3.4
Precipitation [mm]			**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
	1981–2010		**48.2**	**45.1**	**53.6**	**56.1**	**94**	**101.3**	**93.7**	**82.2**	**66**	**59.3**	**67.3**	**62.6**
Hron	KNMI	2025	−3.1	3.4	0.4	−4.2	−9.2	0.8	−11.4	3.9	34.3	−2.1	4.2	20.4
		2055	5.2	8.8	11.7	16.4	−0.6	−15.7	−9.5	2.9	19.4	8.5	2.5	19.9
		2085	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	2025	−0.7	8.8	3.4	−3.6	−8.4	19.7	9.5	−3.3	25.1	−3.9	8.5	13.1
		2055	7.8	6.8	16.7	21.8	−10.5	7.8	−3.7	−8.3	16.4	7.8	1.6	17.1
		2085	15.5	18.1	26.2	18.3	−14.7	0.1	−10.1	−3.8	30.3	18.6	13.9	14.8

the model for each selected river basin; by using these, the best agreement between the measured and simulated mean daily flows in the final river basin profile will be achieved. The model uses 12 global parameters that need to be calibrated. The chosen coefficient in this work (Nash-Sutcliffe [18]) as an optimization criterion is especially suitable for minimizing differences in mean values and overall balance.

RESULTS

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

On the current land use map *(Fig. 2)*, arable land accounts for 6 % and grassland for 24 % of the total river basin. Three forest types occupy the following percentage of the total area: coniferous (36 %), deciduous (17 %), and mixed forest (13 %). Other land use categories occupy only low to negligible percentages. Coniferous forest occupied the largest area of the basin. In the first scenario of land use change, deciduous forest (36 %) and mixed forest (17 %) dominate. Compared to the current state, the area of deciduous forest increased, but the total forest area decreased compared to the current state. This change in forest composition may have the effect of increasing evapotranspiration and runoff; in contrast, the proportion of interception, i.e. the ability to retain water in the river basin, will decrease. In the second scenario, the area of deciduous forest reaches only 9 %, while the area of mixed forest increased to 44 %. Thus, certain differences in forest composition can be seen between the scenarios and the current situation. Deciduous forest area should increase, while coniferous forest should move to higher altitudes, mainly due to global warming.

From the results of climate scenarios, we can say that we can expect a change in the mean monthly runoff in the analysed Hron river basin. We can also see a connection with the increase in long-term runoff, which has a linear relationship with the increase in average precipitation in the coming decades. In the Hron river basin, there will be an increase in the mean monthly runoff values, especially during the autumn and winter months. This will apply to both scenarios and all time horizons (except horizon 2025 in the MPI climate scenario). According to the KNMI scenario *(Fig. 3)*, the runoff in January and February in the last horizon may reach a 100 % increase. The reason may be the higher average daily air temperature and the associated earlier snowmelt in this area. On the other hand, it is obvious that due to climate change, runoff will react in an opposite way in the summer. According to the KNMI scenario, monthly runoff will gradually decrease by 2 % to 40 % from May to August. A similar situation can be expected in the MPI climate scenario *(Fig. 4)*; the difference can only be seen in the 2025 horizon, where the runoff would increase compared to the reference period. In the autumn, an increase in the runoff in both scenarios can be expected compared to the runoff values in the reference period.

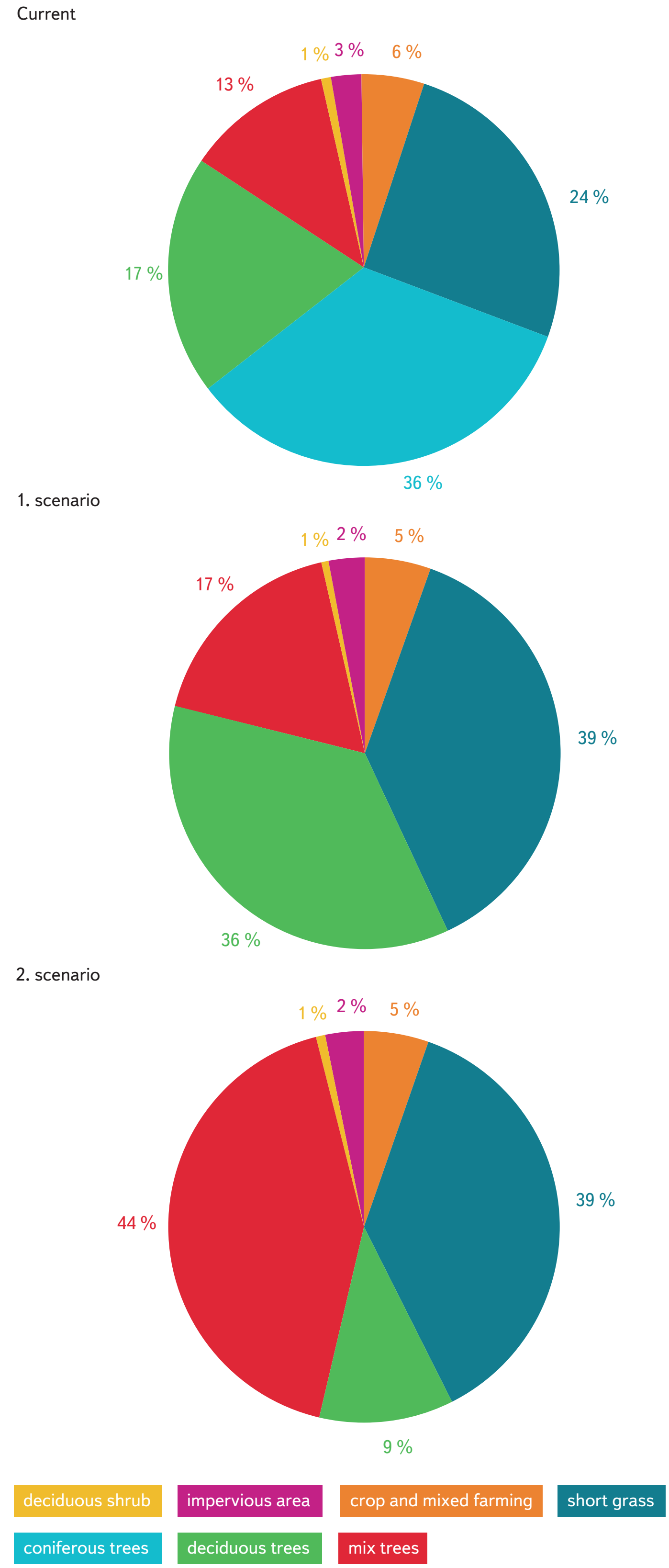

Fig.2. Current land use and land use change scenarios in the Hron river basin

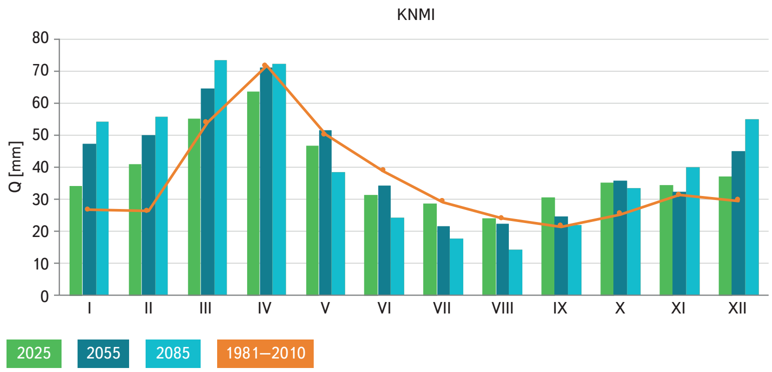

Fig. 3. Comparison of the long-term mean monthly runoff between the KNMI climate change scenario and the reference period

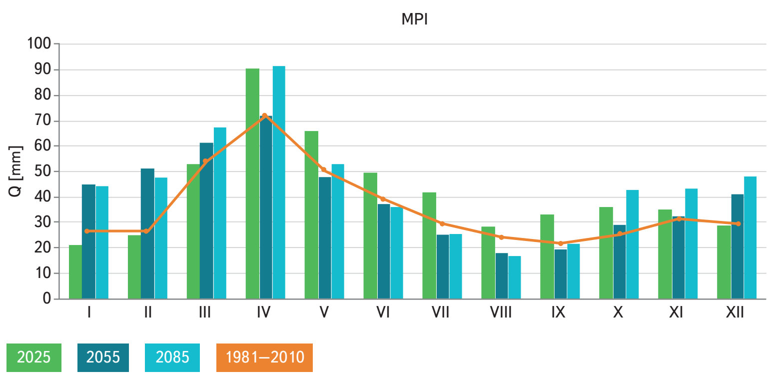

Fig. 4. Comparison of the long-term mean monthly runoff between the MPI climate change scenario and the and the reference period

DISCUSSION AND CONCLUSION

From the presented results, it can be concluded that the climate scenarios KNMI and MPI give similar forecasts in the coming decades. They predict a general increase in total precipitation, expecting higher precipitation from September to April and lower from May to August. Air temperature should increase, especially in the winter, which could result in less snow accumulation and increased runoff from the basin in the winter months, while droughts could be more frequent, characterized by low rainfall and low runoff. Evapotranspiration is expected to be most significantly affected by climate change. Drought periods may be interrupted by heavy rainfall or storms with heavy rainfall, with the number of stormy days not changing compared to the current amount (15–30 days in summer); however, the incidence of extreme rainfall events will be higher.

Climate models indicate a change in the distribution of atmospheric precipitation, a change in the frequency and intensity of extreme weather events. A much more uneven distribution of total precipitation during the year is expected, as well as in individual regions of Slovakia. The development in the distribution of atmospheric precipitation will closely correspond to the development of the runoff regime in Slovakia.

Following the similarly published works mentioned in the introduction, it can be said that the results correspond to these publications. Various river basins in Slovakia were investigated in the mentioned articles. The trend of the impact of climate change and land use change on runoff processes is obvious. Based on the results of the modelled Hron river basin and the results in the cited publications, it is probable that the magnitude of the impact of climate change and land use change will also apply to the rest of Slovakia.

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

ACKNOWLEDGEMENTS

This paper was supported by EIG JC2019-074 "Soil Eco-Technology to Recover Water Storage in disturbed Forests" project and "VEGA 2/0155/21" project.

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This paper has been peer-reviewed.

DOI: 10.46555/VTEI.2022.03.001