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Analysis of changes in monthly and m-daily maximum discharges using the MPI and KNMI climate scenarios in the Myjava and Hron river basins in Slovakia

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The paper is focused on an evaluation of changes in average monthly discharges and selected characteristics of maximum discharges (m-daily maximum discharges and the occurrence of maximum discharges) in the selected gauging station of Myjava in the Jablonica profile (5022) and the Hron gauging station in the Banská Bystrica profile (7160). The Indicators of Hydrological Alteration (IHA) software analyzed the data modelled using the MPI and the KNMI climate scenarios. The researched time period from 1981 to 2100 was divided into 4 thirty-year periods, i.e., 1981–2010, 2011–2040, 2041–2070, and 2071–2100. The paper aims to evaluate the changes in monthly discharges and m-daily maximum discharges in the future as well as to determine the suitability of the simulated scenario, which describes the results from the observed data. The results showed that droughts will continue to occur in the summer months and that the winter months will be accompanied by higher total precipitation in the future.

KEY WORDS: Myjava River, Hron River, IHA program, hydrological regime

Introduction

As a result of global climate change induced by increased greenhouse gas concentrations, temperatures are expected to rise; precipitation trends will evolve; and the frequency of extreme occurrences is likely to increase. Flooding and droughts may cause considerable economic, social, and environmental damage as well as injuries and fatalities, which call for the use of reliable and accurate water supply systems (Booij, 2005).

Floods are an inherent and natural component of river geosystems, but they can also result in severe effects in urbanized landscapes. In Europe, and especially in Slovakia, the intensity and frequency of precipitation events capable of triggering excessive runoff and floods have increased dramatically in recent years (Pišút, 2011). Flooding can cause substantial damage or disruption to commodities, services, human health, and crops. Despite massive investments in flood-control infrastructures such as levees and dams, flood losses have remained significant over the years (Kozlowski, 1984).

Many kinds of flood analyses have treated events in a hydrological time series as a set of variable time-order numerical values until relatively recently. The approaches for modifying, modelling, and predicting flood values that have been created and refined over time have become more sophisticated (Hirschboeck, 1988).

The management of flows and the fragmentation of major global river systems are attracting notice. Riverine flow variability is acknowledged as a driving force of biotic and abiotic conditions (Zhou et al., 2020). Hydrological changes and their effects on ecosystems are critical to the long-term development of water resources. Analyzing current regime changes is an important step that necessitates the use of suitable indicators (Yang et al., 2017).

River ecosystems are organized and defined by their natural flow regimes. Physical processes, particularly the movement of water and sediment inside a channel and between the channel and a floodplain, establish the physical structure of an environment and, as a consequence, of the habitats in rivers. The quantity and heterogeneity of sediments, the shapes of channels and floodplains, and other geomorphic characteristics all contribute to a river´s physical environment. As a result, the habitat conditions of channels and floodplains differ for each river, depending on the flow parameters and the kind and the presence of moving materials. Different habitat characteristics are produced and maintained by a wide variety of flows within a river (Zeiringer et al., 2018).

For establishing the parameters of environmental flows, a lot of methods have been devised; each has its own set of advantages and disadvantages, as well as requiring varying levels of work. Some of these methodologies use a wide range of scientific skills along with complex software models and tools (Mathews and Richter, 2007). Historical tools may be used to address the issue of how

many hydrological alterations are too excessive for river systems. Historical approaches may concentrate on specific aspects of an ecosystem, including aquatic biology or riparian functions, instead of an overall system (Swanson, 2002). A streamflow regime is fundamental for stabilizing biodiversity and ecological integrity. Extreme occurrences such as floods and droughts are the most serious dangers to rivers caused by climate change (Lopéz-Ballesteros et al., 2020).
According to the Nature Conservancy (TNC, 2009), large floods have the following impacts on an ecosystem: a new phase in the life cycle can be a trigger (insects); they allow fish to survive and reproduce in a floodplain, as well as offer a nursery habitat for young fish; they ensure new food sources for fish and waterfowl; they create diversity in types of floodplain forests through long-term flooding (various plant species have varying levels of tolerance); plant distribution and abundance in a floodplain can be controlled, etc.
The identification of long-term changes in a hydrological regime was dealt with by Pekárová et al. (2016), who studied spatial and temporal changes in the magnitude, duration, and frequency of high flows in the Danube River basin. Pramuk et al. (2016) dealt with the analysis of long-term changes in flows in selected Slovak rivers that do not have large reservoirs (e.g., the Váh, Belá, Kysuca, Nitra, Hron, Topľa, Ipeľ and Krupinica rivers). This work focused on the average annual flows and the analysis of changes in the rising and falling rate of flow waves. Halmová et al. (2011) focused on an evaluation of changes in the minimum daily flows at selected stations on the Danube River. Other authors have also dealt with the indicators of hydrologic alteration issue, i.e., Byung-Sik et al. (2011) and Bing et al. (2012).
The aim of the paper is to identify long-term changes in the hydrological regime in the selected Slovak rivers (the Myjava and Hron) using the MPI and KNMI climate scenarios models until 2100. We focused on changes in the characteristics of average monthly discharges and selected characteristics of the maximum discharges (m-daily maximum discharges and the occurrence of maximum discharges). The first part of the paper reviews the literature relating to the problem. The second part deals with a description of the IHA program, the selection of sub-basins, the input data, and the methodology. The third part consists of the resulting values of the monthly discharges and characteristics of maximum discharges.

Material and methods

Study site

The research area of the study is the Myjava River basin in the Jablonica profile (5022) and the Hron River basin in the Banská Bystrica profile (7160) (Fig. 1).
The Myjava River is a left-hand tributary of the Morava River that flows through western Slovakia and a small portion of the Czech Republic. The Myjava River is 79 km long and has an area of 806 km^2. It rises near the Moravian settlement of Nová Lehota in the White Carpathians, but soon crosses the Czech-Slovak boundaries and flows south until it reaches the town of Myjava, where it enters the Myjava Hills and turns west. It comes into the Záhorie Lowlands at Sobotište and goes south until it reaches the village of Jablonica; it then swings northwest until it reaches Senica, when it turns west, passes through Šaštín-Stráže and finally empties into the Morava River near Kúty.
The Hron River springs in the Horehronie at an altitude of approximately 980 m.a.s.l. It is the second-longest Slovak river with a length of 289 km; the catchment area is 5 465 km^2. It is mostly a torrential river with a rapid increase in runoff along with the flow´s longitudinal profile.

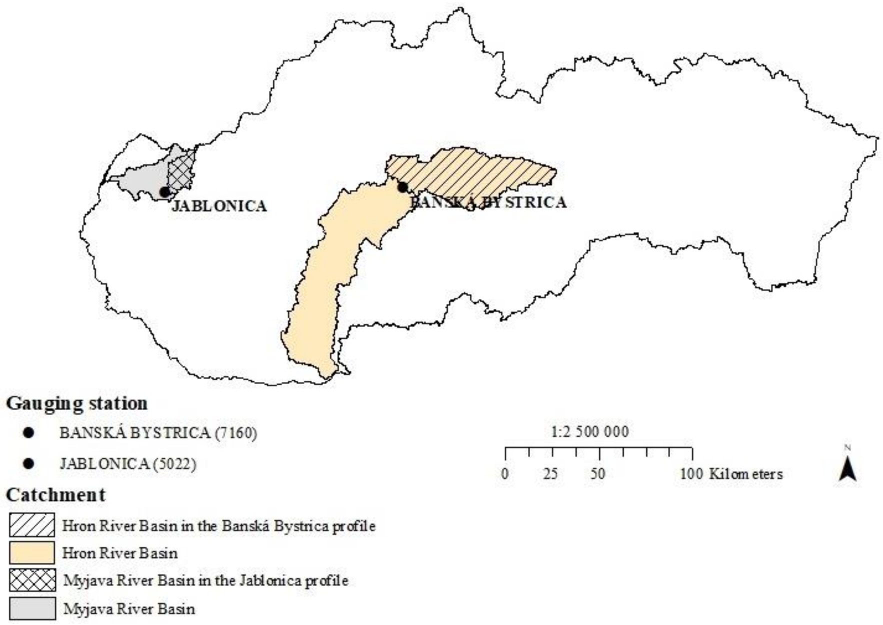

Fig. 1. Location of the Myjava and Hron River basins in Slovakia.

The selection of the river basins was based on the availability of data, their location in Slovakia, and the rate of streamflow of the river. The Hron River has higher flow rates than the Myjava River, especially in the winter and spring months, when the watercourse is affected by heavy rainfall in the form of snow or ice. There is an increased incidence of ice floods on the Hron River.

Methodology and input data

The Indicators of Hydrologic Alteration (IHA) software was created by Brian Richter and colleagues between 1996 and 1998. It contains important information for anyone attempting to comprehend the hydrological impacts of human activities or make environmental references to watercourses. The IHA software is mostly used to examine how human activity has changed rivers, lakes, and river basins over time and analyzes scenarios for future water management (Hersh and Maidment, 2006).

To compare the features of natural and changed hydrological modes, the IHA software version 7.1.0.10 is employed. The program can accept many forms of daily hydrological data (e.g., water levels, groundwater levels, discharges). The ability to summarize long series of daily hydrological data into useable and significant hydrological parameters is a significant advantage of using this application (Pramuk et al., 2016). It is based on hydrological data within an ecosystem or data derived by a model (Yang, 2008).

A total of 67 parameters of the IHA program are split into two groups, i.e., 33 IHA parameters and 34 Environmental Flow Component (EFC) parameters. These hydrological indicators were identified for their ecological significance and capacity to represent human-induced changes in flow regimes along with a wide variety of factors, such as water retraction, dam operations, groundwater pumping, and landscape modifications (Gao et al., 2009).

The 33 IHA criteria are separated into five categories:

- the volume of monthly discharges,
- the magnitude of extremes (3-, 7-, 30-, and 90-day minimum and maximum flows; the base flow index (BFI), the number of days with zero discharges),
- yearly extremes and their timing (days of occurrences of extremes),
- high and low pulse frequencies and durations (a day is defined as a pulse if the value of a discharge is more significant or lower than the present threshold),
- changes in the flow rate and frequency (based on changes in the sequential daily discharges) (Halmová et al., 2011).

The five categories of the IHA EFC parameters are extreme low flows, low flows, high flow pulses, small floods, and large floods (Hersh and Maidment, 2006):

- ***Low flows*** - In most rivers, this is the most common flow state. A river´s low-flow levels are maintained by groundwater discharges, which have a significant impact on the quantity and diversity of species that may exist in the river;
- ***Extreme low flows*** – During droughts, water levels decrease to critical levels, which can be stressful for many species but maybe inevitable for others (TNC, 2009);
- ***High-flow pulses*** – These situations occur, for example, when heavy rains or snowmelt causes rising water to surpass low flow levels but not the banks of rivers;
- ***Small floods*** – This value accounts for all rises in the water level during a main overflow, but excludes extreme floods (Halmová et al., 2011);
- ***Large floods*** – Large floods usually reorganize a river´s biological and physical structure, including its floodplain. These extreme floods flush out many life forms, reducing certain populations while simultaneously providing new competitive advantages for other species. Large floods may also have a role in the formation of critical ecosystems, such as oxbow lakes and floodplain wetlands (TNC, 2009).

The National Research Council of the National Academy of Sciences in USA (The National Research Council, 2005) developed a conceptual model to classify the natural flow regime into four components (Fig. 2):

- ***Subsistence flow:*** during extreme drought situations, the minimum streamflow required to maintain acceptable water quality and allow a minimal aquatic habitat space for the survival of aquatic species is known as subsistence flow.
- ***Base flow***: the normal discharge conditions observed in a river between storms in the base flow, and it provides enough habitats for varied, native aquatic species while also maintaining groundwater levels to sustain riparian vegetation.
- ***High flow pulses***: are of short duration, but are high discharges inside a stream channel that occur during or shortly after a storm event discharges fine sediment deposits and waste products; they restore the normal water quality after continuous low flows and offer longitudinal connections for the migration of species throughout the river.
- ***Overbank flows***: are rare, high-flow occurrences that cause riverbanks to be destroyed. Overbank flows can reshape channels and floodplains, restore groundwater tables, provide nutrients to riparian plants, and connect channels to floodplain ecosystems that provide extra food for aquatic species (Hersh and Maidment, 2006).

In this study, the input data consists of average daily discharge data observed (OBS) from the 1981–2010 period. The observed data were provided by the Slovak Hydrometeorological Institute. We also modelled the average daily discharge data using the MPI and the KNMI scenarios in the time period of 1981–2100. The methodological approach of the non-parametric statistical processing of the daily series of flows

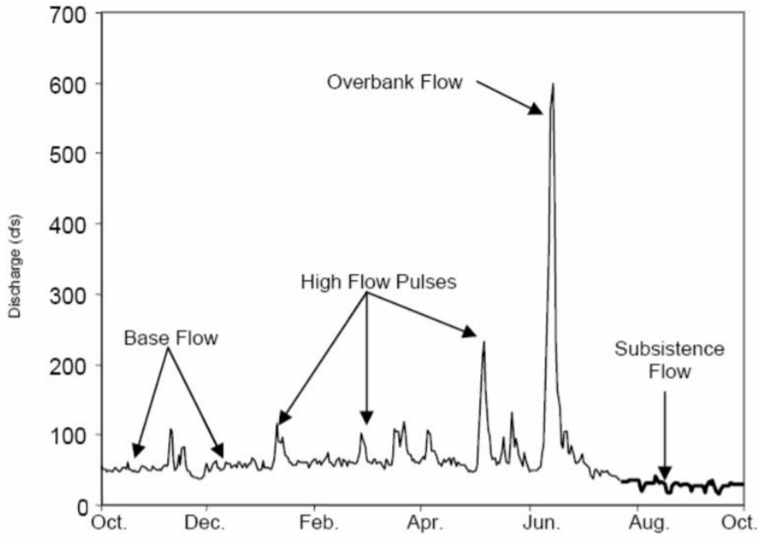

Fig. 2. Example of a daily streamflow hydrograph depicting flow components (Hersh and Maidment, 2006).

Table 1. Selected time periods used in the study

	Data	Time period
First period	OBS, MODEL, MPI and KNMI	1.1.1981 – 31.10.2010
Second period	MPI and KNMI	1.11.2010 – 31.10.2040
Third period	MPI and KNMI	1.11.2040 – 31.10.2070
Fourth period	MPI and KNMI	1.11.2070 – 31.10.2100

measured at the gauging stations in the Hron River and Myjava River sub-basins was used. The hydrological characteristics of the daily discharges were calculated for four periods, i.e., 1981–2010, 2011–2040, 2041–2070, and 2071–2100, which we can see in Table 1. We used modelled data (MODEL) in the first period to a comparison with both climate scenarios. To model the average daily discharges, the HBV rainfall-runoff model was used (Výleta et al., 2020).

The hypothetical climate scenarios used in this study are the Dutch KNMI (with the A1B emission scenario) and the German MPI (with the A1B emission scenario). These regional circulation models use the ECHAM5 global model´s outputs as the boundary terms for solving equations. Both models are linked, i.e., they are atmosphere-ocean cycle models with gas emissions and aerosol effects on changes in radiative forcing (Rončák and Šurda, 2019).

In Slovakia, the MPI and the KNMI regional climate models have 19x10 grid points with a precise topography and a suitable representation of all the topographic features greater than 25 km. The daily means, the maximum and lowest air temperatures, the daily means of the relative air humidity, the total daily precipitation, the daily wind speed means, and the daily totals of the global radiation are among the variables for which scenarios have been developed (Rončák et al., 2021).

Results

First, we focused on an analysis of the changes in monthly discharges in both gauging stations selected. We looked at the resulting discharge values from several points of view:

a) A comparison of the simulated monthly discharges using the MPI scenario and modelled data (MODEL) in the first time period (1981–2010),
b) A comparison of the simulated monthly discharges using the KNMI scenario and modelled data (MODEL) in the first time period (1981–2010),
c) A comparison of the changes in the simulated monthly discharges using the MPI and the KNMI scenarios until 2100.

The analyses of the changes in the monthly discharges at the Jablonica (5022) gauging station revealed (Table 2):

a) The highest mean monthly discharges are concentrated for the MODEL data (2.65 $m^3 s^{-1}$) and simulated data using the MPI scenario (2.99 $m^3 s^{-1}$) in March in the first period. The largest differences between the MODEL and simulated data using the MPI scenario occur in April and June.
b) When we compared the MODEL and simulated data using the KNMI scenario, the highest monthly discharge also occurs in March (2.65 $m^3 s^{-1}$). The simulated data using the KNMI scenario are

close to the MODEL data, that's why the KNMI scenario is a better choice for similar analyses in the future at the Jablonica gauging station.

c) If we focus on the results of the simulated data using the MPI and the KNMI climate scenarios throughout the period under study, we observed that the simulated data using the MPI scenario have an upward trend in the second period, but in the following period, the average monthly values of the discharges decrease. This decline continues until 2100, with the exceptions of November, February, March, and June. On the other hand, the modelled data using the KNMI scenario show a declining trend in the second time period (except for the months of December, January, February, September, and October). In the third period, according to this scenario, the average monthly values of the discharges will average 1:1 (decrease:increase). In the last research period up to 2100, the mean monthly discharges will decrease, especially in the summer months. The decreases occurring in the mean monthly discharges may be due to a higher incidence of drought in the study area in the future.

Using the IHA method (Table 3), it was determined for the Banská Bystrica (7160) gauging station that:

a) According to the simulated data using the MPI scenario, the highest average monthly discharges occur in April (42.94 $m^3 s^{-1}$), and in the same month we record the highest mean monthly discharges of the MODEL data (36.26 $m^3 s^{-1}$) in the first period. For the average monthly discharges, the use of simulated data using the MPI scenario is also a better choice for similar analyses in the future because the scenario describes the closest reality.
b) The simulated data using the KNMI scenario show the highest monthly discharges also in April (32.27 $m^3 s^{-1}$).
c) In terms of their future changes, the simulated data using the MPI and the KNMI scenarios in December, March, April, May, and September show the same trend, i.e., an increase in the values of the average discharges in the second period examined, a decrease in the next period, and again, in the fourth time period, an increase in the values of the average discharges. The simulated data using the MPI scenario show an increase by 2100 in January and February. Within the simulated data using the KNMI scenario, we can observe a decrease in the average monthly discharges up to 2100 in June and July.

The second part of the analysis deals with changes in the m-daily maximum discharges and the occurrence of maximum discharges.

We found that the MODEL data of m-daily maximum discharges at Jablonica (5022) gauging station, see Table 4, are underestimated in the first time period compared to the simulated data using MPI and KNMI scenarios in the 1-daily and 3-daily maximum discharges. With a view to the future, the simulated data of the m- daily maximum discharges using the MPI will increase in the first thirty years, then decrease and increase again by 2100. The simulated data using the KNMI scenario have approximately the same average final values of the m-daily maximum discharges until 2040, and by 2100, its values will also increase.

The occurrence of the maximum discharge until 2010 was in March. According to the scenarios, it will be moved to February by 2040, and by 2070, the maximum discharges will occur again in March. In the last thirty-year period surveyed, the occurrence of maximum discharges is divided into two months, i.e., February and March.

The greatest changes in the m-daily maximum discharges occurred in the course of the 1-day maximum discharge. In Fig. 3, we can see the course of the 1-daily yearly

Table 2. Median values of the mean monthly discharges at the Jablonica (5022) gauging station [$m^3 s^{-1}$] for the selected period

Myjava – Jablonica (5022)	OBS	MODEL	MPI	KNMI	MPI	KNMI	MPI	KNMI	MPI	KNMI
	1981–2010				2011–2040		2041–2070		2071–2100	
November	0.58	0.50	0.60	0.60	0.72	0.58	0.50	0.52	0.64	0.59
December	0.63	0.88	0.99	0.84	1.48	1.89	1.38	1.88	1.31	1.87
January	0.72	1.19	1.22	1.17	1.48	2.02	2.21	2.67	1.89	2.81
February	1.21	1.53	1.62	1.61	2.70	2.17	2.59	2.54	3.05	3.42
March	1.48	2.65	2.99	2.65	3.01	2.39	2.64	2.91	3.84	3.03
April	1.34	2.21	2.62	2.27	2.68	1.89	3.20	2.66	2.59	3.31
May	1.15	1.26	1.60	1.58	1.49	1.35	1.86	1.51	1.51	1.66
June	0.85	0.92	1.36	1.08	1.11	0.94	0.90	0.83	0.95	0.72
July	0.65	0.69	0.67	0.77	0.83	0.51	0.62	0.43	0.48	0.31
August	0.41	0.44	0.39	0.37	0.41	0.34	0.33	0.41	0.28	0.26
September	0.44	0.35	0.56	0.39	0.56	0.46	0.31	0.28	0.26	0.27
October	0.42	0.30	0.37	0.33	0.55	0.61	0.48	0.54	0.43	0.47

Table 3. Median values of the mean monthly discharges at the Banská Bystrica (7160) gauging station [$m^3 s^{-1}$] for the selected period

Hron – Banská Bystrica (7160)	OBS	MODEL	MPI	KNMI	MPI	KNMI	MPI	KNMI	MPI	KNMI
	1981–2010				2011–2040		2041–2070		2071–2100	
November	12.63	10.93	11.61	12.61	15.31	13.77	11.01	11.22	14.36	11.12
December	14.28	13.30	12.16	14.51	20.25	24.18	18.46	22.64	24.89	27.44
January	11.82	11.60	10.59	13.83	13.98	21.14	20.09	26.38	24.43	24.42
February	11.57	11.17	13.10	17.37	16.38	25.44	26.56	23.79	28.58	31.69
March	23.29	24.58	24.60	23.97	24.61	27.86	31.60	31.50	34.74	32.01
April	40.96	36.26	42.94	32.27	37.93	27.71	39.87	34.60	38.63	37.48
May	30.61	26.72	28.34	25.18	25.00	23.60	28.84	26.48	25.38	22.00
June	21.30	25.38	27.61	25.61	23.77	19.45	23.78	17.88	22.48	15.35
July	16.35	19.00	17.50	17.81	19.95	15.50	17.19	13.12	13.05	10.34
August	12.12	12.85	13.76	13.54	13.18	9.90	11.71	11.92	10.61	9.02
September	10.06	10.69	11.36	10.30	12.11	12.44	10.22	9.49	9.48	8.73
October	9.98	10.39	10.54	9.93	14.54	12.67	11.19	10.43	12.56	9.82

Table 4. M-daily maximum discharges and the occurrence of maximum discharges for the Jablonica (5022) gauging station for the selected period

Myjava – Jablonica (5022)		OBS	MODEL	MPI	KNMI	MPI	KNMI	MPI	KNMI	MPI	KNMI
		1981–2010				2011–2040		2041–2070		2071–2100	
1-day maximum	$[m^3.s^{-1}]$	8.92	6.09	6.80	6.48	9.06	6.53	6.70	7.19	6.96	8.64
3-day maximum		6.72	5.84	6.58	6.29	8.61	6.31	6.30	6.87	6.84	8.27
7-day maximum		4.54	5.47	6.11	5.93	7.87	5.79	5.87	6.50	6.62	7.75
30-day maximum		3.13	4.07	4.52	4.79	5.74	4.42	4.49	5.02	5.58	5.78
90-day maximum		2.12	2.69	3.07	3.11	4.11	3.27	3.64	3.62	4.09	4.01
Date of maximum	[month]	March	March	March	March	February	February	March	March	March	February

maximum discharges of the MODEL data until 2010, and the simulated 1-daily yearly maximum discharges from the MPI and the KNMI climate scenarios models until 2100.

Within the 7-day maximum discharge characteristics, the changes in flow rates decreased in the first period examined (Fig. 4). According to the simulated data using the MPI and the KNMI climate scenarios better, the resulting values of the 7-day maximum discharges describe the MODEL data. The simulated data using the KNMI scenario show a calmer course in the future than the MPI scenario.

The second gauging station discussed is the Banská Bystrica (7160), in which the following results were determined by analyses of changes in the m-daily maximum discharges (Table 5): using the MPI scenario in the period 1981–2010, the simulated m-daily maximum discharges contain the lowest resulting values (compared to the MODEL and simulated data using the KNMI scenario). The discharges modelled using the MPI scenario will increase in the second time period, but the simulated discharges using the KNMI scenario will decrease. The occurrence of the maximum discharges is in March. Maximum discharges may also occur in April until 2100.

Even in this case, figures were created to better represent changes for 1-day yearly maximum discharges (Fig. 5) and 7-day yearly maximum discharges (Fig. 6) for the Banská Bystrica (7160) gauging station. The simulated data using MPI and KNMI scenarios show extremes for 1-day yearly maximum discharges in 1987. The simulated MPI scenario is more suitable for the Banská Bystrica (7160) gauging station than to examine other analyses because his course of 7-day yearly maximum discharges is more extreme than the simulated KNMI scenario.

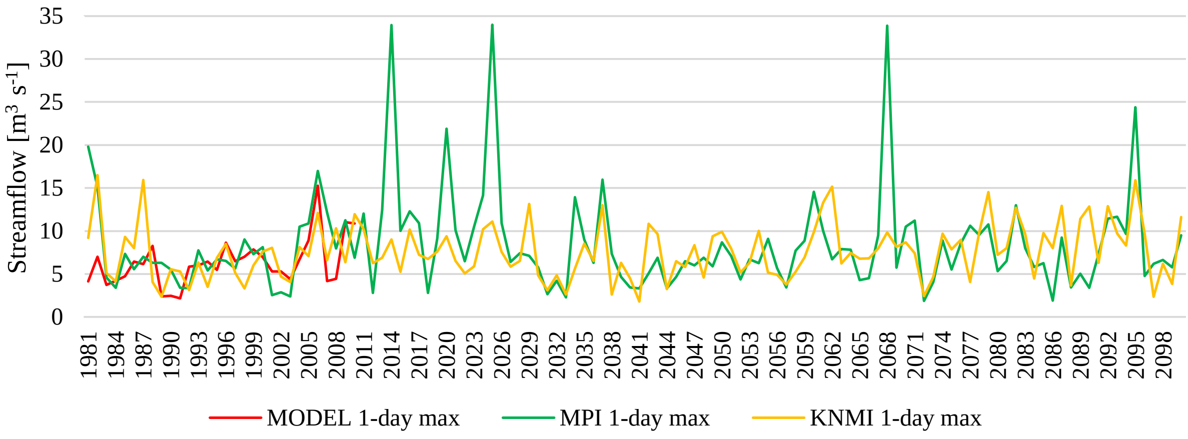

Fig. 3. 1-day yearly maximum discharges for the MODEL (1981–2010) and the simulated data using the MPI and the KNMI scenarios (1981–2100) for the Jablonica (5022) gauging station.

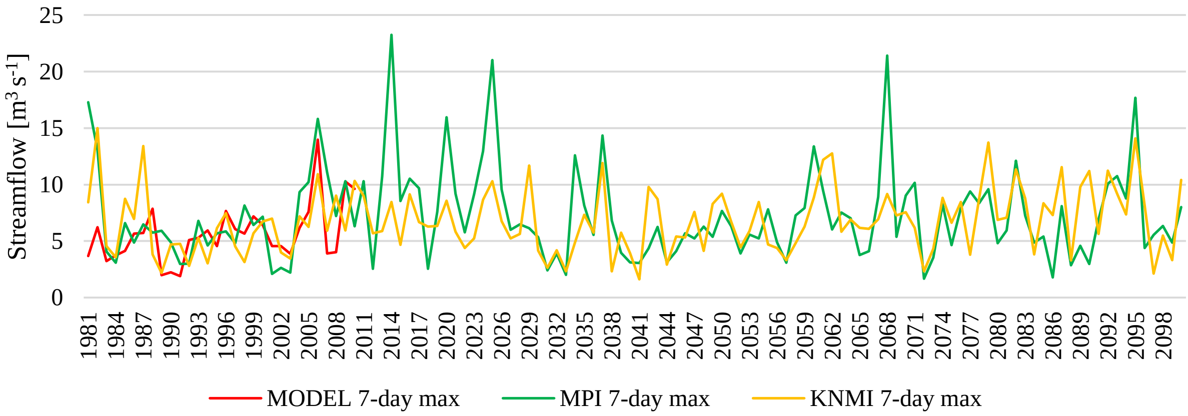

Fig. 4. 7-day yearly maximum discharges for the MODEL data (1981–2010) and the simulated data using the MPI and the KNMI scenarios (1981–2100) for the Jablonica (5022) gauging station.

Table 5. M-daily maximum discharges and the occurrence of maximum discharges for the Banská Bystrica (7160) gauging station during the studied period

Hron – Banská Bystrica (7160)		OBS	MODEL	MPI	KNMI	MPI	KNMI	MPI	KNMI	MPI	KNMI
		1981–2010				2011–2040		2041–2070		2071–2100	
1-day maximum	$[m^3 s^{-1}]$	116.10	87.23	79.21	92.09	95.36	86.51	82.83	85.18	82.70	94.85
3-day maximum		97.90	83.35	76.01	84.59	92.05	81.96	79.08	80.47	79.23	91.41
7-day maximum		81.01	78.13	70.74	78.86	86.84	72.17	69.40	71.35	74.66	83.04
30-day maximum		59.38	55.63	52.28	55.25	62.43	50.57	51.09	56.72	58.03	56.51
90-day maximum		40.53	39.66	39.65	39.36	41.86	36.03	39.75	40.52	43.04	44.63
Date of maximum	[month]	May	April	April	May	April	April	March	March	April	March

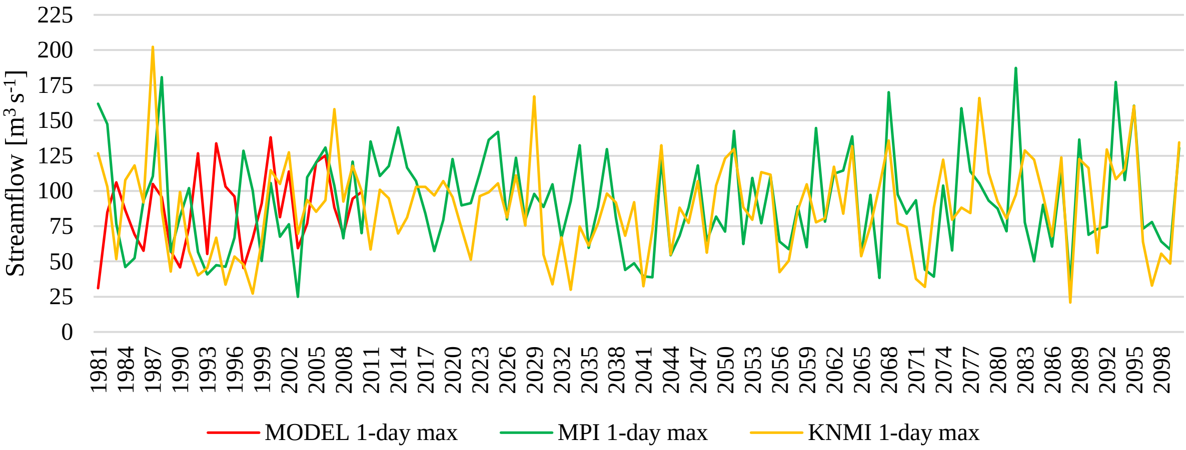

Fig. 5. 1-day yearly maximum discharges for the MODEL data (1981–2010) and the simulated data using the MPI and the KNMI scenarios (1981–2100) for the Banská Bystrica (7160) gauging station.

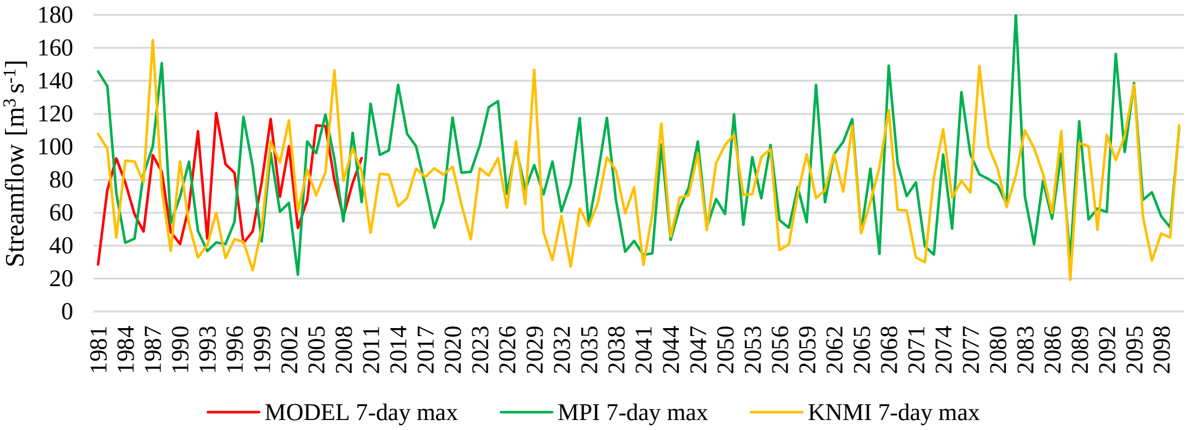

Fig. 6. 7-day yearly maximum discharges for the MODEL data (1981–2010) and the simulated data using the MPI and the KNMI scenarios (1981–2100) for the Banská Bystrica (7160) gauging station.

Conclusion and discussion

In our work, we dealt with changes in the average monthly discharges until 2100, changes in the m-daily maximum discharges, and the occurrence of maximum discharges until 2100 in the Jablonica (5022) gauging station and in the Banská Bystrica (7160) gauging station. We used the IHA program, version 7.1.0.10, in which we focused on the characteristics of the m-daily maximum discharges, i.e., 1-day, 3-day, 7-day, 30-day and 90-day maximums, and the occurrence of maximum discharges. We worked with three groups of data, i.e., the observed data, the MODEL data and simulated data using the MPI and KNMI scenarios until 2100. The time period of 1981–2100 was divided into 4 groups, i.e., 1981–2010, 2011–2040, 2041–2070, and 2071–2100, in which we monitored changes in the hydrological characteristics investigated.

The following characteristics were noted at the Jablonica (5022) gauging station:

- The highest average monthly discharges occur in the months of February, March, and April. The simulated average monthly discharges using the MPI scenario increase until 2040 and then decrease until 2100 (except for November, February, March, and June). The simulated average monthly discharges using the KNMI model scenario decrease until 2040; by 2070, the final values of the average monthly discharges do not significantly differ, and by 2100, their values will decrease, especially in the summer months.
- Within the m-daily maximum discharges, it was determined in this study that there are no significant differences in the first time period between the MODEL and simulated data using the MPI and the KNMI scenarios. The occurrence of maximum

discharges is in February and March. The most extreme fluctuations of the resulting m-daily maximum discharges occur from 2080 to 2100.

For the Banská Bystrica (7160) gauging station it was determined in this work that:

- The highest monthly discharges occur in the months of March and April. The simulated monthly discharges using the MPI and the KNMI scenarios have similar course in December, March, April, May, and September: they increase by 2040, decrease by 2070, and increase by 2100.
- At this gauging station, we see more extreme fluctuations of the m-daily maximum discharges than at the Jablonica (5022) gauging station investigated. The occurrence of maximum discharges is concentrated in the months of March, April, and May.

In general, it was found that the simulated data using the KNMI scenario are more suitable for the Jablonica (5022) gauging station because it shows the smallest differences in the resulting values from the observed and MODEL data compared to the MPI scenario. At the Banská Bystrica (7160) gauging station, on the contrary, the simulated data using MPI scenario are more suitable for the future predictions.

A significant finding is that the maximum discharges at the Banská Bystrica (7160) gauging station occur in April and May and that their occurrence will shift by 2100 for the months of March, and April. This can be caused by warming of the climate (rapid melting of snow in the winter months) and an increase in total precipitation in the colder period of the year. The model outputs assume that the summer precipitation regime should change to periods of more frequent droughts (a decrease in the average monthly discharges).

In the summer months, such changes, i.e., a reduction in total precipitation and an increase in the variability of total precipitation are expected to last longer. The aspects noted are the reason for the emergence of dry periods and the emergence of short-term rainy periods (Minďaš et al., 2011). According to the study "Climate change and its possible consequences in cities" (Lapin et al., 1997), the increase in winter runoff by 2075 may change as follows: northern Slovakia 10–40%, central Slovakia: 20–50%, and southern Slovakia 30–80%.

With the help of the IHA program, it is possible to investigate further changes in the characteristics of a hydrological regime, and changes in the basic settings of the IHA program can achieve the results desired for various watercourses around the world.

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