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THE DETECTION OF CHANGES IN THE UPPER VÁH RIVER BASIN ACCORDING TO A DECADAL ANALYSIS

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In changing climate conditions, hydrometeorological data analysis is an option for determining identifiers for changes in runoff. Various methods are used for the analysis of hydrometeorological elements, e.g., statistical tests or various hydrological analysis. The aim of the article is to analyse hydrological time data series by comparing their averages over decades. The time data series used were mean monthly, seasonal, and annual discharges; the average total monthly rainfall in a river basin, and the average air temperatures in the river basin. The decadal analysis was applied at 16 stage-discharge gauging stations that are located in the upper section of the Váh river basin in Slovakia. The total monthly rainfall and air temperatures were calculated as the average values for the various catchments. The results show the lowest discharge occurred in the 1980s and the highest in the 2000s. Comparing the winter and summer season discharges, stations located in the eastern part of the area have a higher summer season discharges, while other stations have higher discharges in the winter season. The results of the air temperature analysis indicate an apparent upward trend in all the stations. Between the warmest and the coldest decades, the average difference in each river basin is 1.5°C. The precipitation regime in the earlier decades had a variable or decreasing character. Since the 1980s, there has been a slight increase. The increase in air temperature appears to affect the decreasing flow rate due to increasing evapotranspiration. The increase in precipitation in recent decades has been reflected in some stations by an increase in discharges.

KEY WORDS: analysis of decades, Váh river basin, climate change

Introduction

Flood Analysing the hydrological data of an instrumental period and identifying identifiers of changes in a runoff regime allow for determining changes in the statistical properties of the data. This can be used in models of a hydrological regime´s evolution under climate change conditions (Szolgay et al., 2004). Foreign and Slovak authors dealing with the issue of change detection, especially in hydrological data, can detect changes using various methods.

Škoda et al. (2008) examined minimum annual discharges and the frequency of their occurrence in Slovakia. Halmová and Pekárová (2013) evaluated minimum and maximum daily discharges from 1929 to 2011 using IHA hydrological software. Jeneiová et al. (2015) focused on detecting changes in long-term data series. The annual peak discharges from nine stations in southern Slovakia were used for the analysis. Changes in the flood regime of the Danube River in Slovakia were analysed by Pramuk et al. (2013). They evaluated changes in the amount, time of occurrence, and size of flood waves. Frequency analysis and long-term trend analysis were used. The results contained in the papers by the various Slovak authors above show a reduction in the runoff coefficient (Pramuk et al., 2016), following by an increase in the frequency of floods but a reduction their duration (Pramuk et al., 2013).

Various German papers point to an upward trend in discharges on the Rhine River, which were caused by an increase in winter precipitation (Bronstert et al., 2002; Schönwiese and Rapp, 1997). Petrow and Merz (2009) dealt with the frequency of floods in Germany, where increasing trends were also detected.

Bawden et al. (2014) dealt with an analysis of the trends and variability of the hydrological regime in the Athabasca catchment and surrounding catchments in Canada. The study showed a decreasing tendency in the trends.

Wong et al. (2006) identified the change points in a hydrological time series using the grey relational method. The method was applied at several stations on the Shunde River in China. Gautier et al. (2018) investigated the hydrological response to climate change at the Lena River in eastern Siberia. The locality is the coldest area of the northern hemisphere, and the authors focused on the development of the floods. They found an increase in spring floods and peak discharges and also determined the beginning of a flood is less predictable. Summer floods are more frequent and intense.

Material and methods

The decadal analysis was applied at 16 stage-discharge gauging stations that are located in the upper section of the Váh river basin (Fig. 1, Table 1). The selected stations and their catchment areas are small areas. The largest is the Váh river basin with Liptovský Mikuláš station, with an area of 1107.21 km^2. The smallest is the Ipoltica river basin with the Čierny Váh station, with a catchment area of 87.07 km^2.

The discharge was provided by the Slovak Hydrometeorological Institute. The total rainfall and air temperature coming from the CarpatClim database (CarpatClim, 2013).

Some of the catchments are nested. There are smaller basins with identification number (ID) 5310, 5311, 5330 and 5400 belongs to the Váh catchment to the Liptovský Mikuláš station (5550). Then, there is the Kysuce catchment to the Čadca station (6180), which is nested in the Kysuce catchment to the Kysucké Nové Mesto (6200).

A decadal analysis was used in Sleziak, 2017. The work

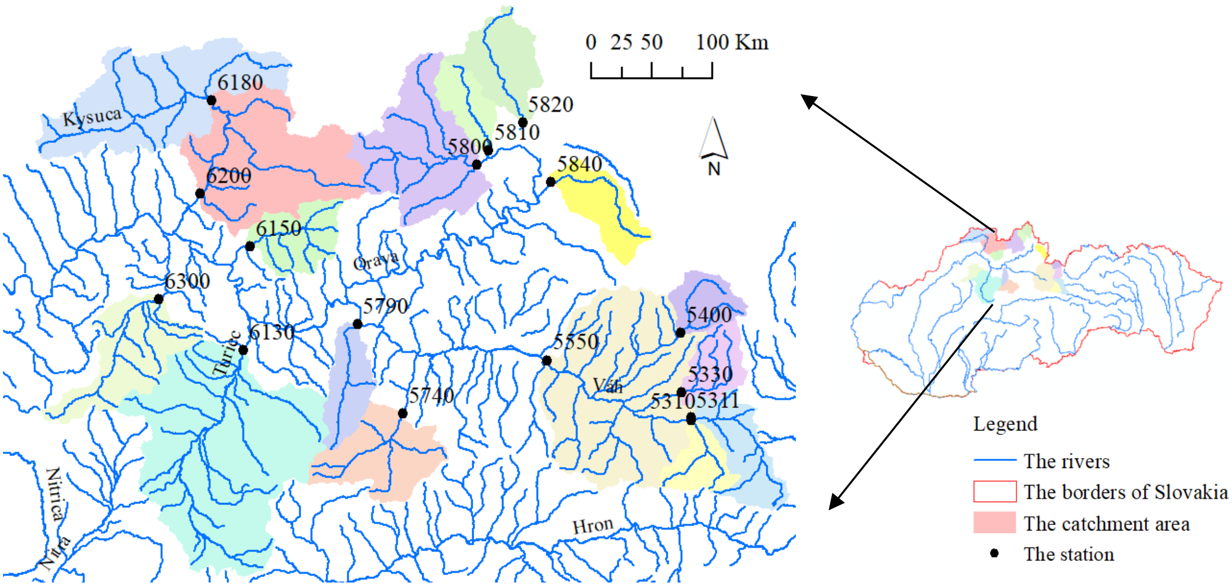

Fig. 1. The localization of the selected stage-discharge gauging stations with their catchments.

Table 1. The list of stage-discharge gauging stations used

ID	Station	River	River Km	Catchment area [km^2]	Altitude of station [m a.s.l]
5310	Čierny Váh	Ipoltica	0.08	87.07	736.36
5311	Čierny Váh	Čierny Váh	11.70	243.06	733.31
5330	Východná	Biely Váh	10.20	105.64	731.64
5400	Podbanské	Belá	21.35	93.49	922.72
5550	Lip. Mikuláš	Váh	346.60	1107.21	567.68
5740	Podsuchá	Revúca	11.20	217.95	558.21
5790	Ľubochňa	Ľubochnianka	0.30	118.39	442.00
5800	Lokca	Biela Orava	4.20	359.96	619.06
5810	Orav. Jasenica	Veselianka	1.00	90.10	618.09
5820	Zubrohlava	Polhoranka	1.60	158.67	605.69
5840	Trstená	Oravica	3.55	129.95	585.49
6130	Martin	Turiec	6.90	827.00	389.90
6150	Stráža	Varínka	5.10	139.70	399.87
6180	Čadca	Kysuca	29.20	492.54	408.36
6200	Kys. N. Mesto	Kysuca	8.00	955.09	346.09
6300	Poluvsie	Rajčianka	13.30	243.60	393.06

was focused on the modelling of rainfall-runoff processes. In this case, a decadal analysis was used to compare changes in model parameter values over three decades. The values were selected according to rain and snow seasons, within which the differences were evaluated.

In our case, three hydrometeorological elements were evaluated over five decades, i.e., the 1960s (from 1961 to 1970), 1970s (from 1971 to 1980), 1980s (from 1981 to 1990), 1990s (from 1991 to 2000), and 2000s (from 2001 to 2010) by a decadal analysis. The following hydrometeorological elements were used:

- the discharges measured at stations,
- the total precipitation per river basin,
- the air temperatures per river basin.

The data from CarpatClim have the form of grid points. The Theissen polygon method was chosen to calculate the total average rainfall and air temperature for the catchments. The total average rainfall and air temperature were calculated as a weighted average of the data from the individual grid points of the CarpatClim database. The weight of the area assigned to the relevant point within the river basin was considered as the weight (Keszeliová, 2019). The range of the CarpatClim data is from 1961 to 2010, which is also the range of the data used in this paper. The form of the data series was as follows:

- average annual data series,
- average seasonal data series for the winter season (November–April) and summer season (May–October),
- average monthly data series (from November to October, i.e., the hydrological year).

The selected data were further averaged for the individual decades. The average values of the decades were thus calculated as the average values for single months, seasons, and years. The results were evaluated using multiple graphs.

Results and discussion

The results of the decadal analysis show a comparison of two river basins, namely, the Čierny Váh river basin to the Čierny Váh station and Rajčianka river basin to the Poluvsie station. There are detailed assessments of the discharges, air temperature, and precipitation for each decade. Subsequently, all the stations were evaluated together. In this case, the winter and summer season time data series were plotted using box charts.

Results from the Čierny Váh and Poluvsie stations

The Čierny Váh river basin to the Čierny Váh station (5311) and the Rajčianka river basin to the Poluvsie station (6300) have the same catchment area, i.e., 243 km^2. The altitude of the Čierny Váh station is 733.31m a.s.l. The second station is situated at a lower altitude, i.e., 393.06 m a.s.l. The long-term mean discharge of Čierny Váh station is Q_a=3.52 m^3.s^{-1} and Q_a=3.42 m^3.s^{-1} for the Poluvsie station.

The results of these stations are shown in the graphs in Figs. 2 and 3. In both graphs, the left Y-axis shows the precipitation scale (green); the right is the air temperature scale (blue, black, and red lines) and the discharge (yellow). The black, blue, and red column borders represent the yearly (*year*) and seasonal averages (*winter, summer*) for the decades. The decades of the stations are plotted on the primary X-axis.

The discharge regime

The mean annual discharge over the decades at the Čierny Váh station (Fig. 2, yellow) and the Poluvsie station (Fig. 3, yellow) are similar. The highest mean annual discharge was in the 1970s. At the Čierny Váh station, the discharge for the recent decades have been slightly rising, but at the Poluvsie station, the discharge has been falling. The slightly increasing discharge at the Čierny Váh station in the last two decades is probably due to higher precipitation. In the Poluvsie station, despite slightly increasing precipitation, the discharge has continued to decrease, which is probably due to the increased evapotranspiration caused by the increasing air temperature.

The courses of the average discharges of the winter and summer seasons are different. The discharge of the summer season at the first station is higher than the discharge of the winter season. It is the other way around in the second station, so the discharge of the winter season is always higher than the discharge of the summer season.

A closer look at the discharge during each month (Fig. 4) allows one to see the maximum discharge in April and May at the Čierny Váh station. The Poluvsie station has the discharge peaks in March and April. This regime was probably reflected in the course of the discharges of the winter and summer seasons. The winter season is defined from November to April; therefore, the highest discharge of the winter season is at the Poluvsie station. The maximum values at the Čierny Váh station belong more to the summer season.

The air temperature regime

The air temperature in the Čierny Váh catchment has a clear upward trend (Fig. 2). The differences in the air temperature appear in comparison to the summer and winter seasons. The average air temperature in the 1970s in the summer season is the lowest, but in the winter season, it is higher than in the 1980s and the same as in the 1990s. Thus, the 1970s seem to be the mildest decade in both seasons. In the Rajčianka catchment to the Poluvsie station, there is a similar course for the air temperature, but it is about 2 ˚C warmer in each decade. The reason for the difference is the various altitudes of the basin.

The air temperature cycle according to months is expected to be higher in the Rajčianka catchment (Fig. 5, green colour). The maximum and the minimum values are found in both basins in the same months. The highest air temperature is in July and August, and the lowest air temperature is in January. The 1960s had the lowest air temperature, while the warmest decade was the 2000s.

The precipitation regime

The course of the total rainfall in the Čierny Váh catchment (Fig. 2, green colour) show variable behaviour until the 1980s. Since the 1980s, the volume of precipitation has been gradually increasing. This applies to the winter and summer seasons of any year. In the Rajčianka catchment (Fig. 3, yellow colour), the total rainfall was slightly decreasing to the 1980s and then was slightly increasing.

The monthly total rainfall in the hydrological year by months are varied at both stations (Fig. 6). Both catchments have similar volumes of total rainfall. The lowest values of the total rainfall at both stations are mostly found in the winter months, especially in February. The maximum total rainfall are in June and July with a significant peak in the 2000s in the Čierny Váh catchment.

Evaluation of all the stations

The box graphs (Figs. 7, 8, and 9) were used to evaluate all the stations collectively. Each box contains a value from each station from the winter and summer seasons. These seasons are chronologically organized from the 1960s to the 2000s.

The discharge regime

In the evaluation of all the stations, a higher discharge in the summer season is found in the eastern catchments. These stations are the Čierny Váh stations (5310, 5311), the Východná station (5330), the Podbanské station

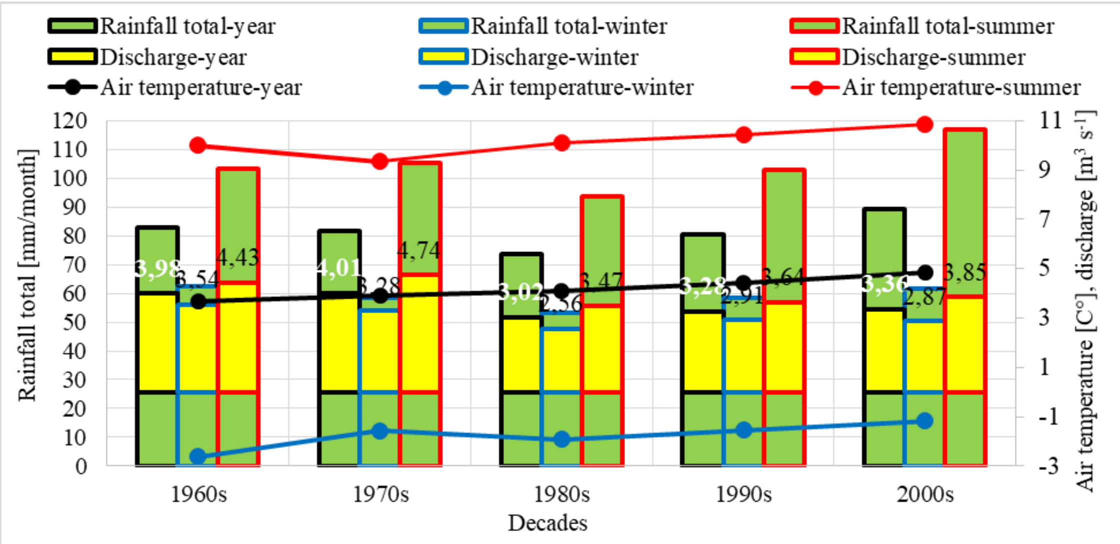

Fig. 2. The results of the decadal analysis at the Čierny Váh station (ID 5311).

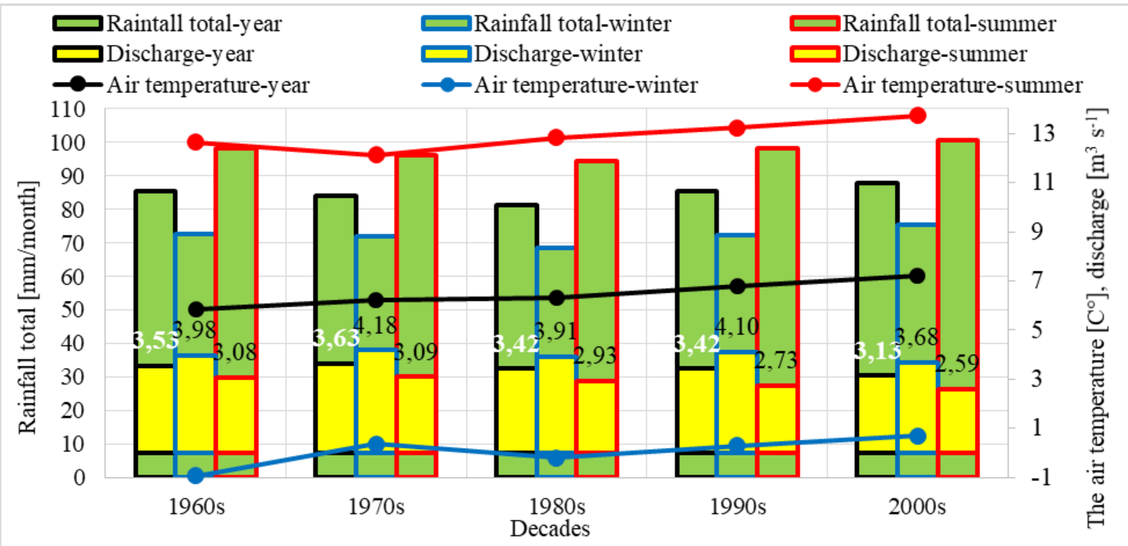

Fig. 3. The results of the decadal analysis at the Poluvsie station (ID 6300).

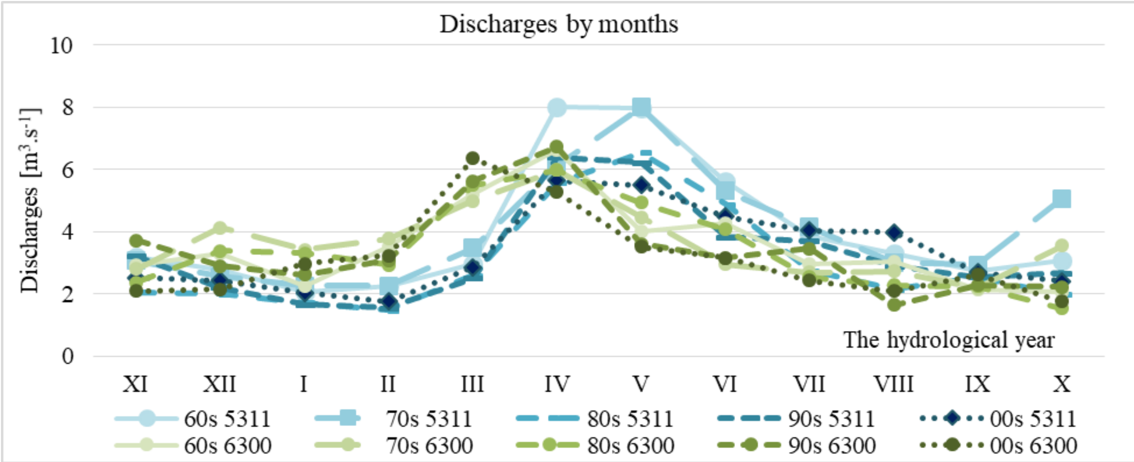

Fig. 4. Comparison of the discharges by the months of the hydrological year at the Čierny Váh station – 5311 (blue colour) and the Poluvsie station – 6300 (green colour).

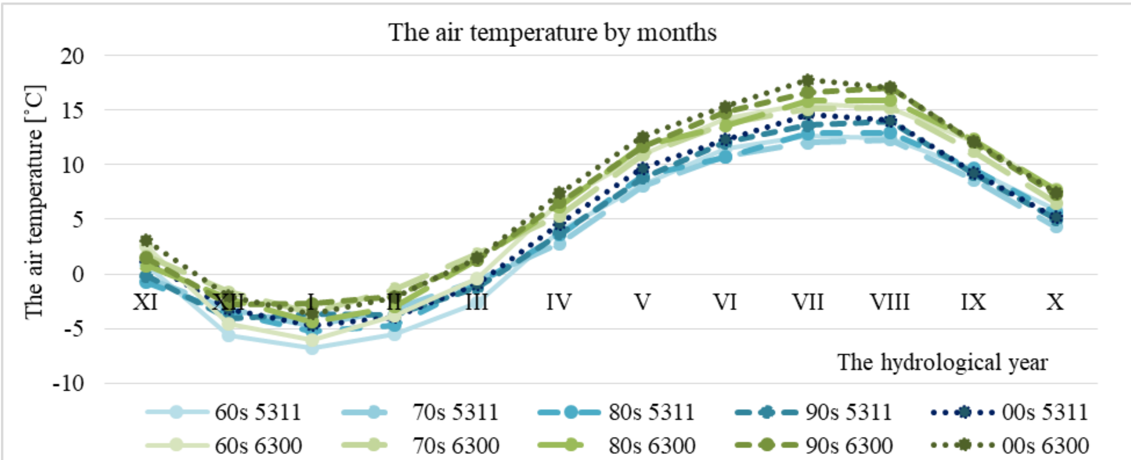

Fig. 5. Comparison of the air temperature by months of the hydrological year at the Čierny Váh station – 5311 (blue colour) and the Poluvsie station – 6300 (green colour).

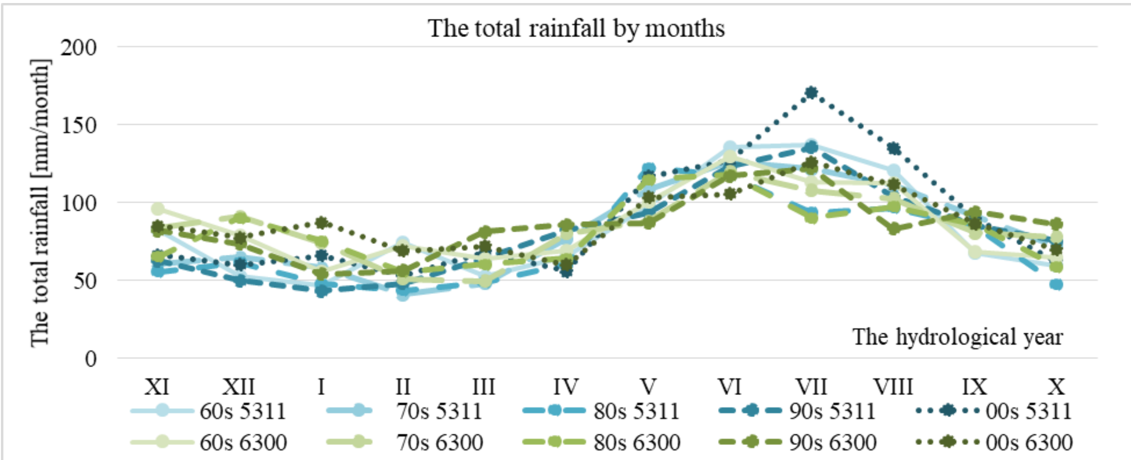

Fig. 6. Comparison of the total rainfall by months of the hydrological year at the Čierny Váh station – 5311 (blue colour) and the Poluvsie station – 6300 (green colour).

(5400), the Liptovský Mikuláš station (5550) and the Trstená station (5840). The reason for the differences is the maximum discharge in May, which belongs to the discharge of the summer season. All the other stations show higher discharges of the winter season than discharges of the summer season. This can be seen in Fig. 4, which show the courses of the discharge by months for the Čierny Váh station and the Poluvsie station.
The differences between the winter and summer seasons are also possible to see in the box graph (Fig. 7). All the winter seasons have a larger range of values at the 0.25 and 0.75 percentiles. The variance between the 0.25 and 0.75 percentiles in the summer season is smaller, but the outliers are more pronounced than in the winter season. This phenomenon is probably due to intense summer floods. The differences between the medians and arithmetic means are small.

The air temperature regime

The coldest catchment is the Belá river basin (the Podbanské station – 5400), and the warmest is the Turiec river basin (the Martin station – 6130). The difference between the coldest and the warmest decade in the winter season is 1.59°C on average for all the stations. The coldest decade is the 1960s, and the warmest decade is the 2000s. In the summer season, the coldest decade is the 1970s, and the warmest is the 2000s. The difference between these decades is 1.56°C on average for all the stations.
The box graph in Fig. 8 shows the course of the air temperature in the winter and summer seasons chronologically. The course of the air temperature in all the stations is generally similar to that described in comparison to the Čierny Váh catchment and the Rajčianka catchment. The outliers are caused by the Belá catchment, which has the lowest air temperature of all the catchments. The mildest decade is the 1970s (Fig. 8, *T winter 1970s* – light grey colour; *T summer 1970s* – yellow colour).

The precipitation regime

The largest amount of precipitation in the winter season fell in the Belá catchment, i.e., about 100 mm/month in each decade. The lowest amount of precipitation in the winter season fell in the Oravica catchment and the Ipoltica catchment, i.e., 50 to 57 mm/month.
The largest amount of precipitation in the summer season fell in the Belá catchment, i.e., an average of 141 mm/month. The lowest amount of precipitation fell in the Turiec catchment during the summer season, an average of 94 mm/month.
When comparing to the decades, the decade with the least rainfall decade is the 1980s in the winter and summer seasons. The 1980s in the winter season had a total rainfall of 64.1 mm/month on average for all the stations and 98.4 mm/month on average in the summer season. The 2000s represent the decade with the highest total rainfall on average. The 2000s in the winter season had total rainfall of 69.5 mm/month on average, and in the summer season it was 114.9 mm/month on average. The difference between the total rainfall of the 1980s and 2000s in the winter season is 5.4 mm/month for all the catchments on average. In the summer season, the difference between the 1980s and 2000s is 16.5 mm/month on average.
The course of the average total seasonal rainfall was decreasing until the 1980s (Fig. 9). Subsequently, the volume of precipitation has been increasing. The Belá catchment is the cause of the outlying values; it has the highest precipitation totals from all the catchments.
The results mentioned above with the average values for all the stations were summarized in Table 2. The summa-

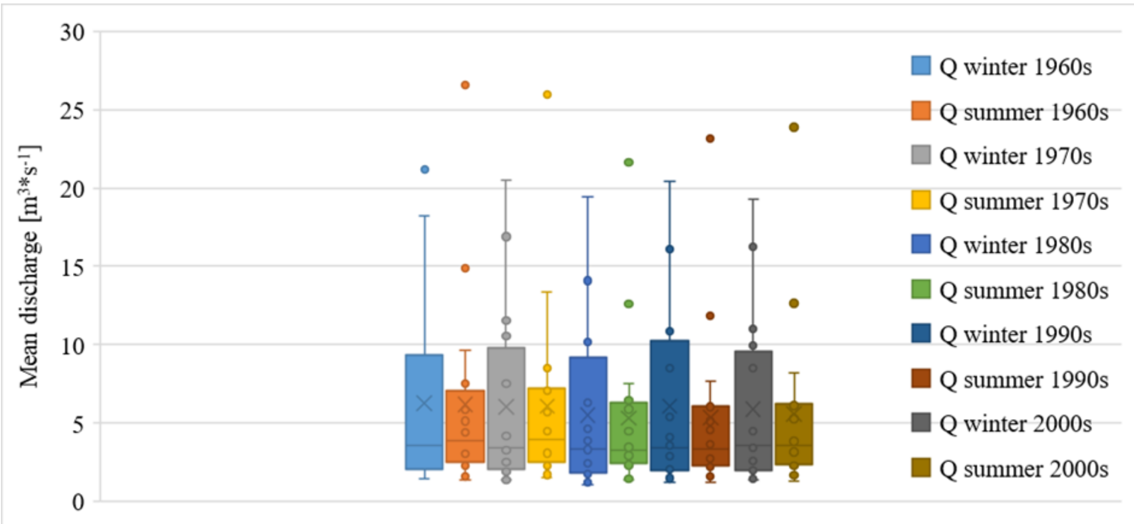

Fig. 7. The results of the discharge for the winter and summer seasons for all the stations in the form of box graph.

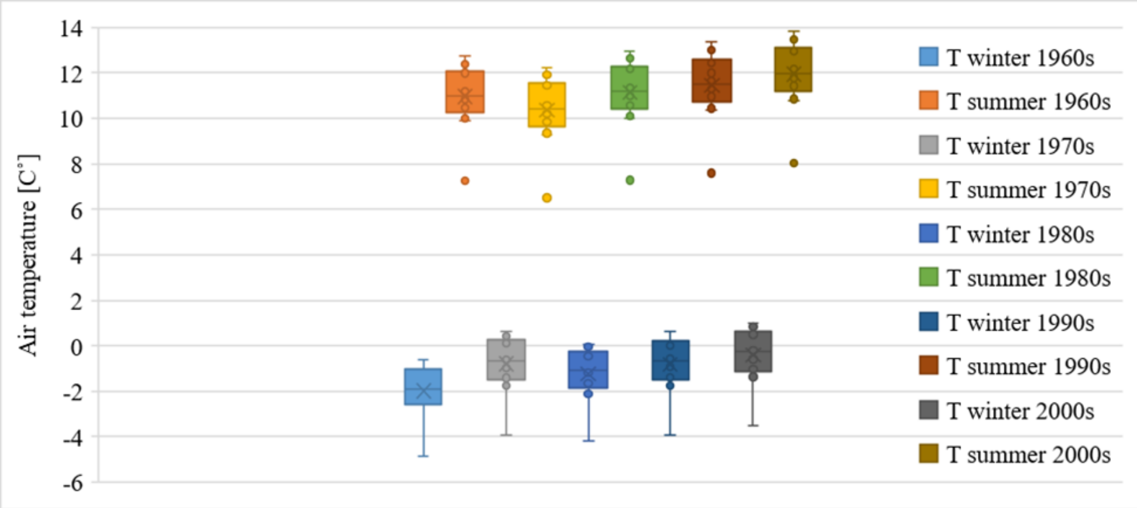

Fig. 8. The results of the air temperature for the winter and summer seasons for all the stations in the form of a box graph.

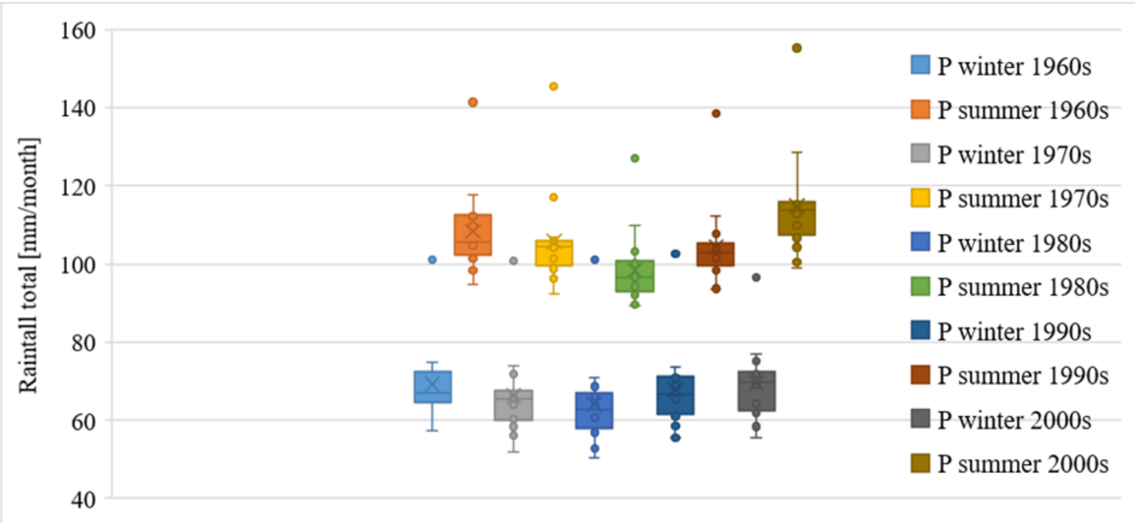

Fig. 9. The results of the total rainfall for the winter and summer seasons for all the stations in the form of a box graph.

Table 2. The summary results of the average values from all the stations with their maximums, minima and the differences between them (Q – discharge, T – air temperature, P – total rainfall)

Decade	Q winter [$m^3 s^{-1}$]	Q summer [$m^3 s^{-1}$]	T winter [°C]	T summer [°C]	P winter [mm/month]	P summer [mm/month]
1960s	**6.3**	**6.2**	**-2.0**	11.0	69.2	108.4
1970s	6.1	6.1	-0.8	**10.4**	66.3	105.8
1980s	**5.5**	**5.3**	-1.2	11.1	**64.1**	**98.4**
1990s	6.1	5.4	-0.8	11.5	68.0	104.5
2000s	5.9	5.6	**-0.4**	**11.9**	**69.5**	**114.9**
Maximum	6.3	6.2	-0.4	11.9	69.5	114.9
Minimum	5.5	5.3	-2.0	10.4	64.1	98.4
Differ. (max-min)	0.8	0.9	1.6	1.6	5.4	16.5

ry shows the largest changes in discharge occurred in the first decades. The air temperature over all the decades and changes in precipitation have become more apparent in recent decades.

Conclusions

The comparison of the Čierny Váh station and the Poluvsie station, which have the same catchment area but are at different altitudes, showed the different courses of discharges in the winter and summer seasons. The Čierny Váh catchment is 2°C colder than the Rajčianka catchment. The precipitation regime showed the highest total rainfall in the 2000s.

The results of the evaluation of all the stations showed the lowest discharge in the 1980s and the highest discharge in the 2000s. In comparison to the discharges of the winter and summer seasons, the stations located in the east part have a higher discharge in the summer season than in the winter season. This phenomenon is probably due to different discharge peaks in the winter and summer months. Either the peaks appear in April, which belongs to the winter season, or the peaks appear in May, which belongs to the summer season.

The results of the decadal analysis in the air temperature pointed to an apparent upward trend in all the stations. The difference between the warmest and coldest decades is 1.5°C. The air temperature curve is similar in all the catchments. The coldest month is January, and the warmest months are July and August.

The precipitation regime in the earliest decades has a variable or decreasing character. There has been a slight increase since the 1980s. The 2000s was the decade with the highest precipitation totals. The least amount of rainfall fell in the 1980s. The difference between the 2000s and 1980s in the winter season is on average 5.4 mm/month for all the stations. In the summer season, the difference is 16.5 mm/month. The influence of the increase in rainfall growth in recent decades has shown a slight increase in discharges in some stations. Nevertheless, the discharges have decreased in some stations. This decreasing discharge is caused by increased evapotranspiration due to the increase in air temperature.

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