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Comparison of mean daily discharge data for under-mountain and highland-lowland types of rivers

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Most Slovak rivers have increasing spring flow followed by a period or two of low flow in the summer, autumn, and, in some cases, winter. The flow rate fluctuations in two different streams in Slovakia are being investigated in this study. The study focused on an under-mountain and a lowland-highland river to investigate the low and peak flow periods and to identify the trends in monthly and annual mean flows for both rivers. Analysing daily mean discharge data from two different types of streams requires the use of a robust normalization approach to verify the comparability between the chosen streams. On both streams, a broad statistical low-flow analysis was performed over different study periods, as well as a hydrological drought analysis utilizing the water-bearing coefficient approach over the period 2010–2020. The evaluation for the foothill river in Slovakia demonstrates that snow melting has a significant impact on annual runoff in the spring months, and both rivers have a low flow period in August, September, and October. Despite the considerable variations in the catchment area, geographical, and hydrological characteristics, drought analysis for the years 2010 to 2020 found a lack of normality and a dry hydrological situation in both streams.

KEY WORDS: drought, hydrological analysis, under-mountain river, highland-lowland river, water-bearing coefficient

Introduction

The surface runoff regime in Slovakia is characterized by increased spring runoff. Due to later snow melting in mountainous areas with higher altitudes, the increased spring runoff is manifested in later months compared to the situation in lowland streams (Fendeková and Blaškovičová, 2018). In most Slovak streams, the summer-autumn period represents the period of low water content (especially the months of August to October which is an important period of the growing season (Velísková et al., 2017). The winter low water period is quite significant in mountainous regions (especially the months of December to February). The low-water winter season is associated with snowfall, which does not contribute to immediate runoff during periods of low temperatures (below freezing) caused by partial or complete freezing of the stream (Fendeková and Blaškovičová, 2018).

Low flow is defined as a period when the flow is equal to or less than the expected threshold discharge (Tokarczyk, 2012). Low flow has always been associated with hydrological drought (Van Loon, 2015) because hydrological drought can be characterized by a series of low flows. In many cases, drought studies have discovered that the dry seasons in summer or fall were anticipated by the absence of regular runoff at the time, most particularly the significantly decreased runoff in the normally wet spring months (Fendeková and Blaškovičová, 2018). However, low flows are typically identified by annual minimum series, which may not always imply a streamflow drought (Hisdal et al., 2004). Many authors associate the concept of hydrological drought with the concept of low flow in rivers, although one hydrological drought may consist of several periods of low flows (Almikaeel et al., 2022).

This study focuses on low-flow indices in two different rivers with different characteristics to evaluate the low flow seasons on both streams. Two rivers from the Slovak territory are selected to represent under-mountain and highland-lowland types of rivers. Gidra and Topľa Rivers are chosen for this study to conduct the comparison.

Hydrological drought consists of low flow periods, but the continuous seasonal appearance of low flow is not necessarily a hydrological drought, although many researchers define hydrological drought as a prolonged period of low flow in the river (Tokarczyk, 2012). Furthermore, hydrological drought is defined as a random event characterized by a duration and deficit volume (Tokarczyk, 2012). Drought should not be confused with low flow, aridity, water scarcity, desertification, or related hazards such as heatwaves and forest fires. Low flows are often characterized by annual minimum series, which do not in all years reflect a streamflow drought.

The water-bearing coefficient is a method used to assess drought based on the annual mean discharge and the long-term mean discharge of the river. The water-bearing coefficient is utilized to assess hydrological drought on in Gidra and Topľa Rivers based on the analysis of the annual discharge data governed by the Slovak Hydrometeorological Institute (WMO, 2008). It is also used to distinguish between low flow characteristics and streamflow drought characteristics (Hisdal et al., 2004).

Material and methods

Several hydrological variables are considered while assessing surface water content. The hydrological regime of discharges is assessed over various time steps and periods. Minimum/maximum mean daily discharges (in monthly or annual steps, for the entire study period), *M*-daily discharges (the flow duration curve of mean daily discharges), minimum/maximum monthly and annual discharges (with the date of occurrence), which are then statistically processed (GWP Slovakia, 2013).

The mean daily discharge is a basic parameter of surface water hydrology and it is obtained using the flow that corresponds to the mean daily water stage as calculated by the valid rating curve (WMO, 2008). In the event of significant variations in water levels over the day, it is calculated as the mean value of discharges corresponding to water levels across appropriately chosen shorter time intervals (e.g. 3 hours) (Výleta et al., 2018). The Slovak Hydrometeorological Institute (SHMI) provides water stage measurements, and flow characteristics are compared to long-term values for the reference period 1961–2000. (determined since 2006 for surface waters).

To make the comparison between mean discharge values and the long-term mean Q_a threshold more convenient, the exceedance rate will be introduced and used in this study. It is defined as the percentage of the years in which the monthly or annual mean discharge values of a specific month surpassed the long-term mean across the study period.

Comparing discharge data between different rivers with a variety of sizes, characteristics and annual mean discharge is not possible without using relative values. Relative values ensure the comparability of different watercourse discharges data by introducing a reference period. The long-term mean discharge is computed over the reference period for each stream and then utilized to normalize the annual mean discharge (Q_{mean}) i.e. the percentage ratio of mean annual discharge (Q_{mean}) and long-term mean discharge for the reference period 1961–2000 (Q_a) for individual discharge gauging stations (Fendeková and Blaškovičová, 2018).

The daily mean discharge of the Topľa and Gidra Rivers was analysed in this study. SHMI provided data for the Gidra and Topľa Rivers from 1961 to 2020 and from 1988 to 2020, respectively. SHMI also provides the long-term mean for both streams for the same reference period of 1961 to 2000.

Hydrological drought analyses of the chosen period are based on the assessment of discharge characteristics of low flow. Low-flow information of annual, seasonal, and different periods typically relied on estimating statistics from all available data. For many purposes, grouping data by months, series of months, or certain seasons may be more appropriate. Both annual minimum and flow-duration analyses can be performed for individual months or groups of months (WMO, 2008). Low flow statistics, namely mean flow is used as the general parameter in this study. The mean discharge is calculated monthly and annually for both Gidra and Topľa Rivers.

The long-term mean Q_a over the period 1961–2000 is used as a threshold to characterize periods of deficient streamflow as anomalies from the daily, monthly, and annual flow range. However, the selected threshold discharge should classify the low-flow events from the analysed time series. The criterion for differentiating hydrological droughts from a sequence of low flow occurrences was based on the classification by Dracup et al. (1980) (Tokarczyk, 2012).

Hydrological drought analyses of the chosen period are based on the assessment of discharge characteristics of low flow. The water-bearing coefficient is used to assess the hydrological status of a given river by comparing the mean discharge value of any year with the long-term mean value (which represents the normal status) (GWP Slovakia, 2013). Thus, the ratio between annual mean discharge value and long-term mean discharge is compared to standard values which define the normal, wet, and dry hydrological status of the river (GWP Slovakia, 2013).

Analysis and Results

The Gidra River

Gidra River was selected as a typical foothill stream. It springs below Baďurka in the Little Carpathians, at an altitude of about 470 m above sea level. It is a right-hand tributary of the Dudváh River and it is 38.5 km long. In the media, the Gidra River was mentioned in connection with the catastrophic flood in 2011. The only water gauging station is located above the village of Píla at an altitude of 270.04 m a. s. l., and rkm 33.30 (Fig. 1), where available measured data on water stages are since 1961, the catchment area is 32.95 km^2 to the profile of the water gauging station (SHMÚ, 2019). The mean daily discharges for the period 1961–2020 were analysed, which means 59 years, while the long-term mean annual discharge for the period 1961–2000 reported by SHMI is $Q_{a\ 1961–2000} = 0.298\ m^3{\cdot}s^{-1}$.

The mean values of discharges were evaluated on a monthly basis (Fig. 2, Tab. 1), and an increasing trend is observed starting from November till April where the peak is usually reached in April or March for the whole study, the period is clearly confirmed. The monthly mean discharges start decreasing from April to reach their minimum in August, September, or October which complies with the summer-autumn low water period of the Slovak streams – months of August and September. The winter season can also be considered a low water period, especially the month of December. Generally, five monthly mean discharges surpass the threshold of $Q_{a\ 1961–2000}$ which are January, February, March, April, and May. Therefore, the normal and wet period for the Gidra River is taking a place between January and May, while the period from June till December tends to be below normal or dry as it is lower by at least 0.04 $m^3 \cdot s^{-1}$from the Q_a threshold.

Table 1 shows the minimum, maximum, and mean daily discharge values for each month over the period 1961–2020. Analysing the values of maximum daily mean discharge values distributed over monthly periods may indicate that large discharge values are more likely to occur from January till July (winter and spring seasons). Thus, the maximum daily mean discharges could be interpreted as a result of heavy rain or as a result of snow melting in the spring season (Fendeková and Blaškovičová, 2018). Large Maximum daily mean discharges are always indicators of floods of different types (usually flash and pluvial floods) (Sauquet and Lang, 2017). The daily minimum values of each month range between 0.02 $m^3 s^{-1}$ in August up to 0.61 $m^3 s^{-1}$ in April.

Comparing monthly mean discharges of March and April with the Q_a value confirms that discharge values in most cases surpass the Q_a threshold (Fig. 3). The exceedance rate of March mean discharges is 73% which is higher compared to the 65% exceedance rate in April. As a result, in the Gidra River, the monthly mean discharge

Fig. 1. Map of Slovakia with areas of interest – Gidra and Topľa River.

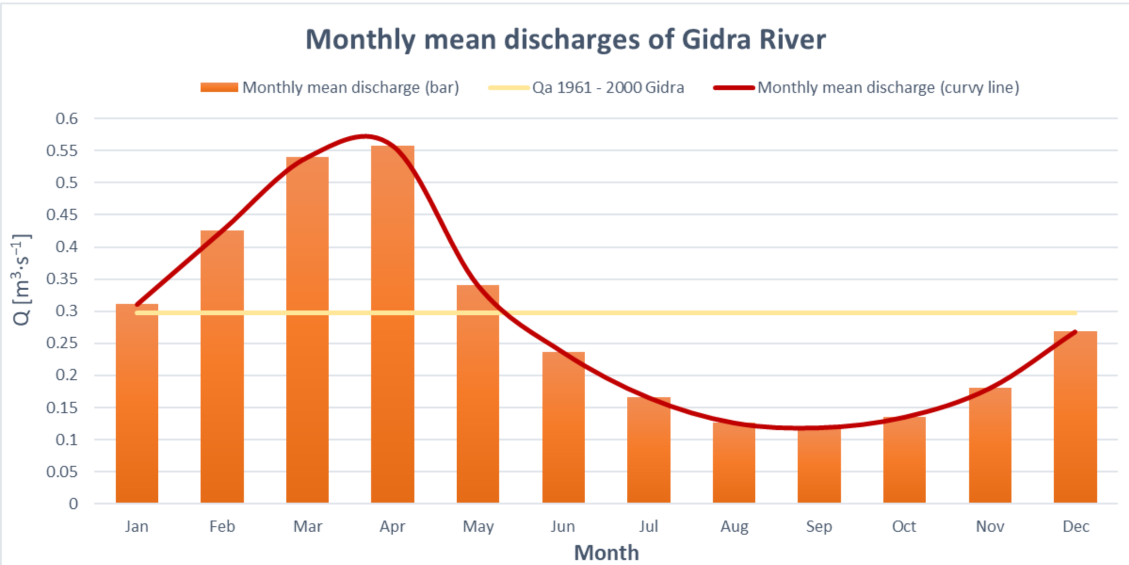

Fig. 2. Evaluation of the mean monthly discharges for the whole assessed period 1961–2020.

Table 1. Monthly mean discharges for the study period 1961–2020

month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Q_{min}	0.040	0.050	0.040	0.061	0.050	0.042	0.024	0.020	0.020	0.028	0.040	0.020
Q_{max}	4.974	4.090	6.473	4.810	4.060	4.880	5.552	2.210	2.546	3.651	1.627	3.698
Q_{mean}	0.310	0.432	0.540	0.554	0.340	0.236	0.165	0.126	0.118	0.135	0.181	0.267

in March is more likely to exceed the Q_a level than in April, making the March mean discharge value an indicator of the hydrological situation's normality.

Comparing the discharge values for August, September, and October over the period 1961–2020 (Fig. 4), the exceedance rates of these months are 7%, 5%, and 5%, respectively. In September and October, the monthly mean discharge values surpass the Q_a threshold only in three years, while the monthly mean discharges in August surpassed the Q_a threshold four times. These results confirm the finding of Fendeková (Fendeková and Blaškovičová, 2018), that most Slovak watercourses have a period of low flow in the summer and autumn (usually from August to October).

The trend of monthly mean discharges in the Gidra River over the period 1961–2020 is decreasing (Fig. 5), where the Gidra River basin is included among the highly vulnerable areas of Slovakia (GWP Slovakia, 2013). As well as the observation of the inhabitants of Malá Mača village in the lower section of the Gidra River (in the area above the confluence with Dudváh River). In 2017, a completely dry Gidra riverbed was recorded by them in the summer months. The previously mentioned information provides an insight into the hydrological situation in the Gidra River and indicates a real change in the hydrological regime.

The Topľa River

The spring of the Topľa River (Fig. 1) is located in the Čergov Mountains, under Minčol peak with an altitude of 975 to 1070 m a. s. l. The total length of Topľa River is 129.8 km, the basin area is 1 506 km² and it is a right-hand tributary of the Ondava River. Topľa was chosen as the representative of the highland-lowland stream (Frandofer and Lehotský, 2014). In the profile of the town of Bardejov in 103.50 rkm, where measured data on water stages since 1967 are available, the catchment area is 325.80 km^2 (SHMÚ, 2019).

The mean daily discharges for the period 1988–2020

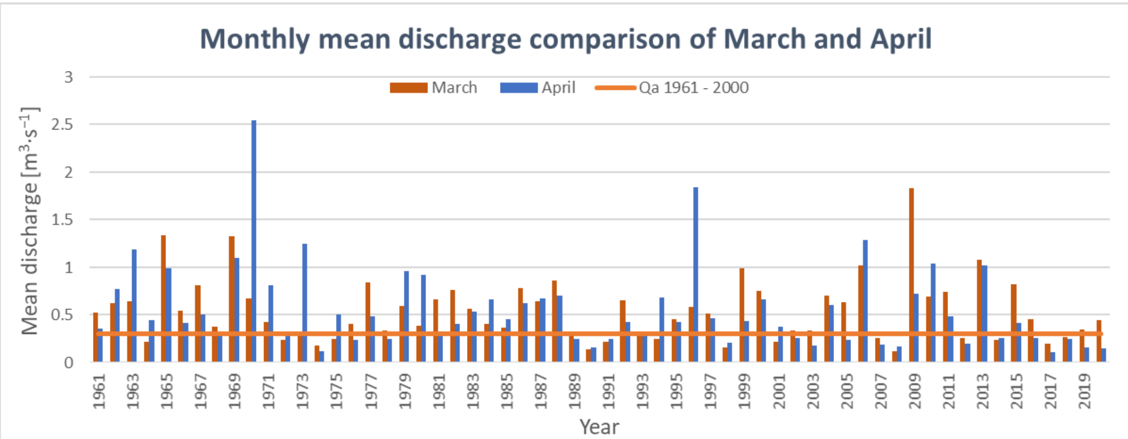

Fig. 3. Comparison of the monthly mean discharges of the most significant months – March and April from the viewpoint of the water content for the period 1961–2020.

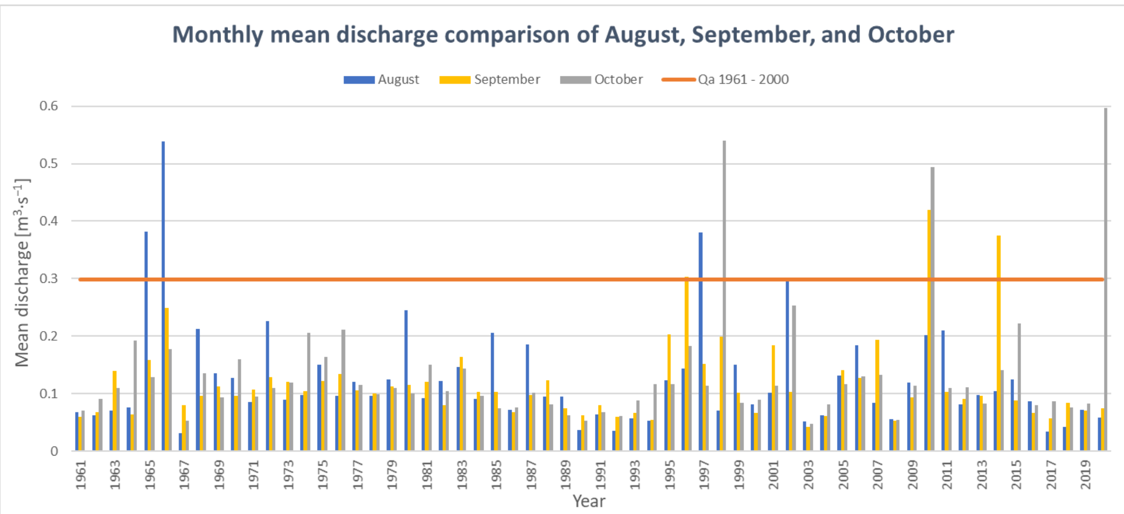

Fig. 4. Comparison of the monthly mean discharges of the driest months – August, September and October for the period 1961–2020.

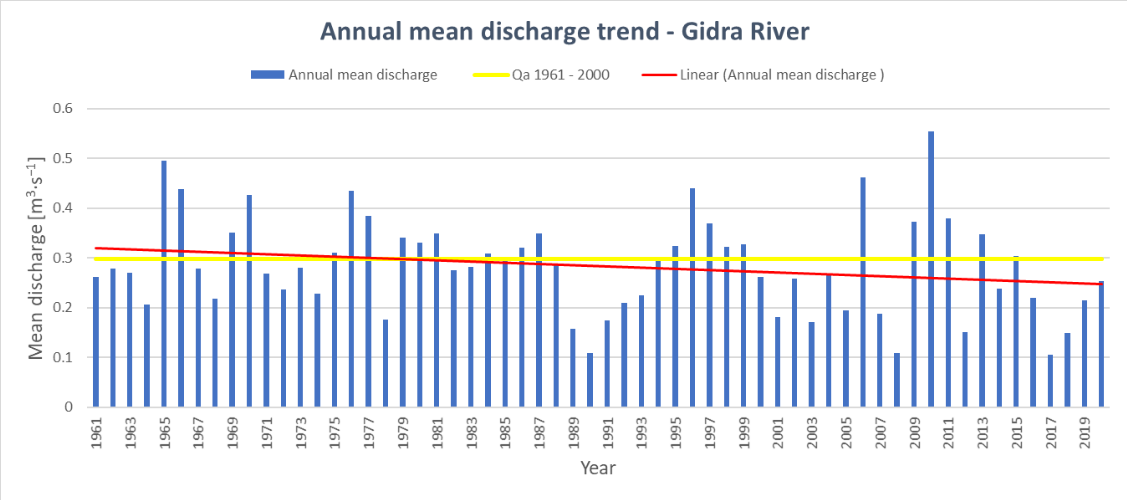

Fig. 5. Evaluation of the annual mean discharges for the period 1961–2020 with decreasing flow trend.

were analysed, which means 32 years, while the long-term mean annual discharge for the period 1961–2000 reported by SHMI is $Q_{a\ 1961–2000}$ = 2.978 $m^3 \cdot s^{-1}$.

The first Gerlachov gauging station is located in Topľa, 118.6 rkm, at an altitude of 358.39 m a. s. l., with a catchment area of 139.4 km^2. The second water gauging station is located in the town of Bardejov at an elevation of 265.05 m a. s. l., 103.5 rkm, and with a catchment area of 325.8 km^2 (Bačova Mitkova and Pekarova, 2019).

The daily mean discharges over the period 1988–2020 are utilized to extract the monthly mean discharge over the period 1988–2020 as shown in Fig. 6. Monthly mean discharges are represented in two different ways, the first one is a bar chart represented in blue and the other representation was a curvy line colored in orange. The long-term mean of the Topľa River over the period 1961–2000 is also plotted to compare the monthly discharges with the long-term mean which can be an indicator of the expected flow relative to Q_a threshold. The peak value of monthly mean discharge is mostly reached in March or April and there are three significant trends on the monthly mean discharges graph. The increasing discharge starts in January to reach a peak in March or April. then the decreasing trend appears starting from April till August or September where the steady trend of monthly discharges continues till December/ January. In the steady trend, we can notice that the discharge values range between 1.5–2 $m^3 \cdot s^{-1}$.

Only four monthly mean discharges surpass the threshold of $Q_{a\ 1961–2000}$ which are March April May and June while monthly mean discharges in February and July are usually ranged closely to the Q_a threshold. Therefore, the normal and wet period for the Topľa River is taking a place between February and July, while the period from August till January tends to be below normal or dry as it is lower by at least 1 $m^3 \cdot s^{-1}$ from the Q_a threshold.

Table 2 shows the minimum, maximum, and mean daily discharge values for each month over the period 1988–2020. Analysing the values of maximum daily mean discharge values distributed over monthly periods may indicate that flood events in Topľa River are likely to happen each month of the year. The maximum discharge value in June supports the findings of Fendeková that spring floods typically have larger volumes because they are usually the result of melting snow or, in some cases, a mixture of melting snow and rain (Fendeková et al., 2018).

As mentioned before, large maximum daily mean discharges are generally indicators of various types of floods (Sauquet and Lang, 2017). The daily minimum values of each month range between 0.21 $m^3 \cdot s^{-1}$ in June up to 1.195 $m^3 \cdot s^{-1}$ in April.

Comparing monthly mean discharges of March and April with the Q_a value confirms that discharge values in most cases surpass the Q_a threshold (Fig. 7). Where the exceedance rate of March mean discharges is 88% which is a higher rate compared to the 70% exceedance rate in April. The significant exceedance rate of March matches a high rate of exceedance in the Gidra River with a different magnitude.

Observing the discharge values of August, September, and October over the period 1988–2020 (Fig. 8) shows that the exceedance rates are 15%, 12% and 12% respectively. In September and October, the monthly mean discharge values surpass the Q_a threshold only in three years, while the monthly mean discharge in August surpassed Q_a threshold five times.

These findings support Fendeková's observation that the highest runoff occurs in the spring, and peak discharges likewise occur in the spring, primarily in March (Fendeková and Blaškovičová, 2018). Also, the increasing spring flow is also vital for runoff levels in the later months of each year (Hanus et al., 2021). There are two concentrated periods of low flow in the year – the summer-autumn depression inflow, which has its lowest point between August and October, and secondary winter depression, which has its lowest point usually in January (Fendeková and Blaškovičová, 2018).

The trend of monthly mean discharges in the Topľa River over the period 1988–2020 is slightly increasing which

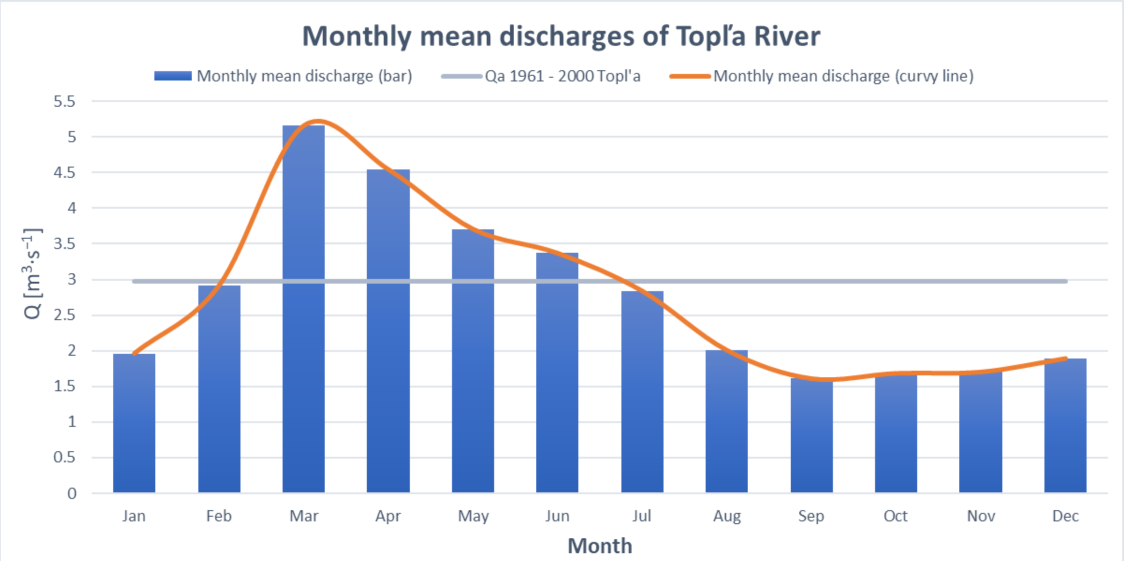

Fig. 6. Evaluation of the mean monthly discharges for the whole assessed period 1988–2020.

Table 2. Monthly mean discharges for the study period 1988–2020

month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Q_{min}	0.42	0.39	0.54	1.20	0.57	0.21	0.28	0.36	0.36	0.30	0.44	0.37
Q_{max}	15.81	48.01	97.63	33.53	65.40	173.57	80.77	42.38	31.50	22.43	18.74	19.11
Q_{mean}	1.96	2.91	5.16	4.54	3.71	3.37	2.84	2.01	1.61	1.68	1.70	1.89

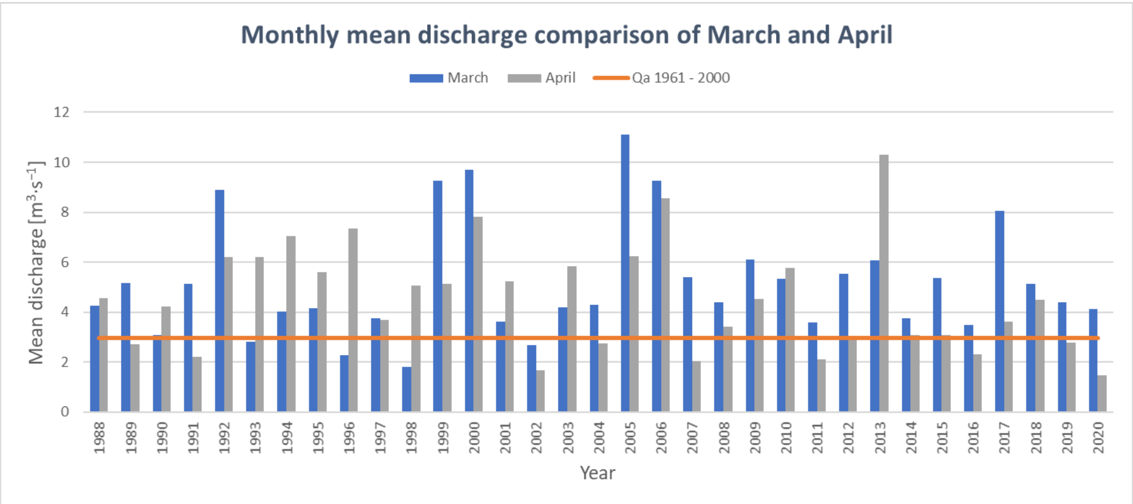

Fig. 7. Comparison of the monthly mean discharges of the most significant months – March and April from the viewpoint of the water content for the period 1988–2020.

can be interpreted as a result of floods events (Fig. 9). However, to reduce the effect of the megaflood that happened in 2010 on the annual mean discharge linear trend, the value of the annual mean discharge of 2010 was substituted by the mean discharge value over the period 1988–2020. The resulting linear trend incline decreased and the trend of the annual mean discharges is approximately steady.

Drought analysis:

Hydrological drought is characterized by low flow periods and is caused by decreasing river discharges. There are numerous indices for measuring and identifying drought, but the availability of different data kinds is the most important factor in determining which index to utilize. The water-bearing coefficient is used to assess the hydrological situation of each year because the daily mean discharge is the only data type used in this study (Almikaeel et al., 2022; GWP Slovakia, 2013).

The water-bearing coefficient is the ratio of annual mean discharge to the long-term mean discharge. This ratio is compared to standard intervals of dry, normal, wet to evaluate the hydrological situation of a stream. Standard water-bearing coefficient values describe the proportion of mean discharge in a certain period compared to the long-term mean, as shown in standard intervals. The standard intervals are classified into three groups (determine whether the year is dry, normal, or wet). The intervals are set as (10%–89%) for dry situations, (90%–110%) for normal situations, and (111%–more) for wet situations (GWP Slovakia, 2013).

The water-bearing coefficient is computed over the period 2010–2020 for both rivers using the annual mean discharge of a given year and the long-term mean given by SHMI (GWP Slovakia, 2013). As a result, the ratio of yearly mean discharge value to long-term mean discharge is compared to standard values that describe the river's normal, wet, and dry hydrological status.

Table 3 shows the evaluation of the hydrological situation using the water-bearing coefficient for the period 2010 to 2020. In the second column of the table, Q_{mean} represents the annual mean discharge of the corresponding year (first column), Q_{mean}/Q_a is the water-bearing coefficient for each river, and status is the corresponding value of the hydrological situation. The status is chosen based on the previously specified intervals to represent the hydrological situation using the water-bearing approach.

In both Gidra and Topľa Rivers, the last ten years were generally dry which confirms the findings of multiple studies (Almikaeel et al., 2022; Repel et al., 2021). Seven years over the period 2010–2020 are classified as dry years according to the water-bearing coefficient method. In the Gidra River, three years are considered as wet years and only one year as a normal year over the period 2010–2020.

A similar situation is observed in the Topľa River, where

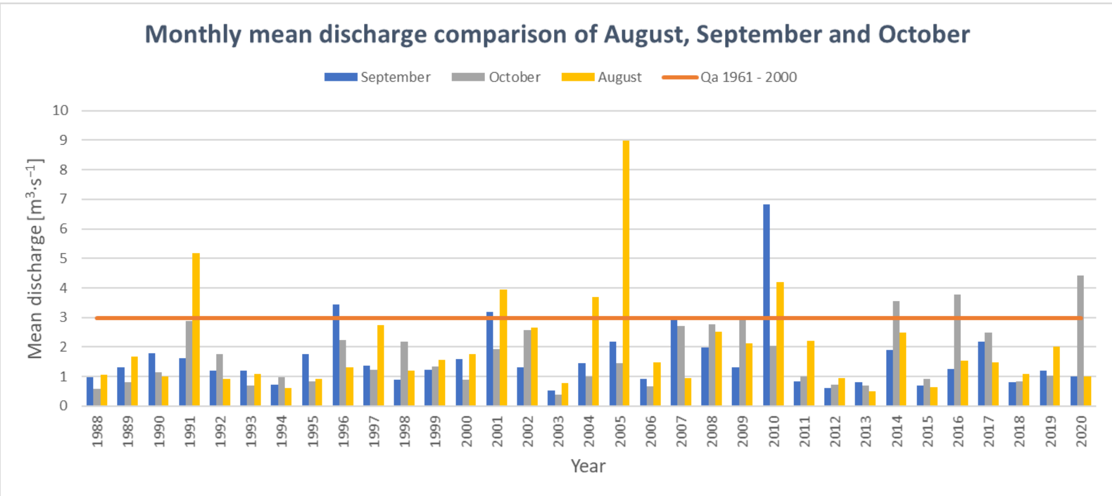

Fig. 8. Comparison of the monthly mean discharges of the driest months – August, September and October for the period 1988–2020.

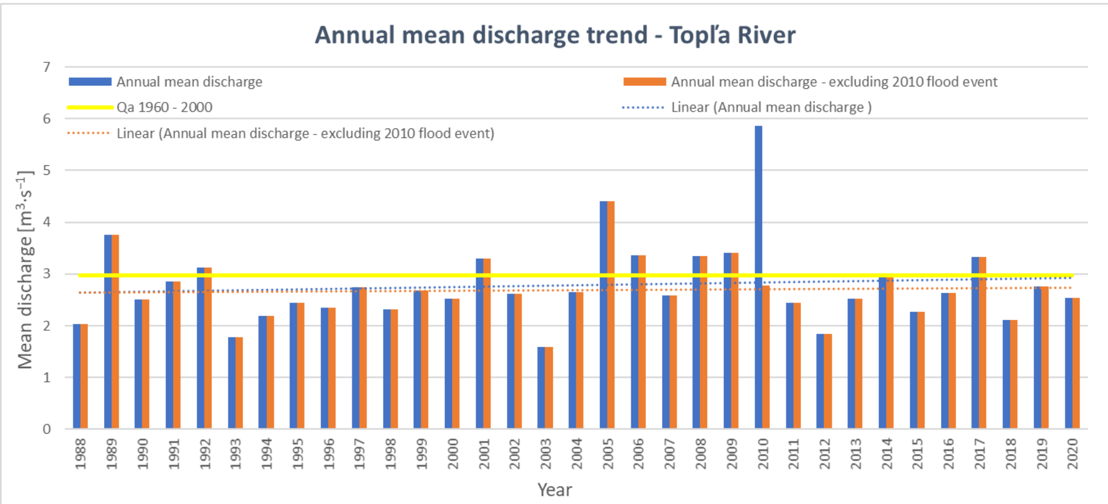

Fig. 9. Evaluation of the annual mean discharges for the period 1988–2020 with a steady (or slightly increasing) flow trend.

Table 3. **The hydrological drought assessment of Topľa and Gidra Rivers over the period 2010–2020**

	Gidra River			Topľa River		
year	Q_{mean}	Q_{mean}/Q_a	**Status**	Q_{mean}	Q_{mean}/Q_a	**Status**
2010	0.55	186%	Wet	5.86	197%	Wet
2011	0.38	127%	Wet	2.44	82%	Dry
2012	0.15	51%	Dry	1.84	62%	Dry
2013	0.35	117%	Wet	2.53	85%	Dry
2014	0.24	80%	Dry	2.98	100%	Normal
2015	0.30	102%	Normal	2.27	76%	Dry
2016	0.22	74%	Dry	2.63	88%	Dry
2017	0.11	35%	Dry	3.33	112%	Wet
2018	0.15	50%	Dry	2.11	71%	Dry
2019	0.21	72%	Dry	2.76	93%	Normal
2020	0.25	85%	Dry	2.54	85%	Dry

two years are considered as wet and also two years are classified as normal years. The water-bearing coefficient values of the Gidra River range from 35% up to 186% while the range for the Topľa River is located between 62%–197%. This means that drought situations in the Gidra River are more severe compared to the Topľa River over the period 2010–2020.

Normal years mean that the annual mean discharge in both rivers is 90% up to 110% of the long-term mean. The lack of normality is observed in both rivers in the last 10 years raises many questions about the main reason for facing such a dry period.

Conclusion and discussion

Based on the findings of previous analysis, both rivers have the typical characteristics of the under-mountain stream and highland-lowland river in terms of the increased spring runoff. The wetted period (increased run-off) of the Gidra River is generally occurring between January and May which is represented as the area under the mean discharge curve and above the corresponded Q_a threshold. The wetted period (increased run-off) of the Topľa River is generally occurring between February and July which is represented as the area under the mean discharge curve and above the corresponded Q_a threshold.

The Gidra river's runoff trend has been decreasing over the study period, implying a change in flow regime due to a variety of factors. Many researchers correlate the changing of discharge regime in mountainous regions directly to climate change. Snow evapotranspiration in mountainous regions is accelerated by climate change (Dankers and Christensen, 2005), which occurs in the season of snow accumulation and melting process. As a result, the predicted flow from snow melting is decreasing, causing a low rate of discharge in rivers (Meira Neto et al., 2020).

In the Topľa River, the trend of annual discharge is slightly increasing due to multiple flood events. Maximum daily mean discharge analysis of Topľa River includes relatively high values in each month of the year. Discharges in March in both rivers tend to exceed the Q_a more often than any other month in the analysis of both rivers.

Finally, some similarities and differences have been addressed in this study regarding both types of rivers, under-mountain and highland – lowland rivers. The results are presented as follow:

The similarities:

- Monthly mean discharge peak values are recorded in March and April.
- The highest exceedance rate of monthly mean discharge is recorded in March.
- The lowest level of monthly discharge values is observed in the summer and autumn seasons (August, September, October).

The differences:

- Maximum values of daily mean discharges are more likely to occur in any month for Topľa River, while large daily mean discharges of the Gidra River are more likely to occur in the first half of the year.
- The trend of annual mean discharge is decreasing in the Gidra River, while it is slightly increasing for the Topľa River.
- The mean wet period where the exceedance rate is high is slightly different for both rivers, January to May for the Gidra River, March to June for Topľa River, which confirms the findings of Fendeková.

Despite all the differences between Topľa and Gidra Rivers in terms of location, catchment size, type, and hydrological situation, drought and lack of normality were the dominant situations of both rivers over the period 2010–2020. There are a large number of factors that cause the different trends and behaviours we observe nowadays in terms of river flows and most of them are directly related to climate change. However, characterizing those changes or predicting them in advance may contribute to designing better water management decisions for all the problems that are associated with drought and low flow (Sýs et al., 2021).

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