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Challenges in selecting the new reference period for long-term hydrological characteristics in Slovakia

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Establishment of a new reference period is an ongoing topic in Slovakia as the currently used reference period is 1961–2000. This contribution focuses on the assessment of spatial and temporal changes in the mean long-term yearly discharges and long-term mean monthly discharges at 140 water-gauging stations. The years 2021 and 2022 have been further evaluated at selected 13 water-gauging stations to assess the possible impacts of using different reference periods (1991–2020, 1981–2020, 1971–2020 and 1961–2000) on the water management. The analyses have confirmed that there are significant changes between long-term values, especially for the period 1991–2020 compared with the reference period 1961–2000, with the highest negative changes in monthly discharges being in April and highest positive changes being in January. Evaluation of mean monthly and annual discharges in 2021 and 2022 for 13 selected water-gauging stations, according to the four above mentioned reference periods, has identified changes especially in set categories of monthly discharges. The same average monthly but also annual flows in one station have fallen into different assessment categories, in several cases. For annual flows the changes have manifested in 6 water-gauging stations in the year 2021 and 2 stations in the year 2022. The number of stations with changes in categories between different reference periods used for particular months have varied from 2 to 8 water-gauging stations in 2021 (62 cases for the whole year) and from 2 to 6 water-gauging stations in 2022 (40 cases for the whole year). The highest number of changes for both years were detected in June (14) and August and December (11). The selection of the reference period can therefore lead into different set of applied water management rules.

KEY WORDS: reference period, design values, mean monthly discharges, annual discharges

Introduction

As the climate change effects are becoming more pronounced, an understanding of spatial and temporal distribution of water resources is crucial for adaptation, management and mitigation of the effects of extreme hydrological situations.

Until the end of 2020, the most current and widely used standard reference period for calculating climate normal was the 30-year period 1981–2010. Recently the World Meteorological Organisation (WMO, 2020) recommends a 30-year period 1991–2020 for the purpose of the comparison of the hydrological and climatic characteristics. However, for the purposes of historical comparison and climate change monitoring, WMO recommends the 1961–1990 period for the computation and tracking global climate anomalies relative to a fixed and common reference period.

In the water management of Slovakia, the reference period 1961–2000 is currently valid in decision-making and hydrological regime evaluation (Šipikalová, 2005). However, various changes of hydrological regime were described in recent studies (Pekárová et al., 2017; Fendeková et al., 2018; Ďurigová and Hlavčová, 2020; Halmová et al., 2022; Poórová et al., 2023). Establishment of a new reference period is a sensitive topic, as the hydrological design values based on this reference period, are a vital part of many decision-making processes (e.g., flood protection, hydrological drought management, water use permits, etc.). Therefore a significant change in these limit values can start a cascade effect of changes in the water management, where the societal and economical effects are yet to be addressed.

This contribution focuses on the assessment of spatial and temporal changes in the mean long-term yearly discharges and long-term mean monthly discharges for the purpose of the establishment of a new reference period in Slovakia. The recent years 2021 and 2022 have been evaluated in comparison with selected reference periods 1991–2020, 1981–2020, 1971–2020 and 1961–2000, at selected water gauging stations to assess the possible impacts on the water management.

Material and methods

In Slovakia, the currently used 40-year long reference period (1961–2000) was preceded by a 50-year reference period 1931–1980 and the 30-year period 1931–1960. Therefore, we have focused on the comparison of 30-, 40- and 50-year long periods (1991–2020, 1981–2020, 1971–2020) with the reference period 1961–2000.

For the analysis, we have selected 140 mainly near natural water-gauging stations (WS) (WS with affected regime by the human influence are marked in the results, if relevant), with sufficiently long observation period (covering all analysed periods) (Fig. 1). WS are representing the main sub-basins in Slovakia: Morava (Slovak part only), Danube, Váh (assessed separately for sub-catchments with different regimes: Váh, Nitra and Malý Dunaj), Hron, Ipeľ, Slaná, Bodva, Hornád, Bodrog and Poprad (including Dunajec).

The long-term mean discharges and mean monthly discharges were computed for all three above-mentioned periods and compared with the long-term values of currently used reference period 1961–2000. We have used the hydrological years, i.e. from November to October.

The long-term values of all 4 periods have been also used for the classification of mean yearly discharges and mean monthly discharges for 2021 and 2022 in 13 selected WS in Váh sub-catchment, to see the differences in results by using different reference periods (Fig. 1).

Results

Mean long-term discharges (Q_a)

The % deviations of the mean long-term discharges (ΔQ_a [%]) for selected periods, from the values of the reference period, have differed in individual sub-catchments of Slovakia. However, the stations with the decrease of Q_a in all three periods (1971–2020, 1981–2020, 1991–2020) were prevailing compared with $Q_{a,1961\text{-}2000}$. Positive deviations have been observed mostly in the sub-basin of Poprad and Dunajec, as well as in the upper parts of sub-basins Váh and Hornád (Fig. 2). Comparing the changes in the three periods from

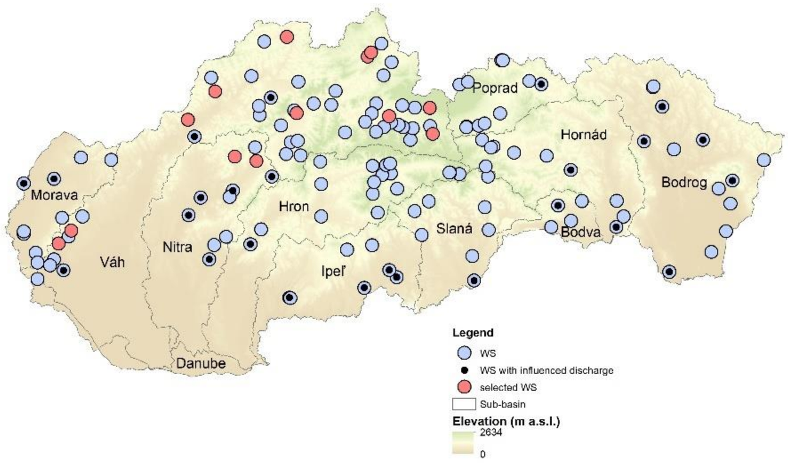

Fig. 1. Location of WS used in analysis, with marked WS with influenced discharge and selected 13 stations used for further analysis.

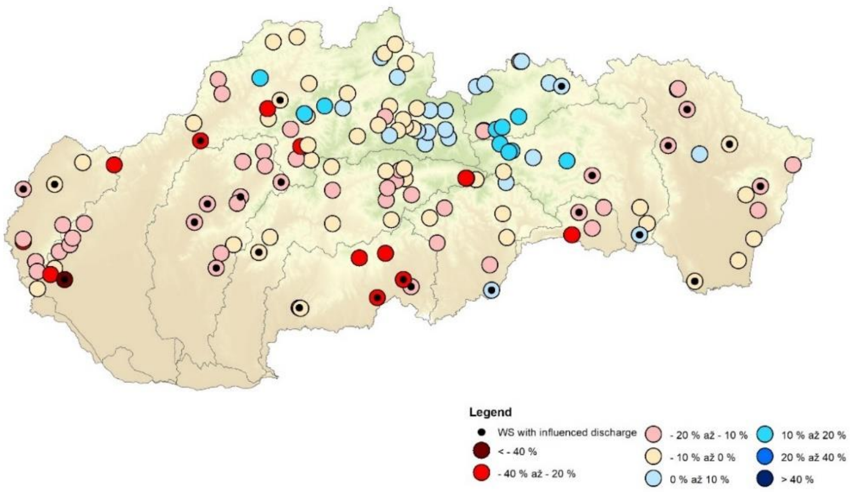

Fig. 2. Deviations [%] of mean long-term discharges for period 1991–2020 compared with reference period 1961–2000.

the period 1971–2020 to 1981–2020 toward period 1991–2020, the extremality of deviations of Q_a is in many cases increasing, both in positive and negative values. According to the average values of ΔQ_a [%] for individual sub-basins, most negative values for period 1991–2020 have been shown in sub-basins Bodva (-19.0%), Ipeľ (-17.8%), Morava (-14.9%) and sub-catchments of lower part of Váh sub-basin: Malý Dunaj (16.8%) and Nitra (-14.5%).
This can be seen also in the average values of ΔQ_a [%] for Slovakia. The values of average deviations are negative for all three evaluated periods, with higher magnitudes in two later periods ($\Delta Q_{a,1971-2020}$: -5.1%, $\Delta Q_{a,1981-2020}$: -7.9%, $\Delta Q_{a,1991-2020}$: -7.3%); in medians the changes are even higher (-5.2%; -8.4%; -8.6%). However, these values do not adequately describe the situation, as in all three periods the deviations in the individual sub-basins and water-gauging stations vary considerably both in positive and negative directions (Fig. 3) (minimum -34.9 % (Hosťovce – Bodva, sub-basin Bodva, period 1981-2020), maximum +19.5 % (Kežmarok – Ľubica, sub-basin Poprad and Dunajec, period 1991–2020).

Mean monthly discharges (Q_{ma})

The variability of the deviations of the mean long-term monthly discharges ΔQ_{ma} [%] in all three periods is much wider than for Q_a. The mean values of the deviations vary in the particular months, with largest magnitudes for most months in the period 1991–2020 and less for the period 1971–2020. The most extreme average deviations can be seen in April (negative deviation: -14.9%) and in January (positive deviation: +6.1%), both for period 1991–2020 (Table 1).
Extreme values for individual WS vary from -59.4% (August, 1991–2020, WS in sub-catchment of Malý Dunaj in Váh sub-basin) to +103.5% (September, 1991–2020, WS in Morava sub-basin).
Looking at the boxplot of the deviations for period 1991–2020 (Fig. 4), we can state, that the months with prevailing WS with negative deviations are December, April, May, June, July, August and October, while months with prevailing WS with positive deviations are November, January, February and September. March is the month with the least changes in Q_{ma} on average.

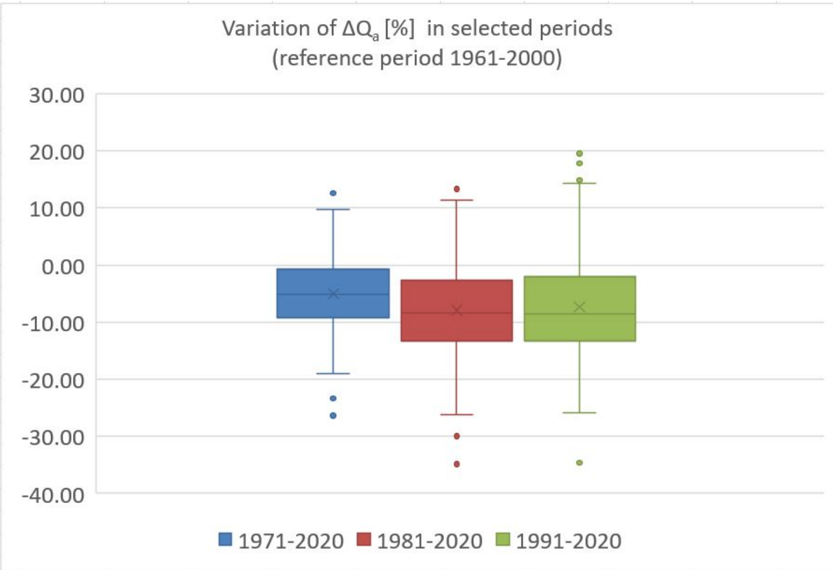

Fig. 3. Variations of ΔQ_a [%] of periods 1971–2020, 1981–2020 and 1991–2020 compared with reference period 1961–2000.

Table 1. Average deviations of mean long-term monthly discharges in the periods 1971–2020, 1981–2020 and 1991–2020 from the values of the reference period 1961–2000

ΔQ_{ma} [%] = $(Q_{ma,obd} - Q_{ma,ref})*100/Q_{ma,ref}$ - average for SR													
Period	11	12	1	2	3	4	5	6	7	8	9	10	Q_a
1971–2020	-4.7	-4.3	5.5	1.7	-3.4	-13.1	-4.6	-8.2	-6.8	-4.4	1.6	-1.5	-5.1
1981–2020	-5.6	-9.9	3.3	-3.4	-2.8	-14.6	-7.9	-9.8	-10.4	-7.8	1.4	-12.5	-7.9
1991–2020	0.1	-9.3	6.1	2.0	-1.8	-14.9	-13.9	-13.8	-6.5	-5.4	3.8	-7.1	-7.3

The results show, that the month with the most negative changes of $Q_{ma,1991\text{-}2020}$, in the terms of frequency of the occurrence of negative deviations from the reference period among the WS, is April. This is clearly visible also on Fig. 5.

The negative deviations in this month are present in the majority of the WS, with the exception of several WS in the north of Slovakia (High Tatras region), in the upper parts of the sub-basins of Poprad and Váh. The negative deviations with higher magnitudes occur mostly in southern half of the Slovak territory. Assessing the individual sub-basins, the worst situation in terms of negative deviations in prevailing number of WS and the magnitudes of the deviations for April, is in sub-basins of Morava, Ipeľ, Bodva, and Nitra and Malý Dunaj (sub-catchments of Váh). The average of deviations in these sub-basins are as follows: -30.1% (Malý Dunaj), -29.1% (Bodva), -27.7% (Ipeľ), -22.5% (Morava), -19.5% (Nitra). The situation is similar in May.

Positive changes have been observed mostly in January, and also in September. The higher magnitudes of ΔQ_{ma} [%] in January can be seen mainly in the mountainous areas (Fig. 6). This is connected with the phenomena of the earlier snowmelt at the beginning of the year, as one of the consequences of the climate change. In the Poprad River basin (High Tatras region), the higher positive magnitudes of ΔQ_{ma} [%] are shifted to February.

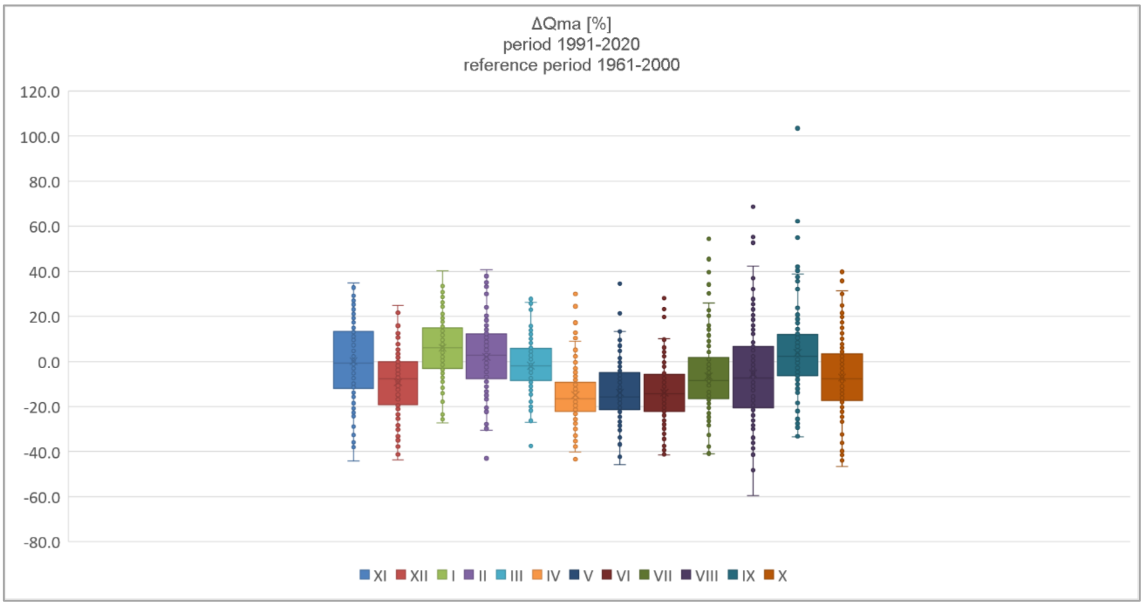

Fig. 4. ΔQ_{ma} [%] of period 1991–2020 compared with reference period 1961–2000.

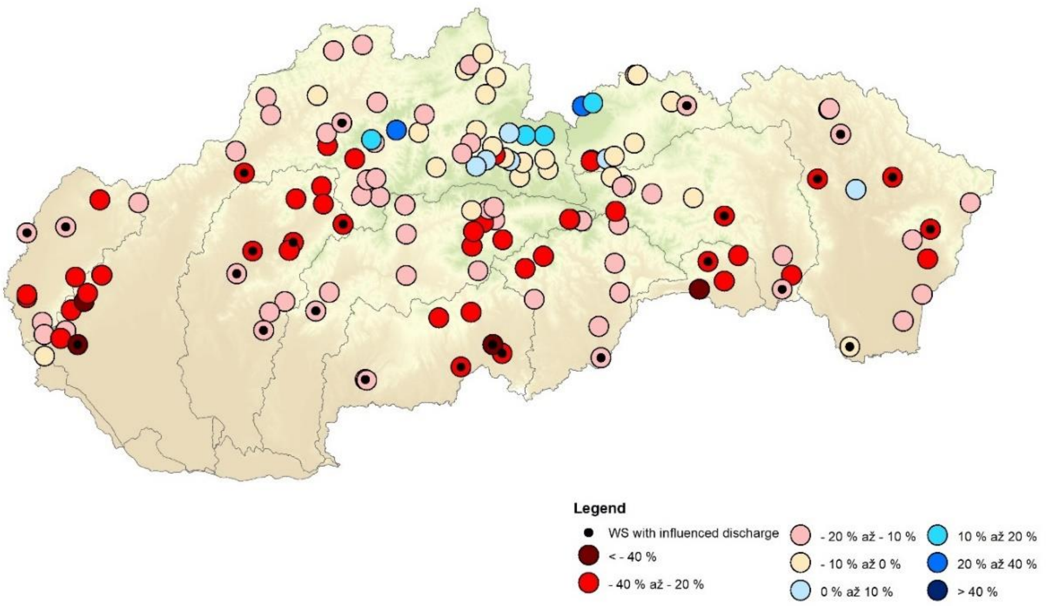

Fig. 5. ΔQ_{ma} [%] in April for period 1991–2020 compared with reference period 1961–2000.

Situation in the individual sub-basins

The situation vary between particular sub-basins, and also among WS inside individual sub-basins. Especially for larger sub-basins, the deviations in WS can vary significantly, according to different hydrogeological and morphological conditions in upper and lower parts of the basins. In the sub-basins, where the most significant negative deviations of Q_a have been identified, the prevailing number of the months of the year is with negative values of ΔQ_{ma} [%] as well. This can be seen on Table 2, where the median values of ΔQ_{ma} [%] for individual sub-basins are listed. The Nitra sub-catchment is the only one, where the medians of ΔQ_{ma} [%] are negative in all months of the year, with greatest magnitudes in December (-25.1%) and then in April, May, June, and August (around -20%). The other sub-basins with more or equal than 10 months of the year with negative medians of ΔQ_{ma} [%] are Morava, Bodva, Ipeľ and sub-catchment Malý Dunaj.

The highest magnitudes of negative deviations (median values for sub-basin) have been identified in Ipeľ sub-basin (-33.2% in May for period 1991–2020) (Fig. 7). There are visible increases of the magnitudes of median deviations among the three consecutive periods in April and May. However, comparing the values of medians of ΔQ_{ma} for all three periods we can see the changes in months August and September, where the negligible values (less than 1%) in period 1971–2020 were replaced by negative values in period 1981–2020 (-4.0%, -7.9%), and then by positive values in period 1991–2020 (+10.1%; +3.0%).

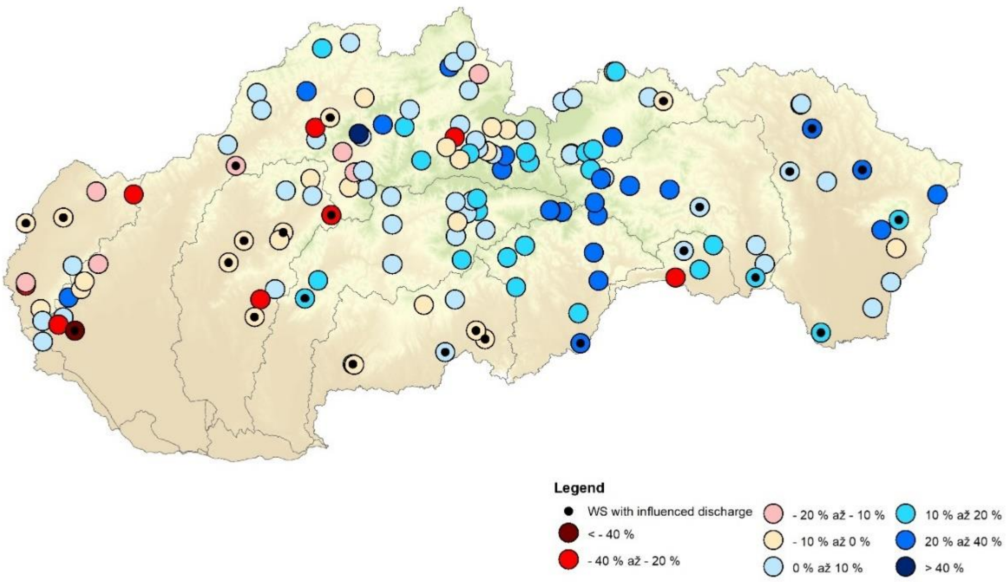

Fig. 6. ΔQ_{ma} [%] in January for period 1991–2020 compared with reference period 1961–2000.

Table 2. ΔQ_{ma} [%] for period 1991–2020 vs reference period 1961–2000 – median values for sub-basins

ΔQ_{ma} [%] = $(Q_{ma,1991-2020} - Q_{ma,1961-2000})*100/Q_{ma,1961-2000}$ - median													
Sub-basin	11	12	1	2	3	4	5	6	7	8	9	10	Q_a
P	18.6	-3.2	6.6	13.9	6.2	-0.4	5.1	0.9	11.6	-2.9	13.6	10.2	5.2
M	-4.7	-23.2	-9.9	-15.8	-3.4	-20.7	-18.5	-22.9	-18.1	-21.2	8.1	9.9	-13.8
D	-4.2	-10.5	6.6	-6.1	3.9	-12.1	-14.2	-14.1	-13.1	-8.0	24.2	3.0	-6.8
V	6.1	-9.8	3.9	7.9	3.8	-9.9	-11.9	-15.1	-3.7	-9.4	1.0	-3.2	-4.1
N	-9.6	-25.1	-6.1	-10.1	-9.7	-20.2	-19.8	-20.5	-16.6	-20.0	-2.8	-5.3	-13.6
MD	-15.7	-15.9	-3.0	-11.3	-3.4	-29.1	-25.3	-16.9	-22.3	-20.3	9.0	8.9	-14.3
R	-4.6	-4.1	9.3	2.3	-1.5	-17.3	-24.2	-20.9	-6.4	6.3	-0.6	-17.1	-9.7
I	-21.7	-13.6	-0.6	-12.7	-17.9	-28.8	-33.2	-12.9	-8.6	10.1	3.0	-24.6	-21.0
S	-2.2	0.5	21.7	1.6	-5.6	-17.1	-19.2	-4.6	-7.7	16.0	8.5	-18.2	-7.9
A	-13.2	-12.2	11.2	-15.0	-8.6	-26.9	-22.4	-9.8	-19.3	-15.7	-16.6	-21.5	-15.4
H	18.3	13.3	13.1	9.3	4.6	-15.0	-7.9	-2.3	21.6	21.3	19.1	2.1	5.0
B	3.4	-8.0	13.2	7.3	-7.3	-19.0	-7.8	-14.2	-23.7	-17.3	-17.6	-17.2	-9.7

LEGEND of sub-basins/sub-catchments: P-Poprad, M-Morava, D-Danube, V-Váh, N-Nitra, MD-Malý Dunaj, R-Hron, I-Ipeľ, S-Slaná, A-Bodva, H-Hornád, B-Bodrog

The sub-basin with most positive changes in Q_{ma} identified is Poprad (including Dunajec), Fig. 8. The highest positive medians of ΔQ_{ma} can be seen in November, February and September, however, positive deviations are also in January, May, July and October. In December we can see the change of the positive value in the period 1971-2020 (+2.2%), small negative magnitude in period 1981-2020 (-0.5%) to negative deviation -3.2%. Other months with negative medians of ΔQ_{ma} are April and August, however in April there is visible decreasing of the negative magnitude towards the third period (-7.1%; -5.5%; -0.4%). This is the opposite trend in April compared to most of the other sub-basins. Another change from negative value to positive shows in June, however the magnitudes are not significant.

Danube River itself presents a different hydrological regime than the rest of Slovak streams, as the majority of the waters of this significantly bigger river does not originate from Slovak territory. However, we have noticed changes also on this river (Fig. 9). Negative changes we can see in the deviations of Q_a in all 3 periods (-2.3%; -1.8%; -2.4%). Negative changes in Q_{ma} are visible in months December and April to August, with highest magnitude in July (-8.3%; -11.7%; -13.3%). Positive deviations have been identified in November, January, March, September and October, being highest in January (+8.3%; +11.1%; +9.6%).

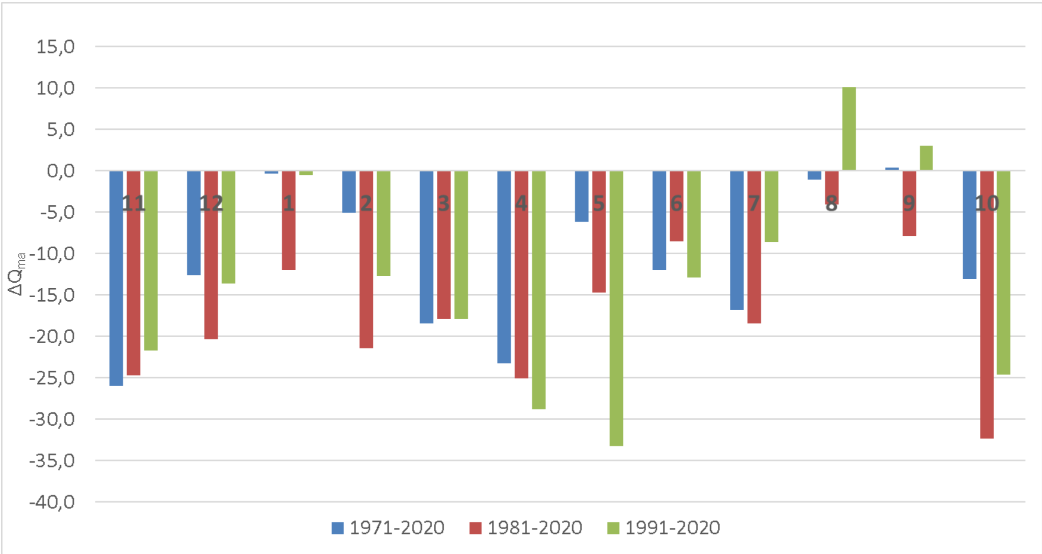

Fig. 7. Median values of ΔQ_{ma} for periods 1971–2020, 1981–2020 and 1991–2020 compared with reference period 1961–2000, sub-basin Ipeľ.

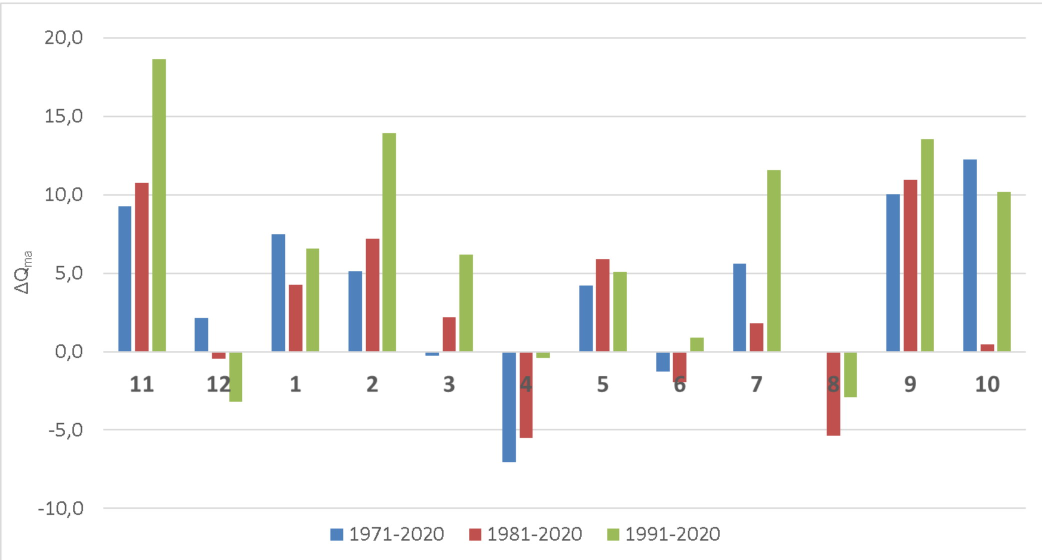

Fig. 8. Median values of ΔQ_{ma} for periods 1971–2020, 1981–2020 and 1991–2020 compared with reference period 1961–2000, sub-basin Poprad.

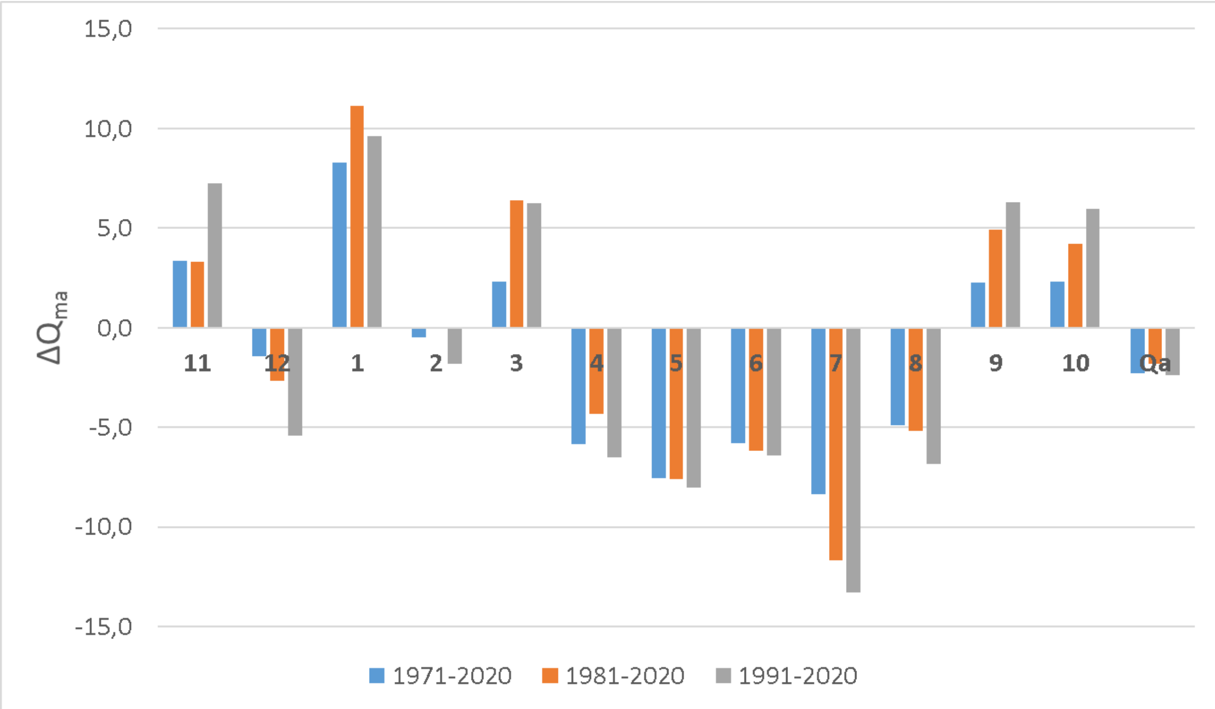

Fig. 9. *ΔQ_{ma} and ΔQ_a for periods 1971–2020, 1981–2020 and 1991–2020 compared with reference period 1961–2000, WS Bratislava – Danube.*

Assessment of the selected WS in 2021 and 2022

We have evaluated mean monthly discharges (Q_m) and mean yearly discharges (Q_r) in 13 selected WS in the sub-basins of Váh River basin (including sub-catchments Malý Dunaj and Nitra) for calendar years 2021 and 2022. These years have been chosen as two hydrologically different years (2021 being normal and 2022 being dry in average runoff in Slovakia). The values of Q_r and Q_{ma} have been assessed according to four reference periods: 1961–2000, 1971–2020, 1981–2020 and 1991–2020.
The Q_r values (Table 3) in the evaluated WS in 2021 ranged from normal, subnormal to dry year categories. Q_r in two WS (Dohňany – Biela Voda, Horné Sŕnie - Vlára) in the middle part of the Váh sub-basin were assessed as dry year when comparing Q_r with the long-term values of Q_a for reference period 1961–2000, for other reference periods, the Q_r in these WS was assessed as subnormal. In three WS (Pezinok – Blatina, Píla - Gidra, Nedožery - Nitra) in the lower part of the sub-basin and in one WS in the upper part of sub-basin (Čierny Váh - Ipoltica), a difference in a placement into a category was detected, when Q_r values were evaluated according to reference period 1961–2000 (subnormal year) and reference periods 1981–2020 and 1991–2020 (in one case also 1971–2020) (normal year). The assessment in six WS (Podbanské - Belá, Liptovský Mikuláš - Váh, Lokca - Biela Orava, Oravská Jasenica - Veselianka, Martin - Turiec, Čadca - Kysuca) was in the same categories for all reference periods (normal/subnormal years).
The Q_r values in 2022 were at the level of the normal, subnormal, dry and very dry year categories, while the values of Q_r in dry to very dry year categories were classified in WSs mainly in the lower half of the Váh sub-basin, including WS on Kysuca. Changes of categories within one WS according to different reference periods were manifested only in two WS (Martin - Turiec, Liešťany - Nitrica).
The assessment of Q_m has shown bigger differences between categories related to particular reference periods. The number of stations with changes in categories between different reference periods used for particular months vary from two to eight WS in 2021 (62 cases for the whole year) and from two to six in 2022 (40 cases for the whole year). The months with highest number of such cases for both years is June (14) and August and December (11). Generally, more cases were in the less dry year 2021. The example of difference in years for the month July, which was dry for both evaluated years, is shown in Table 4; however, it was more significantly dry in 2022. There is one case in 2021 in WS in lower part of the Váh sub-basin (Pezinok - Blatina) where, according to the reference period used, there are 3 categories of the assessment of the month: from dry (ref. period 1961–2000), significantly sub-normal (ref. periods 1981–2020 and 1991–2020) to sub-normal month (ref. period1971-2020). There are changes in categories in seven WSs (Podbanské - Belá, Martin - Turiec, Čadca - Kysuca, Dohňany - Biela Voda, Nedožery - Nitra, Liešťany - Nitrica, Pezinok - Blatina) in 2021, but only two cases (Nedožery - Nitra, Liešťany - Nitrica) in 2022.
Less number of changes in categories was found in January (four cases for both years), March (6) and

September (5). January was relatively wet in both years in the majority of WS and we can see quite uniform results for individual WSs (two cases of the changes in categories per year) (Table 5).
The most extreme deviations of % values of Q_m evaluated according to reference periods 1971–2020, 1981–2020 and 1991–2020, from the values of reference period 1961–2020, have been identified as follows: the negative deviations with highest magnitudes occurred mostly in January and February (about -50%, mainly in the upper part of the sub-basin), the positive deviations appeared mainly in the lower half of the sub-basin (up to +129% in 2021). Comparing the three reference periods, the most extreme values of % deviations have been identified in the period 1991–2020.

Table 3. Assessment of Q_r in 2021 and 2022 according to four reference periods

WS	Čierny Váh - Ipoltica	Podbanské - Belá	L. Mikuláš - Váh	Lokca - Biela Orava	Or. Jasenica - Veselianka	Martin - Turiec	Čadca - Kysuca	Dohňany - Biela Voda	Horné Srnie - Vlára	Nedožery - Nitra	Liešťany - Nitrica	Pezinok - Blatina	Píla - Gidra
ref. period	2021												
1961–2000	89.8	99.3	99.0	82.8	75.8	91.4	79.0	69.7	69.3	82.7	96.0	84.4	81.2
1971–2020	90.0	97.0	100.0	81.3	76.3	94.2	81.5	75.4	72.4	89.5	104.4	101.8	88.4
1981–2020	92.4	98.6	102.0	83.0	78.3	95.4	83.0	77.2	72.7	91.7	107.8	102.2	90.3
1991–2020	88.4	96.4	99.4	80.4	79.0	93.6	83.6	79.7	74.2	94.1	109.4	95.2	90.9
	2022												
1961–2000	67.8	92.8	78.9	98.9	85.5	68.7	65.9	45.3	36.8	53.9	61.8	16.0	25.5
1971–2020	67.9	90.7	79.7	97.2	86.1	70.8	67.9	49.0	38.5	58.3	67.2	19.3	27.8
1981–2020	69.8	92.2	81.3	99.1	88.3	71.7	69.2	50.2	38.6	59.7	69.4	19.4	28.4
1991–2020	66.7	90.1	79.2	96.1	89.1	70.3	69.7	51.8	39.4	61.3	70.4	18.0	28.5

LEGEND

$Q_r / Q_{a,ref}$ [%]	Category of the year
0 – 40	very dry
40 – 70	dry
70 – 90	sub-normal
90 – 110	normal
110 – 130	above normal
130 – 160	wet
> 160	very wet

Table 4. Assessment of $Q_{m,VII}$ in 2021 and 2022 according to 4 reference periods

WS	Čierny Váh - Ipoltica	Podbanské - Belá	L. Mikuláš - Váh	Lokca - Biela Orava	Or. Jasenica - Veselianka	Martin - Turiec	Čadca - Kysuca	Dohňany - Biela Voda	Horné Srnie - Vlára	Nedožery - Nitra	Liešťany - Nitrica	Pezinok - Blatina	Píla - Gidra
ref. period	2021												
1961–2000	56.4	56.6	63.7	31.3	20.2	56.9	17.9	19.4	23.4	78.4	129.7	39.5	40.4
1971–2020	53.9	57.5	64.1	34.0	22.5	61.4	21.1	23.7	27.6	92.0	151.8	60.7	48.1
1981–2020	55.0	61.4	65.9	35.4	23.4	61.2	22.4	26.5	30.0	96.6	160.4	57.9	50.3
1991–2020	50.4	60.0	62.2	33.4	22.2	58.3	21.2	26.8	28.0	97.9	155.5	47.0	47.3
	2022												
1961–2000	33.3	40.4	35.5	22.1	21.5	36.5	21.3	11.6	7.0	38.6	39.1	3.4	16.1
1971–2020	31.8	41.0	35.7	24.0	24.0	39.4	25.0	14.2	8.2	45.3	45.8	5.2	19.1
1981–2020	32.4	43.8	36.7	25.0	24.9	39.2	26.5	15.8	9.0	47.6	48.4	5.0	20.0
1991–2020	29.7	42.8	34.6	23.6	23.7	37.4	25.1	16.0	8.3	48.2	46.9	4.1	18.8

LEGEND

$Q_m / Q_{ma,ref}$ [%]	Category of the month
0 – 20	extremely dry
20 – 40	dry
40 – 60	significantly sub-normal
60 – 80	sub-normal
80 – 120	normal
120 – 160	above normal
160 – 200	significantly above normal
> 200	extremely wet

Table 5. Assessment of $Q_{m,I}$ in 2021 and 2022 according to 4 reference periods

WS	Čierny Váh - Ipoltica	Podbanské - Belá	L. Mikuláš - Váh	Lokca - Biela Orava	Or. Jasenica - Veselianka	Martin - Turiec	Čadca - Kysuca	Dohňany - Biela Voda	Horné Sŕnie - Vlára	Nedožery - Nitra	Liešťany - Nitrica	Pezinok - Blatina	Pila - Gidra
ref. period	2021												
1961–2000	125.9	117.3	131.4	108.2	80.6	182.6	113.4	132.8	182.9	152.4	187.0	252.9	188.5
1971–2020	116.0	114.0	122.9	91.7	72.4	166.6	101.5	122.0	174.5	148.0	181.3	229.4	185.7
1981–2020	116.7	113.0	124.2	92.3	73.1	169.1	104.6	123.2	176.4	148.3	184.3	223.1	186.2
1991–2020	109.1	111.8	120.4	88.9	74.4	166.4	105.2	131.7	179.3	150.6	182.4	200.9	193.0
	2022												
1961–2000	96.0	169.5	138.7	278.2	204.6	115.2	163.7	87.2	65.7	87.2	78.8	37.2	36.5
1971–2020	88.5	164.8	129.7	235.8	183.9	105.2	146.6	80.1	62.7	84.7	76.4	33.8	36.0
1981–2020	89.0	163.3	131.1	237.5	185.7	106.7	151.1	80.9	63.3	84.8	77.7	32.8	36.1
1991–2020	83.2	161.5	127.1	228.6	189.0	105.0	151.8	86.5	64.4	86.2	76.8	29.6	37.4

LEGEND

$Q_m / Q_{ma,ref}$ [%]	Category of the month
0 – 20	extremely dry
20 – 40	dry
40 – 60	significantly sub-normal
60 – 80	sub-normal
80 – 120	normal
120 – 160	above normal
160 – 200	significantly above normal
> 200	extremely wet

Discussion and conclusion

The comparison of the long-term values of Q_a and Q_{ma} for periods 1971–2020, 1981–2020 and 1991–2020 with the currently valid reference period in Slovakia (1961–2000) has been made in selected water-gauging stations. The results are in line with the findings of previous national studies (Blaškovičová et al., 2019, 2020; Poórová et al., 2018), which have focused on the analyses of the changes in runoff in last decades. These studies have pointed to the fact, that the differences in the runoff distribution throughout the year as well as other changes in hydrological characteristics (long-term values, extreme discharges connected with floods and droughts, their frequency and duration, etc.), is attributed mostly to the climate change, and are becoming more significant. The changes in discharge in Slovak streams, according to the results of this article, show the decrease of long-term values in most parts of Slovakia. The increase of Q_a has been identified in the northern part of Slovak territory, in Poprad and Dunajec sub-basin and the upper parts of sub-basins Váh and Hornád. Among the three evaluated periods, these changes are more pronounced in the period 1991–2020, than for periods 1971–2020 and 1981–2020. This logically follows from the fact, that the period 1971–2020 overlaps with the reference period 1961–2000 to a much greater extent than the last considered one. The 30-year period 1991–2020 is more influenced by the 20-year period after 2000 with significantly increased manifestations of the effects of climate change in hydrological regime of Slovak streams. Similarly, the changes in the runoff distribution in the year are most significant for the period 1991–2020 in the majority of the evaluated WS. The changes in Q_{ma} are showing the positive deviations in average in January, February and September; for the rest of the months we can see the negative deviations in average, being most important in April.

The comparison of the three periods of different length (50-, 40- and 30-years) is connected with the general problem of the recommended length of the reference period in hydrology. This follows from the long-term regime of flow fluctuations and its rules. Kašpárek (2000) in Czech region, with similar climatic conditions as Slovakia, does not recommend extending the primary period over 50 years, as far as they are considered to be stationary. It is more appropriate to limit the length of the data series to 40 - 50 years, to reduce the possible errors corresponding to long-term fluctuations in precipitation. Pekárová et al. (2003) identified 28-year cycle in the large rivers of Europe and World. This points to the possible suitability of using a 30-year period, especially if the aim is to provide the basis for proposals for solutions and measures in the sense of a forecast for the future, not an evaluation of a long-term regime. The results in Poórová et al. (2023) indicated as well, that the use of the 30-year long period 1991–2020 is probably suitable, especially for mutual comparison between climatic and hydrological characteristics for climate change research.

The period 1991–2020 is the one recommended by WMO as the reference period for current assessment of hydrological situation, to be comparable with climatic assessment based on the same reference period. However, for long-term comparison as well as climate change assessment, there is the recommendation to use the period 1961–1990. This is quite close to the period 1961–2000, currently valid as reference period for surface water hydrology in Slovakia. It is therefore important to consider for what purpose which reference period is used. On the example of the assessment of Q_r and Q_m in selected WSs in the Váh sub-basin for the years 2021 and 2022 according to different reference periods, it can be seen that the same average monthly but also annual flows in one station can fall into different assessment categories. This is especially important in the periods of low flows, when the water use needs to be carefully managed to provide the necessary balance between the requirements of the users and the ecological status of waters. The differences in evaluated categories can thus lead into different set of applied water management rules.

This study covers only one part of the evaluation, focused on long-term values analyses. More detailed analyses (the assessment of the data series of monthly discharges, yearly discharge analyses are partially published in Poórová et al., 2023, daily and extreme discharges, long term trends, precipitation, etc.) are needed to fully support the selection of the new reference period (or more of them for specific purposes) used for the water management and decision making needs.

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References

Blaškovičová L. (Ed.) (2019): Hodnotenie hydrologického sucha, časť 2: Hodnotenie zmien a trendov mesačných a ročných prietokov, čiastková správa. 64 s. SHMÚ, ISBN 978-80-99929-14-3. (in Slovak)

Blaškovičová L. (Ed.) (2020): Hodnotenie hydrologického sucha, časť 3: Hodnotenie M-denných prietokov a neprietokových charakteristík, čiastková správa. 92 s. SHMÚ, ISBN 978-80-99929-26-6. (in Slovak)

Ďurigová, M., Hlavčová, K. (2020): The detection of changes in the upper Váh river basin according to a decadal analysis. Acta Hydrologica Slovaca, 21, 1, 39–47; DOI: https://doi.org/10.31577/ahs-2020-0021.01.0005.

Fendeková, M., Gauster, T., Labudová, L., Vrablíková, D., Danáčová, Z., Fendek, M., Pekárová, P. (2018): Analysing 21st century meteorological and hydrological drought events in Slovakia. Journal of Hydrology and Hydromechanics, 66, 4, 393–403.

Halmová, D., Pekárová, P., Podolinská, J., Jeneiová, K. (2022): The assessment of changes in the long-term water balance in the Krupinica River basin for the period 1931–2020. Acta Hydrologica Slovaca, 23, 1, 21–31; DOI: https://doi.org/10.31577/ahs-2022-0023.01.0003.

Kašpárek, L. (2000): Vliv kolísaní klimatu na postup výpočtu návrhových hydrologických dat, Hydrologické dny 2000, Plzeň, Zborník konferencie. (in Czech)

Pekárová, P., Miklánek, P., Pekár, J. (2003): Spatial and temporal runoff oscillation analysis of the main rivers of the world during the 19th – 20th centuries. Journal of Hydrology, 274, 1–4, 62–79, https://doi.org/10.1016/S0022-1694(02)00397-9.

Pekárová, P., Miklánek, P., Pekár, J., Pramuk, B. (2017): Identifikácia zmien režimu denných prietokov slovenských riek II. časť: Porovnanie dvoch období [Identification of the Slovak rivers daily discharge regime changes. Part II.: Comparison of the two periods]. Acta Hydrologica Slovaca, 18, 2, 183–192; ISSN 2644-4690. (in Slovak)

Poórova, J. (Ed.) (2018): Hodnotenie hydrologického sucha, časť 1: Hodnotenie vodnosti roka a zmien rozdelenia odtoku v roku, čiastková správa, 110 s, SHMÚ, ISBN 978-80-99929-09-9. (in Slovak)

Poórová, J., Jeneiová, K., Blaškovičová, L., Danáčová, Z., Kotríková, K., Melová, K., Paľušová, Z. (2023): Effects of the Time Period Length on the Determination of Long-Term Mean Annual Discharge. Hydrology, 10, 88. https://doi.org/10.3390/hydrology10040088.

Šipikalová, H. (Ed.) (2005): Spracovanie hydrologických charakteristík - Koordinácia, Záverečná správa čiastkovej výskumno-vývojovej úlohy 3030-05, SHMÚ. (in Slovak)

WMO (2020): Statement on the term Hydrological Normal, Hydrological Coordination Panel. Available online: https://community.wmo.int/activity-areas/hydrology-and-water-resources/hydrological-coordination-panel (accessed on 27.1.2023).

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