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REGULARITIES OF VARIABILITY IN AVERAGE MONTHLY FLOW RATES DURING THE LOW-WATER PERIOD IN THE RIVERS OF BELARUS

***S. V. Sidak*[1]*, A. A. Volchak*[2]*, S. I. Parfomuk*[3]*, V. A. Kofanov*[4]**

[1] *Senior Lecturer of the Department of Mathematics and Informatics, Brest State Technical University, Brest, Belarus, e-mail: harchik-sveta@mail.ru*
[2] *Doctor of Geographical Sciences, Professor, Professor of the Department of Environmental Management, Brest State Technical University, Brest, Belarus, e-mail: volchak@tut.by*
[3] *Ph.D in Engineering, Associate Professor, Head of the Department of Mathematics and Informatics, Brest State Technical University, Brest, Belarus, e-mail: parfom@mail.ru*
[4] *Ph.D in Engineering, Associate Professor, Associate Professor of the Department of Mathematics and Informatics, Brest State Technical University, Brest, Belarus, e-mail: vakofanov@g.bstu.by*

Abstract

The research is devoted to the study of long-term dynamics of fluctuations in average monthly flow rates during the summer-autumn and winter low-water periods in the rivers of Belarus. The assessment of extreme water flows of rare frequency in the summer-autumn period for the two time intervals (1961–1990, 1991–2020) demonstrates an increase in their frequency at most gauging stations over the last 30-year period. The minimum average monthly flow rates in the summer-autumn period are most often observed in August or September. The research shows that all months covering the winter low-water period are characterized by a tendency to increase runoff, more pronounced after 1988.

Key words: flow rates, average monthly runoff, summer-autumn low water, winter low water, frequency of hydrological phenomena, modular coefficient.

ЗАКОНОМЕРНОСТИ ИЗМЕНЧИВОСТИ СРЕДНЕМЕСЯЧНЫХ РАСХОДОВ СТОКА В МЕЖЕННЫЙ ПЕРИОД НА РЕКАХ БЕЛАРУСИ

С. В. Сидак, А. А. Волчек, С. И. Парфомук, В. А. Кофанов

Реферат

Работа посвящена исследованию многолетней динамики колебаний среднемесячных расходов стока в период летне-осенней и зимней межени на реках Беларуси. Выполненная оценка экстремальных расходов воды редкой повторяемости в летне-осенний период для двух временных интервалов (1961–1990 гг., 1991–2020 гг.) демонстрирует увеличение их частоты по большинству гидрологических постов за последний 30-летний период. Минимальные средние месячные расходы в летне-осенний период чаще всего наблюдаются в августе или сентябре. В работе показано, что для всех месяцев, охватывающих период зимней межени, характерна тенденция к увеличению стока, более выраженная после 1988 г.

Ключевые слова: расход воды, среднемесячный сток, летне-осенняя межень, зимняя межень, повторяемость гидрологических явлений, модульный коэффициент.

Introduction

Many scientists have studied the patterns of formation of river runoff in Belarus and its variability in the spatiotemporal aspect [1–3]. The analysis of hazardous hydrological phenomena on the territory of Belarus over the past 20 years carried out in [4] shows that the most frequent are hazardous phenomena accompanied by low water levels. Therefore, the study of runoff during low water periods is of particular relevance. Analysis of the dynamics of runoff elements during this period and the identification of the main patterns of its variability is of great practical interest due to their consideration in the justification and development of water management and water protection measures. Minimum flow acts as a limiting factor in the use of water resources, and identifying patterns in the frequency and intensity of droughts is critical to assessing the potential environmental and social impacts on processes associated with surface water resources.

Despite the large number of works devoted to the study of minimum runoff, today the issue of long-term dynamics of average monthly flow rates during low-water periods in the rivers of Belarus remains insufficiently studied.

The purpose of this work is to assess the variability of the long-term average monthly flow of rivers in Belarus during the summer-autumn and winter low-water periods.

To achieve this goal, the following tasks were solved:

– Analysis of the dynamics of average monthly water flows during the low-flow period.
– Assessment of the frequency of extreme values of minimum summer-autumn runoff for the period 1961–2020.
– Identification of trends in the month during which the lowest river flow discharges of the year were observed.

Materials and methods

As a rule, on the rivers of Belarus, the summer-autumn low-water period begins in early June and ends in late November – mid-December [5]. Winter low water usually begins at the end of November – mid-December, and on the rivers of the southern part of Belarus – at the end of December and lasts until the start of the flood, which usually begins in the first ten days of March in the south-west of Belarus, in the second or third ten days of March on the rivers of the northern and northeastern parts of the country. In view of this, the object of the study is the average monthly water flow (from June to March) at the gauging stations with long series of observations (the Pripyat River at Mozyr station, the Neman River at Grodno station, the Western Dvina River at Vitebsk station, the Berezina River at Bobruisk station, the Dnieper River at Orsha station, the Sozh River at Gomel station, and the Viliya River at Mikhalishki station).

To solve the above problems, the study used observation materials from the State Institution “Republican Center for Hydrometeorology, Radioactive Pollution Control and Environmental Monitoring” of the Ministry of

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Natural Resources and Environmental Protection of the Republic of Belarus for the studied hydrological gauging stations for the period of instrumental observations, published in the materials of state cadasters. The period of systematization and analysis covers a 60-year period (1961–2020). The restoration of gaps in data series was carried out using the "Hydrolog" computer software package [6].

In this study, moving 10-year averaging was used to identify larger changes in the course of monthly runoff curves, as well as to compare series of long-term runoff fluctuations at different gauging stations.

The assessment of changes in the probability of the formation of extreme water flows of rare frequency under conditions of modern climate warming was carried out using the following criterion: to analyze changes in the frequency of dangerous minimum summer-autumn water flows, the number of years with a water flow less than the 90 % probability flow was selected. This threshold value was chosen based on an analysis of data on the most significant droughts on the rivers of Belarus [5, 7].

Results and discussion

Figure 1 shows the long-term variation of modular runoff coefficients for the summer months over moving average 10-year periods for the period 1961–2020.

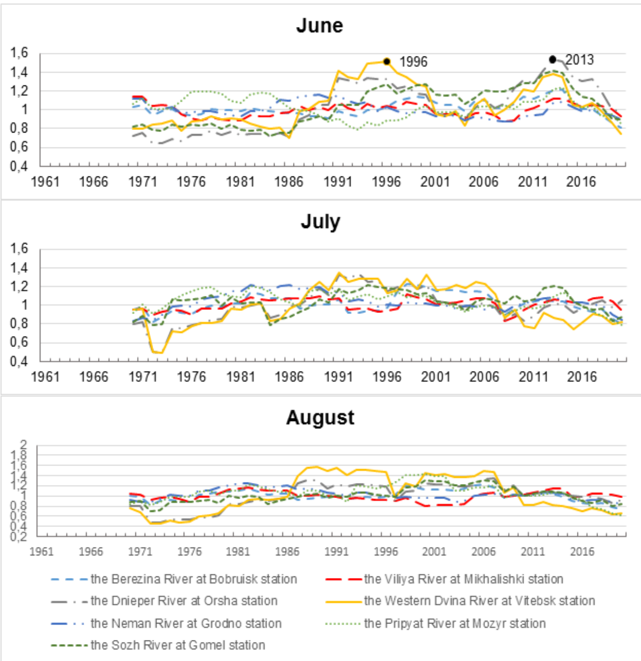

Figure 1 – Change in modular runoff coefficients for the summer months by moving average 10-year periods, 1961–2020

The graph of moving 10-year average modular coefficients of river runoff for the summer months clearly shows that the long-term variability of river flow in June for most of the study observation points remained stable until 1986. From 1986 to 1997, June runoff was close to or above normal. From 1986 to 2020, there are two waves in runoff variability with peaks in 1996 and 2014. Runoff in August at the Western Dvina River at Vitebsk gauging station from 1973 to 1986 is characterized by indicators below normal, however its growth is observed; from 1986 to 2010, the flow in August at this gauging station was higher than normal; from 2007 to 2020 there is a steady downward trend in runoff. A similar situation arises for the Dnieper River at Orsha gauging station. For the Pripyat River at Mozyr station the deviation of runoff from the long-term average in August until 1996 did not exceed 20 %; until 2000 there was an increase in runoff; from 2000 to 2020 there was a trend towards a decrease in runoff. For the remaining gauging stations for the period 1961–2020 the runoff in August is characterized by high correlation between the series of 10-year moving averages; almost over the entire time interval, the deviation of the runoff for August from the long-term average value for these gauging stations does not exceed 20 %.

Figure 2 shows the multi-year variation of modular runoff coefficients for the autumn months over moving average 10-year periods for the period 1961–2020.

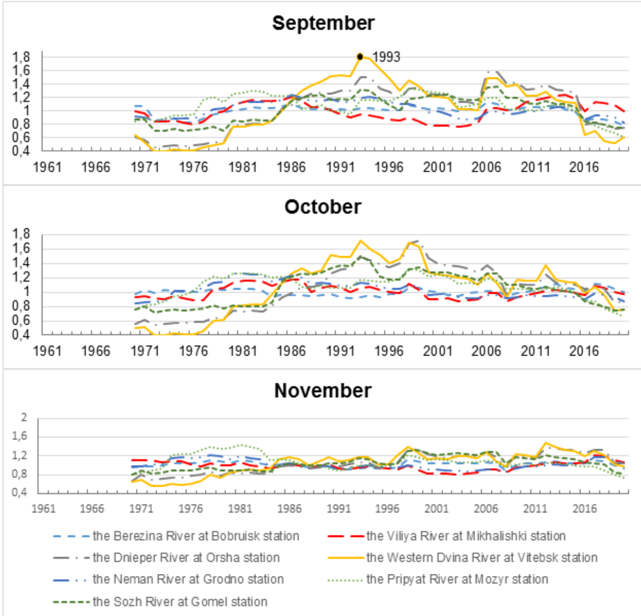

Figure 2 – Change in modular runoff coefficients for the autumn months by moving average 10-year periods, 1961–2020

Graphs of moving 10-year average modular coefficients of river flow for the autumn months at the gauging stations Western Dvina River at Vitebsk, the Dnieper River at Orsha, and the Sozh River at Gomel clearly demonstrate a fairly stable trend towards an increase in flow until 1993, and then a decrease in flow until 2020, which is changeable. In November, for these gauging stations until 2015, there is a trend towards an increase in runoff in the long-term course. For the Berezina River at Bobruisk station, runoff deviations in October over the entire studied time interval from the norm do not exceed 10 %. For the Neman River at Grodno station, the runoff from 1974 to 2000 is higher than normal and has a wave-like character with a peak in 1982; after 2000, the flow is below the long-term average flow rate for October, the deviation from which does not exceed 10 %. The course of the curve of modular runoff coefficients for October according to sliding 10-year periods for the river is similar for the Viliya River at Mikhalishki station. For the Pripyat River at Mozyr gauging station for the 40-year period 1975–2015 the runoff in October is higher than the long-term average flow rate for October, and the change in runoff has a wave-like character. Statistically insignificant negative trends in moving 10-year average modular coefficients of river flow for November are characteristic of gauging stations Berezina River at Bobruisk, the Viliya River at Mikhalishki, the Neman River at Grodno, and the Pripyat River at Mozyr. The greatest variability of runoff in September was noted at the Western Dvina River at Vitebsk gauging station. It is characterized by a stable tendency to increase runoff until 1993, runoff values above the long-term average for September during the period 1985–2015.

From Table 1 it can be seen that for all the studied stations there was an increase in runoff during the months covering the winter low-water period. The exception is the flow in December at the Viliya River at Mikhalishki station and the Pripyat River at Mozyr station (reduction of runoff by 2 % and 7.6 %, respectively). The greatest change in runoff is typical for February. For the months covering the period of summer-autumn low water, the situation is ambiguous: at the Dnieper River at Orsha station and the Sozh River at Gomel gauging station, an increase in runoff is observed in these months; for the remaining gauging stations, multidirectional changes in runoff are characteristic.

An assessment of the frequency of dangerous minimum summer-autumn water flows was carried out for two periods: 1) from 1961 to 1990 (base period), 2) from 1991 to 2020 (modern period). The assessment results for the studied gauging stations are shown in Table 2.

Table 1 – Average runoff values by month for three time intervals and changes in runoff values for the period 1961–1990 in relation to the period 1991–2020 (Δ, %).

Period	Months									
	December	January	February	March	June	July	August	September	October	November
	the Berezina River at Bobruisk station									
1961–1990	97.9	94.0	87.5	133.6	100.3	87.8	84.6	83.8	97.9	100.8
1991–2020	99.2	103.3	114.2	156.0	105.0	89.3	80.5	77.2	99.2	102.4
1961–2020	98.5	98.6	100.9	144.8	102.6	88.6	82.5	80.5	98.5	101.6
Δ, %	**1.3**	**9.9**	**30.5**	**16.8**	**4.7**	**1.7**	–4.8	–7.9	**1.3**	**1.6**
	the Western Dvina River at Vitebsk station									
1961–1990	138.6	113.1	100.8	183.2	152.5	125.1	108.8	111.4	139.1	163.2
1991–2020	171.2	166.0	131.8	298.8	174.8	118.6	104.4	116.6	158.3	204.5
1961–2020	154.9	139.5	116.3	241.0	163.6	121.8	106.6	114.0	148.7	183.8
Δ, %	**23.5**	**46.8**	**30.8**	**63.1**	**14.6**	–5.2	–4.0	**4.7**	**13.8**	**25.3**
	the Viliya River at Mikhalishki station									
1961–1990	55.2	52.2	48.6	78.9	52.8	48.0	48.0	47.3	52.4	58.5
1991–2020	54.1	60.9	63.8	86.2	51.6	46.9	42.6	44.8	47.3	54.1
1961–2020	54.6	56.5	56.2	82.6	52.2	47.5	45.3	46.0	49.9	56.3
Δ, %	–2.0	**16.7**	**31.3**	**9.3**	–2.3	–2.3	–11.3	–5.3	–9.7	–7.5
	the Dnieper River at Orsha station									
1961–1990	77.1	60.3	53.6	114.3	81.8	77.9	65.5	61.1	65.1	79.1
1991–2020	89.1	87.8	82.1	166.3	111.2	83.6	73.8	76.7	88.0	107.9
1961–2020	83.1	74.1	67.8	140.3	96.5	80.7	69.7	68.9	76.5	93.5
Δ, %	**15.6**	**45.6**	**53.2**	**45.5**	**35.9**	**7.3**	**12.7**	**25.5**	**35.2**	**36.4**
	the Neman River at Grodno station									
1961–1990	161.5	161.0	155.3	257.7	164.1	138.5	125.7	129.2	153.7	173.9
1991–2020	163.6	186.5	210.1	290.2	144.9	128.2	110.6	113.9	133.9	165.3
1961–2020	162.6	173.8	182.7	274.0	154.5	133.4	118.1	121.5	143.8	169.6
Δ, %	**1.3**	**15.8**	**35.3**	**12.6**	–11.7	–7.4	–12.0	–11.8	–12.9	–4.9
	the Pripyat River at Mozyr station									
1961–1990	322.5	333.7	310.6	487.5	408.1	320.1	260.4	236.7	254.2	300.0
1991–2020	298.0	334.1	407.1	666.9	401.0	292.9	270.6	223.0	240.9	279.7
1961–2020	310.3	333.9	358.9	577.2	404.6	306.5	265.5	229.9	247.5	289.9
Δ, %	–7.6	**0.1**	**31.1**	**36.8**	–1.7	–8.5	**3.9**	–5.8	–5.2	–6.8
	the Sozh River at Gomel station									
1961–1990	124.5	119.1	105.1	201.8	121.4	115.3	96.6	92.6	108.9	123.9
1991–2020	145.9	149.5	160.4	273.5	164.5	119.6	106.9	99.0	115.3	147.7
1961–2020	135.2	134.3	132.8	237.6	142.9	117.5	101.7	95.8	112.1	135.8
Δ, %	**17.2**	**25.5**	**52.6**	**35.5**	**35.5**	**3.7**	**10.7**	**6.9**	**5.9**	**19.2**

Note: the highlighted values correspond to the gauging stations and months that are characterized by an increase in runoff values for the period 1991–2020 in relation to the period 1961–1990.

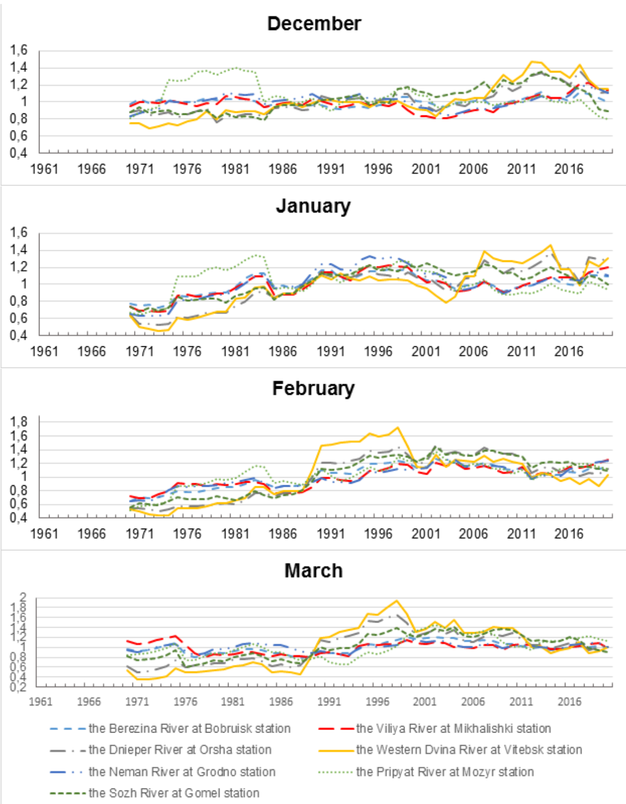

Figure 3 – Change in modular runoff coefficients for the winter low-water period by moving average 10-year periods, 1961–2020

Table 2 – Assessment of the formation of extreme water flows of rare frequency in the summer-autumn period

River – gauging station	Amount of cases	
	1961–1990	1991–2020
the Pripyat River at Mozyr station	**2**	**3**
the Neman River at Grodno station	**2**	**4**
the Western Dvina River at Vitebsk station	**1**	**4**
the Berezina River at Bobruisk station	4	3
the Dnieper River at Orsha station	2	2
the Sozh River at Gomel station	5	1
the Viliya River at Mikhalishki station	**3**	**4**

Note: the highlighted values correspond to the gauging stations where there was an increase in the amount of extreme water flows of rare frequency

The assessment results allow us to conclude that for most gauging stations over the last 30-year period, there has been an increase in the number of extreme values of the minimum summer-autumn runoff of rare frequency. Moreover, this increase occurs "against the background" of a statistically insignificant decrease in the average value of the minimum summer-autumn runoff for the second period for the Neman River at Grodno station, an increase in the minimum summer-autumn flow (by 4–28 %) for the remaining sections under study [9].

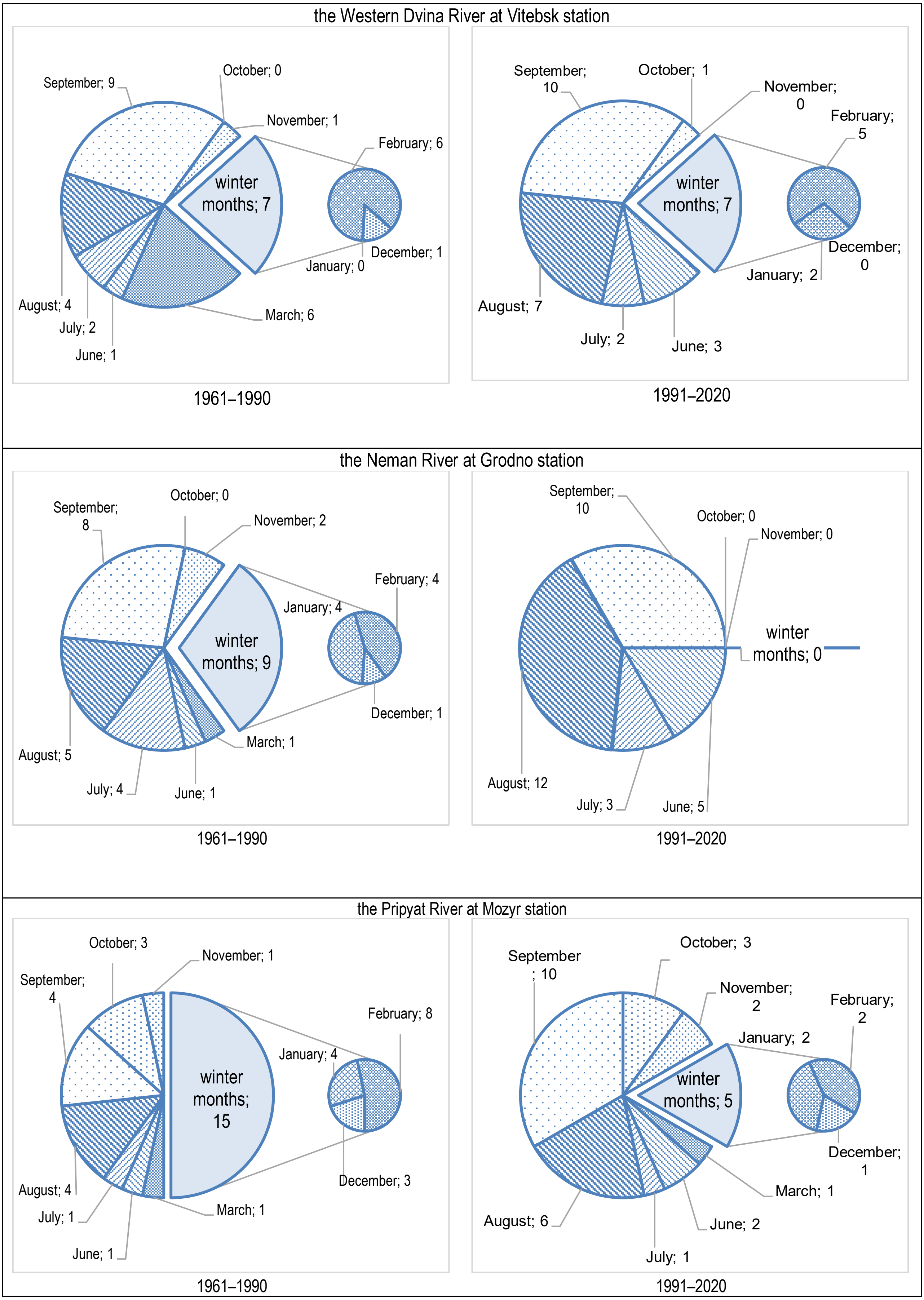

Figure 4 – Amount of cases of observation of the minimum annual average monthly flow for the periods 1961–1990 and 1991–2020

Figure 4 clearly demonstrates the change in months in which minimal river flows were observed. The minimum average monthly runoff in the summer-autumn period is most often observed in August or September. For the period 1961–1990 for some stations the minimum values of water flow in 50 % of cases occurred in the winter months, then for the period 1991–2020 the minimum expenses of the year occur in the summer and autumn months.

Conclusion

An analysis of the long-term dynamics of river runoff for individual months of summer-autumn and winter low water showed that the water regime of the rivers in Belarus is characterized by certain transformations, primarily manifested in an increase in the runoff of winter months, most pronounced after 1988 and the relative constancy of the flow in February and March in the period from 2000 to 2020. The assessment of extreme water flows of rare frequency in the summer-autumn period for two time intervals (1961–1990, 1991–2020) demonstrates an increase in their frequency at most gauging stations over the last 30 year period. The minimum average monthly flow rates in the summer-autumn period are most often observed in August or September. All months covering the winter low-water period are characterized by a tendency to increase run-off, more pronounced after 1988.

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References

1. Loginov, V. F. Vodnyj balans rechnyh vodosborov Belarusi / V. F. Loginov, A. A. Volchek // NAN Belarusi, In-t problem ispol'z. prirod. resursov i ekol., Polesskij agrarno-ekol. in-t. – Minsk : Tonpik, 2006. – 160 s.
2. Parfomuk, S. I. Ocenka i metody modelirovaniya kolebanij godovogo stoka rek Belarusi : avtoref. dis. … kand. tekhn. nauk : 05.23.16 / S. I. Parfomuk. – Minsk, 2008. – 21 s.
3. Osobennosti formirovaniya vodnosti rek Belarusi v poslednie desyatiletiya / I. S. Danilovich [i dr.] // Prirodnye resursy. – 2017. – № 2. – S. 5–12.
4. Osnovnye tendencii razvitiya opasnyh gidrologicheskih yavlenij na territorii Belarusi / A. A. Volchek [i dr.] // Vestn. Brest. gos. tekhn. un-ta. – 2023. – № 2 (131). – S. 110–114.
5. Volchek, A. A. Minimal'nyj stok rek Belarusi: monografiya / A. A. Volchek, O. I. Gryadunova. – Brest : BrGU, 2010. – 169 s.
6. Volchek, A. A. Paket prikladnyh programm dlya opredeleniya raschetnyh harakteristik rechnogo stoka // A. A. Volchek, S. I. Parfomuk // Vesnik Paleskaga dzhzyarzhaýnaga universiteta. Seryya pryrodaznaýchyh navuk. – 2009. – № 1. – S. 22–30.
7. Ocenka vlagozapasov i povtoryaemosti pochvennyh zasuh na territorii Belorusskogo Poles'ya v period sovremennogo potepleniya klimata / V. I. Mel'nik [i dr.] // Prirodnye resursy. – 2020. – № 2. – S. 104–114.
8. IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group Ito the Third Assessment Report of the Intergovernmental Panel on Climate Change / J. T. Houghton [et al.]. – Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2001. – 881 p.
9. Volchek, A. A. Mnogoletnyaya izmenchivost' stoka rek Belarusi v usloviyah izmeneniya klimata i antropogennyh vozdejstvij / A. A. Volchek, S. V. Sidak, S. I. Parfomuk // Aktual'nye nauchno-tekhnicheskie i ekologicheskie problemy sohraneniya sredy obitaniya : sb. tr. IV Mezhdunar. nauch.-prakt. konf., posvyashch. 55-letiyu Brest. gos. tekhn. un-ta i 50-letiyu f-ta inzhenernyh sistem i ekologii, Brest, 7–8 okt. 2021 g. / Brest. gos. tekhn. un-t ; redkol.: A. A. Volchek [i dr.]. – Brest, 2021. – S. 101–113.

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