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MODERN TRENDS IN RIVER DISCHARGE VARIABILITY IN THE PRIPYAT BASIN AND THEIR FORCASTED ASSESSMENTS

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Abstract

This article presents the results of a study on the spatial and temporal variability of characteristic water discharges of the Pripyat River and its tributaries within Belarus, based on instrumental observations. At the Mozyr gauging station, a 145-year hydrological record from 1877 to 2021 was analyzed.

The findings indicate that climate change has increased the irregularity of flow fluctuations in the Pripyat basin rivers, affecting both the intra-annual seasonal distribution and variations related to catchment size. Notable changes were observed during the spring period, characterized by a reduction in flood runoff and an earlier onset of the spring flood. Distinct trends in flow variability were identified across spring, summer, and autumn, with a pronounced increase during summer.

Flow projections up to 2035 largely confirm the trends identified for the period 1961–2015. Although average annual flow is expected to change only slightly, there is a high likelihood of increased irregularity and divergent seasonal and monthly flow patterns. Enhanced unevenness in intra-annual flow distribution, combined with elevated flood risks due to abrupt winter thaws, earlier spring flood onset, and intensified rain-induced floods, may contribute to a greater frequency of extreme hydrological events.

The significance of these flow assessments and forecasts under changing climatic conditions lies in their critical role for informing water resource management and protection strategies. Incorporating these projections is essential for the effective planning and sustainable management of the Pripyat River basin.

Keywords: water discharge, annual runoff, spring flood, minimum summer-autumn flow, minimum winter flow, climate, forecast assessments.

СОВРЕМЕННЫЕ ТЕНДЕНЦИИ В КОЛЕБАНИЯХ СТОКА РЕК БАССЕЙНА ПРИПЯТИ И ИХ ПРОГНОЗНЫЕ ОЦЕНКИ

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Реферат

В статье представлены результаты исследований пространственно-временных колебаний характерных расходов воды р. Припять и ее притоков, расположенных на территории Беларуси за период инструментальных наблюдений. Для створа г. Мозырь рассматривался гидрологический ряд в 145 лет, с 1877 по 2021 гг.

Показано, что изменение климата увеличило неравномерность колебаний стока, как для рек бассейна Припяти, так и его внутригодовому распределению по сезонам года, а также в зависимости от размера водосбора. Значительные изменения стока произошли в весенний период, связанные со снижением стока половодья и более ранним его наступлением. В весенний, летний и осенний период прослеживается разная направленность изменения стока, особенно в летний период – его увеличение.

Прогноз стока на период до 2035 года в основном подтвердил выявленные тенденции его изменения за период с 1961 по 2015 год. При незначительном изменении стока в среднем за год, высокая вероятность его неравномерности и разнонаправленности в сезоны и месяцы. Усиление неравномерности внутригодового распределения стока и увеличение рисков наводнений, обусловленных резкими оттепелями в зимний период, более ранним наступлением весеннего половодья и увеличением интенсивности дождевых паводков может привести к увеличению рисков экстремальных явлений.

Значимость оценок и прогнозов речного стока в условиях изменяющегося климата определяется целесообразностью их последующего учета при планировании водоохранных и водохозяйственных мероприятий, связанных с совершенствованием управления речным бассейном Припяти.

Ключевые слова: расход воды, годовой сток, весеннее половодье, минимальный летне-осенний сток, минимальный зимний сток, климат, прогнозные оценки.

Introduction

The issues surrounding the rational management of water resources have emerged as a critical focus for the international community, particularly in light of the growing scarcity of water resources globally and the continuously increasing demand for water in many countries.

In response, the international community has coordinated efforts among nations to establish 17 Sustainable Development Goals (SDGs) to be achieved by 2030. One of these goals is to ensure the availability and equitable distribution of river flow, alongside its sustainable use and sanitation for all [1]. This goal is especially pertinent to transboundary rivers. The Republic of Belarus actively participates in this initiative.

Most major rivers in Belarus are transboundary, making the management of their water regimes an intergovernmental responsibility. A primary objective is to provide an objective assessment of the current state of water resources, both for the river basin as a whole and for the individual countries through which these rivers flow. A key aspect of researching river water regimes involves forecasting water resource availability for both the near and distant future. The Pripyat River, one of the largest rivers in Belarus, serves as a pertinent case study in this context [2].

The objective of this study is to identify current trends in the fluctuations of river flow within the Pripyat basin in Belarus and to provide forecast assessments to facilitate rational and objective management of the water regime.

Methods and materials

The Pripyat River, with a length of 761 km, is a right-bank tributary of the Dnieper River. Its basin is transboundary, shared between Ukraine and Belarus. The basin's shape approximates a square with a somewhat indented watershed boundary. The catchment area encompasses 121,000 km², of which 52,700 km² (44 %) lies within Belarus. The basin's maximum length is 460 km, with an average width of 256 km and a mean elevation of 179 m. The catchment is predominantly flat and asymmetrical in shape, largely situated within the Polesie Lowland. The relief of the Pripyat basin within Belarus is characterized by alternating moraine hills and flat plains [3, 4, 5, 6, 7 et al.].

The Pripyat River originates near the city of Volodymyr-Volynskyi in Ukraine. It flows for approximately 200 km through Ukrainian territory, then nearly 500 km through Belarus before discharging into the Kyiv Reservoir on the Dnieper River. From its source to the city of Pinsk (Belarus), the river flows predominantly from southwest to northeast. At Pinsk, the Pripyat turns eastward and continues almost along a latitudinal course to Mozyr, where it shifts southeastward, maintaining this direction until its confluence.

The current hydrography of the basin comprises meandering, slow-flowing, and overgrown rivers, numerous reclamation canals, artificial reservoirs, and wetlands. The river system within the catchment includes approximately 800 watercourses longer than 1 km, with a combined length exceeding 46,000 km. The drainage density is 0.4 km/km². Most tributaries are fully or partially canalized. Forests cover 42 % of the catchment area within Belarus. Major tributaries include the Pina, Yaselda, Bobrik, Tsna, Lan, Sluch, Ptich, Tremlya, and Ipa (left bank), as well as the Stokhod, Styr, Horyn, Stvyha, Ubort, and Slovechna (right bank). The Pripyat is connected to the Mukhavets River (Western Bug basin) via the Dnieper-Bug Canal, linked to the Neman basin by the (currently inactive) Oginsky Canal, and connected to the Mikashevichi river port through the Mikashevichi Canal [3, 4, 5, 6, 7 et al.].

The river's hydrological regime is mixed, predominantly snowmelt-driven. A distinctive feature is the prolonged spring flood, a brief summer low-water period interrupted by rain-induced floods and nearly annual autumn water level rises. The spring flood accounts for 60 % of the annual flow, summer-autumn low water for 24 %, and winter low water for 16 %. Average annual discharge rates are 119 m³/s near the village of Korobye in the upper reaches, 264 m³/s near Turov, 383 m³/s at Mozyr, and 450 m³/s at the mouth [5].

The river regime has been studied at 21 hydrological stations; currently, seven remain operational: Pinsk, Kachanovichi (upper and lower reaches), Chernychi, Petrikov, Mozyr, and Narovlya.

The hydrographic network of the Pripyat River basin is illustrated in Figure 1.

Climate Conditions

The climate of the Pripyat River basin is classified as moderately continental, characterized by warm and humid summers and relatively mild winters. The degree of continentality increases toward the southeast. Annual sums of the radiation balance increase from the southwest to the east and southeast, ranging from 1200 MJ/m² to 1735 MJ/m². The radiation balance of the region significantly influences the temperature regime [8, 9]. The spatial and temporal distribution of the average monthly air temperature is dependent on radiation conditions, seasonal fluctuations in atmospheric circulation, and the physical and geographical features of the area. The average annual air temperature in the basin varies from +6.3 °C to +7.2 °C. The average temperature of the coldest month (January) ranges from –4.6 °C in the southwest to –7.0 °C in the northeast, while the average temperature of the warmest month (July) increases from +18.3 °C in the northwest to +19.2 °C in the southeast. The frost-free period lasts from 170 days in the southwest to 150 days in the eastern part of the basin. A key pattern in the spatial distribution of precipitation within the Pripyat River basin, influenced by general circulation factors, is a decrease in precipitation from the northwest and southwest toward the west and east. A slight increase in precipitation is observed at higher absolute elevations. Monthly precipitation totals exhibit a distinct annual cycle, with a minimum occurring in February and March and a maximum in June and July. Precipitation is predominantly of low intensity, although individual heavy showers can produce several tens of millimeters of rainfall. The highest daily precipitation recorded at various meteorological stations within the basin ranges from 114 to 177 mm.

Figure 1 – General Map-Scheme of the Pripyat River Basin

The snow cover within the basin is characterized by considerable instability. The timing of its onset fluctuates significantly, with average dates for the formation of stable snow cover ranging from December 20 in the northeast of the basin to December 30 in the southwest. A similar pattern is observed for the disappearance of snow cover, with average dates for the melting of stable snow cover varying in the opposite direction – from March 5 in the southwest to March 15 in the northeast of the Pripyat River basin. The average maximum snow depth ranges from 10 to 15 cm in the west to 20 to 25 cm in the east of the basin. The average depth of soil freezing is between 30 and 50 cm and depends not only on temperature and snow cover thickness but also on soil type [8]. The wind regime in the Pripyat River basin is influenced by macro-circulation processes in the atmosphere and the positioning of pressure centers over the Eurasian continent and the Atlantic Ocean [9]. A clear trend in the distribution of total evaporation indicates a decrease from the north and northwest of the basin toward the south and southeast, ranging from 590 mm to 525 mm. Winters in this region are mild and overcast, with frequent thaws. Average monthly temperatures below freezing persist from December through March, except in the southwestern part of the basin, where average temperatures in March exceed 0 °C. A characteristic feature of winter is the frequent intrusion of warm air masses, which are often accompanied by thaws. This phenomenon can lead to the complete disappearance of the snow cover, which typically re-establishes itself after several days. In some winters, when the basin is affected by ridges of high pressure, severe frosts can occur. Spring in the basin is prolonged and unstable, characterized by frequent alternations of cold and warm air masses. Cyclonic activity during spring diminishes due to the reduction of temperature contrasts between maritime Atlantic and continental air. Alongside a rapid increase in air temperature, significant temperature drops may also occur on certain days. Summer within the basin is warm and rainy. Ridges of high pressure from the Azores maximum extend into the area, facilitating the transport of moist air from the west. More than 200 mm of precipitation falls during the summer months, with a significant portion occurring as showers associated with cyclones moving from the southwest. The average temperature during the summer months (June–August) remains around +16 °C to +20 °C. The transition from summer to autumn is gradual, with frequent returns of warm weather.

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Autumn is prolonged, predominantly overcast, and characterized by drizzly rain, especially in November, when approximately 75 % of days are cloudy, of which 25 % are rainy.

Characteristics of Water Resources

The volume of river runoff for the Pripyat River over the long-term observation period and for the year 2023 is presented in Table 1 [10].

Table 1 – River runoff of the Pripyat River (km³/year) for the long-term period and the year 2023

Gauge Station	Catchment area, thousand km^2	Long-term river runoff			River runoff in 2023
		average	maximum	minimum	
Kachanovichi Chernychi Petrikov Mozyr Narovlya	13.8 74.0 87.8 101.0 103.0	12.2	22.3	4.5	16.3

The hydrometric station in the city of Mozyr, established in 1876, has the longest period of river runoff observations in this basin, spanning from 1877 to 2021, i. e., 145 years. At the preliminary stage, statistical analyses were conducted, and missing data were reconstructed using the methodology described in [11], employing the software package Gidrolog-2 [12]. To assess the impact of recent climate warming, a comparative analysis was performed for two intervals: 1877–1986, representing the pre-warming period, and 1987–2021, representing the warming period. Additionally, observation series from the last 50 years (1972–2021) were analyzed separately, corresponding to the standard calculation period recommended for determining statistical hydrological characteristics.

Within the Pripyat River network, small watercourses predominate both in number and total length; the catchments of these watercourses generate the majority of the local river runoff.

The primary data were obtained from the State Institution "Republican Center for Hydrometeorology, Radioactive Contamination Control, and Environmental Monitoring" (Belhydromet) of the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus. These data encompass various types of runoff from active hydrological stations across Belarus for the period of instrumental observations up to and including 2021, as published in official state cadastres. In studies evaluating runoff changes during the period 1961–2015 and forecasting through 2035, data from 11 stations with the longest and most continuous observation records were utilized, provided data were available for the specified period (Table 2) [13].

Table 2 – List of hydrological stations used for the assessment and projection of surface runoff changes

River – Gauge station	Catchment area, km^2
Pripyat – Chernichi (Turov)	74000
Pripyat – Mozyr	101000
Yaselda – Beryoza	1040
Yaselda – Senin	5110
Tsna – Diatlovichi	1100
Horyn – Malye Vikorovichi	27000
Sluch – Lenin	4480
Ubort – Krasnoberezhye	5260
Ptich – Luchitsy	8770
Shat – Shatsk	208
Oressa – Andreevka	3580

The analysis of the internal structure of time series can be performed using various methods, including the construction of difference-integral curves, correlation, autocorrelation, and spectral functions, as well as spectral-temporal analysis. Each of these methods has its own advantages and limitations [14].

Trends or systematic changes in runoff associated with anthropogenic factors typically develop slowly and gradually, which complicates their detection. Only in certain cases, when anthropogenic influence is minimal, can trends be discerned through graphical analysis of data homogeneity using the method of analogy.

Objective identification of anthropogenic trends is possible provided the time series is representative. Representativeness is assessed by comparison with an analogous river and involves analyzing an even number of periods characterized by varying flow conditions. Following this assessment, trends are determined analytically.

For practical calculations, linear trends can be employed with sufficient accuracy, expressed as:

$$Q(t) = Q(0) \pm \Delta Q \cdot t, \quad (1)$$

where $Q(t)$ is the water discharge at time t, m³/s; $Q(0)$ is the water discharge at the start of the calculation period, m³/s; ΔQ is the rate of change of water discharge, m³/s/year; and t is the calendar year.

In some cases, more complex forms of trends have also been utilized.

Climate Forecasting Methodology

Both global and regional climate models must be employed for climate change projections. These models are based on the description of dynamic processes and rely on numerical solutions to systems of partial differential equations from mathematical physics [15 et al.]. Moreover, the necessity of using climate models to forecast meteorological parameters, rather than relying solely on statistical methods for processing meteorological data, arises from the complexity and diversity of both natural and anthropogenic factors – at global and regional scales – that influence, and potentially may influence, climate change [16].

Studies assessing and forecasting climate change for the territory of Belarus, conducted in accordance with the Republic of Belarus's commitments under the UN Framework Convention on Climate Change, are described in our work [16]. Here, we focus on specific issues related to climate forecasting within Belarus.

According to the Fourth National Communication, submitted pursuant to the Republic of Belarus's obligations under the UN Framework Convention on Climate Change (2006), a decrease in water availability has been observed in river basins since 1988, with runoff reductions ranging from 4 % to 13 % [17]. A notable characteristic of the period under review is the change in the distribution of average monthly runoff throughout the year, particularly during the winter and spring months, when monthly river discharges across the country increase significantly – by 30 % to 90 % from January through March. The increase in winter runoff is associated with a higher frequency of thaws and the occurrence of winter floods. Conversely, runoff decreases sharply in April and May. The Communication provides an overall conclusion indicating a decline in the maximum runoff of rivers in the Pripyat basin.

The Fifth National Communication of the Republic of Belarus, submitted in accordance with its obligations under the UN Framework Convention on Climate Change (2009), employs the LEAP model [18].

This Communication concludes that "climate change will lead to increased variability of runoff and a higher frequency of extreme events (droughts, intense floods)."

In Belarus, climate research is also conducted within the framework of the cross-border cooperation project TACIS SKPI, titled "Support for the Implementation of the Kyoto Protocol in the CIS Countries" [19]. This project employs models such as ECHAM5, the atmospheric circulation model from the Max Planck Institute, and the CSIRO Mk3 bioproductivity model.

According to this scenario, in the 21st century, the average surface air temperature across Belarus is expected to continue rising, primarily due to increases in minimum temperatures. These trends, along with many other characteristics of the changing climate, will have significant impacts on the living conditions of citizens and economic activities [20 et al.].

The consequences of rapid variability in climatic conditions will manifest as an increase in the frequency of hazardous hydrometeorological phenomena and adverse abrupt weather changes, which lead to socio-economic damage and directly affect the efficiency of vital sectors of the economy, such as agricultural production, forestry, energy, transportation, construction, housing and communal services, as well as public health.

Based on an analysis of data from the Republican Hydrometeorological Center (RHMC), researchers have obtained the following results.

At the turn of the 20th and 21st centuries, Belarus experienced the longest period of warming recorded in nearly 130 years of instrumental temperature observations. This warming is notable not only for its unprecedented duration but also for the higher air temperatures, which, on average over a 20-year period (1989–2009), exceeded the climatic norm by 1.1 ºC. Of the 20 warmest years since the post-war period (1945), 16 occurred between 1989 and 2010.

Temperature increases were observed in nearly every month, with the most significant rises occurring during the winter and early spring months. A trend towards an extended frost-free period is emerging. Frosts of varying intensity in May are observed annually and pose particular risks to heat-loving crops. The risk of autumn frosts is less significant, as rising temperatures in spring and summer accelerate the maturation of agricultural crops.

Increased temperatures during the early spring months lead to earlier snowmelt and a transition of air temperatures above 0 ºC towards higher values. On average, this transition occurred 10 to 15 days earlier than the long-term averages during the period under consideration. The duration of the snow cover period in the Republic of Belarus has decreased by 10 to 15 days, and the depth of frost penetration has reduced by 6 to 10 cm. The growing season begins a decade earlier.

In a scientific and methodological context, a comprehensive study of climate change and its consequences for the economy of Belarus has been conducted by Academic V.F. Loginov [9]. His work provides a comparative analysis of various atmospheric and ocean circulation models (AOGCMs). According to his findings, the HadCM2 model (United Kingdom) [21] best simulates the baseline period data, taking into account the combined increase of greenhouse gases and sulfate aerosols. The CSIRO Mk2 model (Australia) [22] and CGCM1 model (Canada) [23] demonstrate somewhat poorer comparative results.

Forecast data using the HadCM2 model for the period 2010–2039 indicate an increase in the average annual air temperature by 1 ºC, with the average annual daily temperature rising by 0.92 ºC and the nightly temperature by 1.15 ºC. Increases in temperature sums above 0.5 and 10 ºC are expected to be approximately equal, around 200–220 ºC, while the increase for 15 ºC is significantly higher.

Existing assessments of climate change for the territory of Belarus are consistent with the concept of global warming. In recent decades, a clear trend of warming has been observed, particularly in the winter and spring months (January-April). The end of the 20th century and the beginning of the 21st century represent the longest period of warming in over 120 years of systematic instrumental observations in Belarus.

It should be noted that the results of the studies and assessments conducted in Belarus are of a general and approximate nature. In terms of river basins, the impact of global climate change on water resources in Belarus has not been thoroughly investigated. Only a few individual studies can be noted [24, 25, 26, et al.].

Methodology for Assessing the Impact of Climate Change on River Runoff

For forecasting changes in river flow, we have adapted the hydrological-climatic calculation method (HCC) proposed by V.S. Mezentsev, which is based on the simultaneous solution of water and thermal energy balance equations [27]. Building upon Mezentsev's hydrological-climatic hypothesis [27], we developed a multifactorial model incorporating the standard water balance equation for a land area, with independent assessments of the main balance components—atmospheric precipitation, total evaporation, and climatic runoff—on an annual basis. This approach has been implemented as a computer system, which we have used to evaluate potential changes in river water resources under various hypotheses concerning climate variability and anthropogenic influences on watershed characteristics [28].

The water balance equation for a river basin over a given time interval is expressed as follows:

$$H(I) = E(I) + Y_K(I) \pm \Delta W(I), \qquad (2)$$

where $H(I)$ denotes the total moisture resources (mm); $E(I)$ is the total evaporation (mm); $Y_K(I)$ represents the total climatic runoff (mm); $\Delta W(I)$ is the change in moisture reserves in the active soil and ground layer (mm); and I is the averaging interval.

Total evaporation is calculated using the formula:

$$E(I) = E_m(I)\left[1 + \left(\frac{\dfrac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}{\dfrac{KX(I)+g(I)}{W_{HB}} + V(I)}\right)^{n(I)}\right]^{-\frac{1}{n(I)}}, \qquad (3)$$

where $E_m(I)$ is the maximum possible total evaporation (mm); W_{HB} is the minimum soil moisture capacity (mm); $V(I) = W(I)/W_{HB}$ is the relative humidity of the soil at the start of the calculation period; $KX(I)$ is the sum of measured atmospheric precipitation (mm); $g(I)$ is the groundwater component of the water balance (mm); $r(I)$ is a parameter dependent on the water-physical properties and mechanical composition of the soil; and $n(I)$ is a parameter accounting for the physical-geographical conditions of runoff.

The relative humidity of the soil at the end of the calculation period is determined as follows:

$$V(I+1) = V(I)\cdot\left(\frac{V_{cp}(I)}{V(I)}\right)^{r(I)}; \qquad (4)$$

$$V_{cp}(I) = \left(\frac{\dfrac{KX(I)+g(I)}{W_{HB}} + V(I)}{\dfrac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}\right)^{\frac{1}{r(I)}}. \qquad (5)$$

The obtained values of $V_{cp}(I)$ are compared with the relative value of the total moisture capacity $V_{\Pi B}$. If $V_{cp}(I) \le V_{\Pi B}$, the calculated value of the relative average soil moisture is accepted; otherwise, when $V_{cp}(I) \ge V_{\Pi B}$ the calculation assumes $V_{cp}(I) = V_{\Pi B}$, and the difference $(V_{cp}(I) - V_{\Pi B})\cdot W_{HB}$ is attributed to surface runoff.

The amount of atmospheric precipitation during the cold months, after subtracting total evaporation, is transferred to the flood period, i. e., to March.

The maximum possible total evaporation was determined according to the methodology described in [29, 30].

Total moisture resources are determined as follows:

$$H(I) = KX(I) + W_{HB}(V(I) - V(I+1)). \qquad (6)$$

The system of equations (2) – (6) is solved iteratively until the value of relative soil moisture at the beginning of the calculation interval equals the value of relative soil moisture at the end of the previous interval. At the start of the calculation, the initial moisture value is taken as equal to the minimum moisture capacity, i. e., $W(1) = W_{HB}$, from which it follows that $V(1) = 1$. Convergence of the HCC method is typically achieved by the fourth iteration.

Adjustment of the climatic runoff is performed using coefficients that account for the influence of various factors on the formation of channel runoff, i. e.,

$$Y_P(I) = k(I)\cdot Y_K(I), \qquad (7)$$

where $Y_P(I)$ denotes the total channel runoff (mm), and $k(I)$ is a coefficient reflecting the hydrographic characteristics of the watershed.

The water balance modeling of the river under study has been implemented as a computer program and is conducted in two stages. In the first stage, the model is calibrated using known components of the water and thermal balances of the river under study. The objective of this calibration is to achieve the best possible agreement between the calculated climatic and channel runoff. This stage concludes with the construction of graphs for climatic and channel runoff and the presentation of the modeling error.

A good agreement between measured and calculated runoff indicates the model's validity. The obtained model parameters were subsequently used in conducting numerical experiments.

The second stage involves directly calculating the water balance of the river under study using parameters obtained during model calibration. The calculation of the water balance components for the river takes into account the specific characteristics of the watershed being analyzed [28].

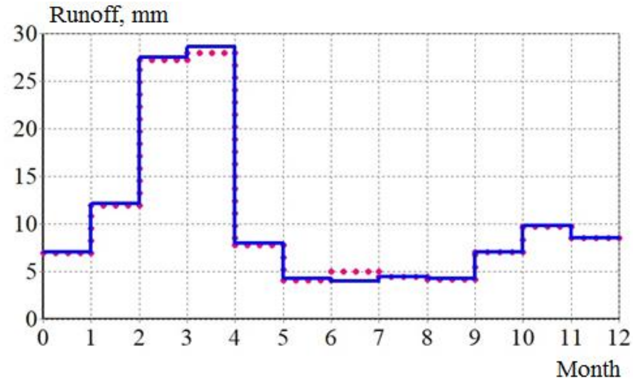
The modeling results demonstrate a high level of accuracy in estimating the water balance, suitable for both practical applications and theoretical research. This has been validated on numerous rivers in Belarus with watershed areas of about 1000 km², where hydrometric observations are conducted. Thus, given data on atmospheric precipitation, air temperature, air moisture deficits for the calculation period, current river runoff values, and hydrographic characteristics of the watershed, this methodology makes it possible to produce predictive estimates of the water balance of small rivers in Belarus for the forecast period.

Solving the water balance equation for a watershed involves determining average values of the components observed at specific points within the watershed. Therefore, one of the key aspects of modeling the water regime is accurately assessing climatic characteristics and averaging them across the watershed. This issue is discussed in detail in [28].

During model calibration using the proposed methodology, difficulties arose in determining parameters for the winter months. The problem was that the model did not adequately account for the increasingly frequent thaws in recent years. As a result, the model was adjusted to incorporate the effects of thaws. The difference between channel runoff and climatic runoff obtained during calibration was attributed to runoff generated during thaw periods, which was recorded in the model settings.

Predictive estimates of changes in river runoff were made according to the following procedure. The model was calibrated using long-term average data on river runoff, atmospheric precipitation, air temperature, and air moisture deficits. Then, forecasted values for the relevant period were input for the meteorological stations used in the calibration. The calibration parameters were applied, and a predictive assessment was conducted. The resulting climatic runoff values were compared according to the ratio $\Delta_{кл.} = Y_{кл.}^{пр.} / Y_{кл.}^{сов.} \cdot 100\ \%$. The direct predictive estimate of channel runoff was derived from the relationship $Q^{пр.} = Q^{сов.} \cdot \Delta_{кл.} \cdot 100,\ м^3/с.$

An example of modeling the long-term average annual runoff and its intra-annual distribution (model calibration and forecast) for the Grivda River near the town of Ivatsevichi is shown in Figure 2.



── measured runoff, - - - calculated runoff

Figure 2 – Measured and calculated runoff of the Grivda River at Ivatsevichi

Results and discussions

Analysis of Long-Term Variations in Annual Runoff Annual Runoff

The long-term average flow of the Pripyat River was estimated based on observations at the Mozyr hydrological station for the period from 1877 to 1881. Accordingly, the long-term average runoff of the Pripyat over the past 145 years at the Mozyr gauge station is 391 m³/s, increasing to 450 m³/s near the river's mouth. The maximum average annual discharge recorded at the Mozyr station occurred in 1958, reaching 643 m³/s, while the minimum was observed in 1954, at 142 m³/s. Analysis of the available data enables experts to conclude that the Pripyat's runoff exhibits an increasing trend and is greater than that of the Dnieper or Desna rivers.

As part of this study, a statistical analysis was conducted on the long-term fluctuations in the annual runoff of the Pripyat River at the Mozyr gauge station over the period 1877–2021, with the aim of identifying quasi-periodic patterns and trends.

The chronological series of average annual discharges of the Pripyat River at the Mozyr station is presented in Figure 3.

The main statistical characteristics of the analyzed series are presented in Table 3.

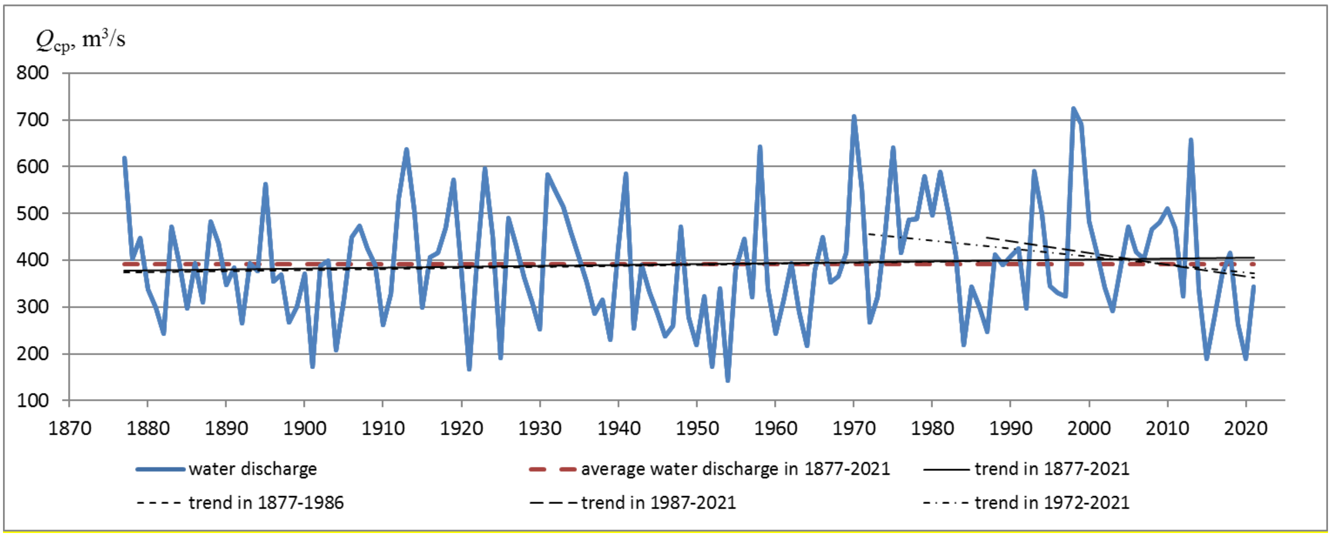


Figure 3 – Chronological series of average annual discharges of the Pripyat River at the Mozyr station

Note – Explanatory notes in Figures 4–6 correspond to the ones in Figure 3.

Table 3 – Key statistical characteristics of the average annual discharges of the Pripyat River at the Mozyr gauge station for different averaging intervals

Characteristics	Averaging interval			
	1877–2021 (145 years)	1877–1986 (110 years)	1987–2021 (35 years)	1972–2021 (50 years)
Q_{cp}, m^3/s	391	387	405	414
C_v	0.31	0.31	0.31	0.30
C_s	0.44	0.34	0.74	0.47
$r(1)$	0.28	0.26	0.30	0.37
ΔQ 10, m^3/s	2.00	2.20	–25.18	–17.35
r	0.07	0.06	–0.20	–0.20
$r_{кр,\ p=5\ \%}$	*0.16*	*0.19*	*0.33*	*0.28*
% of Q_{cp}	0.51	0.57	–6.22	–4.19
Maximum in the period/year	725/1998	708/1970	725/1998	725/1998
Minimum in the period/year	142/1954	142/1954	189/2020	189/2020

Note – Q_{cp} is long-term average annual water discharge; C_v is a coefficient of variation; C_s – is a coefficient of skewness; r(1) is an autocorrelation coefficient; ΔQ 10 is a gradient of change in water discharge over 10 years; r is a correlation coefficient of model (1); $r_{кр,\ p=5\ \%}$ is critical values of the correlation coefficient [31]; % of Q_{cp} is percentage change in water discharge over 10 years relative to the long-term average annual discharge. Statistically significant correlation coefficients are highlighted.

No statistically significant differences were found in the mean water discharge values between the periods 1877–1986 and 1987–2021. The critical value for the one-tailed Student's t-test is $t_{кр} = 1.67$, where as $t_{статистика} = 0.76$. No differences were detected in the variances (coefficients of variation). The coefficient of skewness has changed significantly, which should be taken into account when selecting probability distribution models. The gradient of discharge changes did not undergo any statistically significant transformations. The results obtained are in good agreement with our previously published findings [32, 33, 34].

Refinement of Water Resources in the Pripyat Basin

In recent years, the country's water resources have undergone transformations due to the influence of both natural and anthropogenic factors on runoff [35]. The refined surface water resources of the Pripyat basin for the period from 1956 to 2015, along with data on runoff transformations over the studied 60-year interval relative to the period of instrumental observations prior to 1996 for the Pripyat basin, are presented in Table 4.

The total surface water resources of the Pripyat basin have remained largely unchanged. However, there has been a redistribution of natural water resources among the basins of individual rivers. A slight increase in the water flow of the Pripyat River has been observed in recent years.

The rivers of the Pripyat basin are characterized by a slight increase in runoff values. Changes in river runoff volumes and hydrological regimes under current conditions are attributed to an intensification of general atmospheric circulation.

Spring Floods

The study included a statistical analysis of long-term fluctuations in the maximum water discharges during the spring flood of the Pripyat River at the Mozyr gauge station over the period from 1877 to 2021, with the aim of identifying quasi-periodicity and trends [36].

The chronological series of maximum water discharges during the spring flood of the Pripyat River at the Mozyr gauge station is presented in Figure 4.

Table 4 – Natural resources of the Pripyat basin and Belarus as a whole during 1956–2015 (Numerator) and changes in runoff relative to the period prior to 1996 (Denominator)

River basin	River runoff, km^3/year									
	Local					Total				
	Exceedance probability, %					Exceedance probability, %				
	5	25	50	75	95	5	25	50	75	95
Pripyat	11.2 / 1.3	7.6 / 1.1	6.6 / 1.0	5.0 / 0.6	3.5 / 0.4	23.9 / 1.7	16.8 / 1.5	14.4 / 1.4	11.0 / 0.9	8.3 / 1.3
Entire Belarus	**51.8 / 0.3**	**37.9 / 0.4**	**34.1 / 0.1**	**28.1 / -0.2**	**22.7 / -0.1**	**88.2 / 1.1**	**64.3 / 0.9**	**56.9 / 0.7**	**46.4 / 0.2**	**37.5 / 1.2**

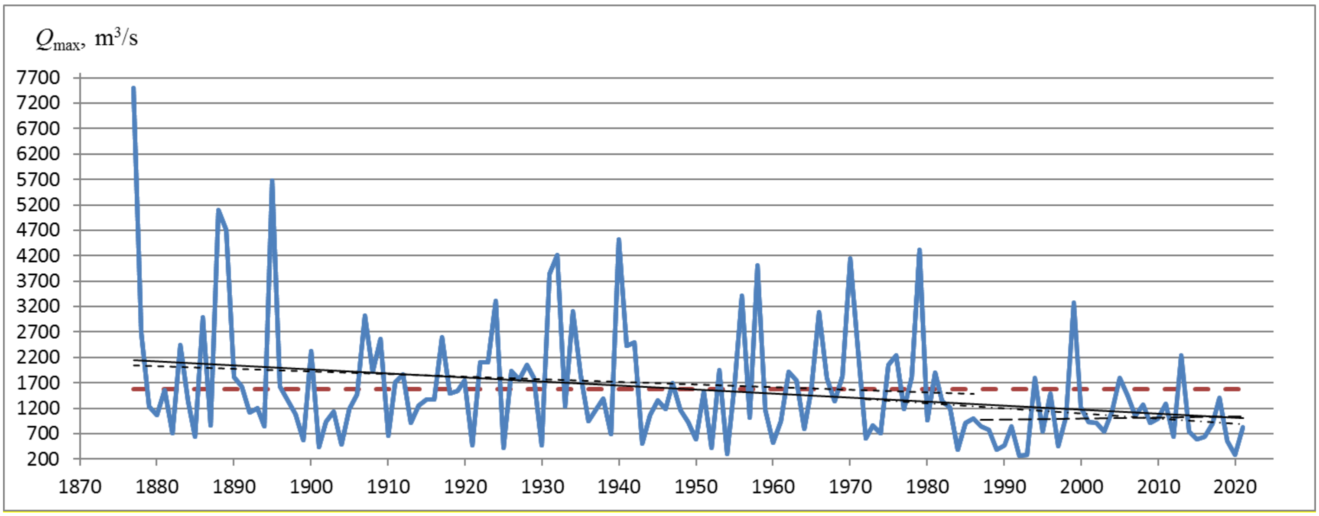


Figure 4 – Chronological series of maximum water discharges during the spring flood of the Pripyat River at the Mozyr gauge station

Principal statistical characteristics of the analyzed time series are presented in Table 5.

A statistically significant difference is observed in the maximum water discharges during the spring flood between the periods 1877–1986 and 1987–2021. The critical value for the one-tailed Student's t-test is т $t_{кр}$ = 1.67, while $t_{статистика}$ = 4.87. Significant differences were also found in the variances (coefficients of variation). The critical value for the one-tailed F-test is 1.64, whereas the calculated F-statistic is 4.19. No significant differences were detected in the coefficients of skewness. The gradient of runoff change has undergone a statistically significant transformation, as confirmed by the correlation coefficient.

In the rivers of the Pripyat basin, maximum runoff is generated either from snowmelt or from heavy rainfall events. A characteristic phase of the hydrological regime in this region is the spring flood, which occurs annually in spring as a result of snowmelt and precipitation during the snowmelt period [37, 38]. On the Pripyat River, the spring flood typically begins in the first half of March, although in some years it may shift to February or April. The long-term average duration of floodplain inundation ranges from 80 to 110 days, extending up to 150–180 days in certain years [39]. The width of the spring floodplain on the Pripyat River varies from 5 to 15 km, reaching up to 30 km in specific sections (notably near the city of Pinsk). The duration of the flood on smaller rivers ranges from 40 to 45 days.

Table 5 – Principal statistical characteristics of the maximum water discharges during the spring flood of the Pripyat River at the Mozyr gauge station across different averaging intervals

Characteristics	Averaging interval			
	1877–2021 (145 years)	1877–1986 (110 years)	1987–2021 (35 years)	1972–2021 (50 years)
$Q_{ср}$, m³/s	1577	1760	1005	1133
C_v	0.73	0.70	0.60	0.66
C_s	2.05	1.88	1.84	2.16
$r(1)$	0.14	0.07	0.06	0.15
ΔQ 10, m³/s	–79.39	–51.68	23.53	–103.11
r	**–0.29**	–0.13	0.04	–0.20
$r_{кр,\ p=5\ \%}$	*0.16*	*0.19*	*0.33*	*0.28*
% of $Q_{ср}$	–5.03	–2.94	2.34	–9.10
Maximum in the period/year	7500/1877	7500/1877	3270/1999	4310/1979
Minimum in the period/year	272/1992	306/1954	272/1992	272/1992

Table 6 presents the water discharges of the ten most significant spring floods [36].

The peak of the spring flood on the majority of rivers occurs from late March to early April. On the tributaries, compared to the Pripyat River, the timing of the flood onset varies somewhat: on the left-bank tributaries, the flood begins later, while on the right-bank tributaries, it begins earlier. However, during a prolonged spring, nearly simultaneous ice break-up can occur across the basin's rivers, resulting in elevated flood levels on the Pripyat River. The rise in water level primarily depends on water availability as well as the morphology of the river valley or its specific sections. The highest levels of the spring flood are generally the maximum levels recorded during the year. The average height of the spring flood above the minimum summer level ranges from 3.5 to 4.5 meters on the Pripyat River, 1.5 to 3.0 meters on the left-bank tributaries, and 1.0 to 2.5 meters on the right-bank tributaries. On small rivers, floodplain inundation typically lasts an average of 25 to 30 days, while on medium and large rivers, it lasts approximately 1.5 to 2 months. The maximum historical value of spring flood runoff on the Pripyat River occurred in 1845, when the discharge was estimated at 11,000 m³/s, with a runoff modulus of 113 L/s·km². Considering the maximum flood level of 1845, the conditions of flood formation, and the available historical data, it can be inferred that at least since the late 19th century to the present, the height of this flood remains unsurpassed. The maximum level and discharge of the Pripyat River during the 1845 flood can be approximately considered to recur no more frequently than once every 800 years. Data analysis indicates that the maximum runoff moduli during the spring flood vary between 34.6 and 364 L/s·km². As a general rule, with increasing catchment area, the maximum runoff moduli decrease. This trend is also characteristic of the average runoff moduli over the flood period. The spring flood begins earlier in the southwest (on average in early March) and somewhat later in the northeast (mid-March). The onset dates of the spring flood vary significantly from year to year. There exists a certain relationship between the timing of the flood onset, its intensity, and its duration. Typically, during late springs with rapid snowmelt, the flood is higher and shorter, exhibiting the greatest peak discharges. In early springs, snow cover melts gradually, leading to increased losses of meltwater due to infiltration, resulting in a flood that is usually low and prolonged. The duration of the flood also depends on the river length, forest cover, swampiness, and karst features of the catchments. For small rivers with karstified and swampy catchments, the average duration is 40 to 45 days, whereas for large rivers, it can reach up to 80 days. For rivers with non-karstified and slightly swampy catchments, the duration is significantly shorter, amounting to 36 and 55 days, respectively. Currently, there is a trend toward earlier onset and peak of spring floods [40, 41].

Relatively regular observations of hydrological runoff parameters began in the late 19th century. However, unsystematic data on levels and discharges from the early period are not utilized in hydrological calculations of design values due to the absence of elevation referencing. The maximum hazardous water levels recorded during the spring flood observation period on the rivers of the Pripyat basin are presented in Table 7 [42].

Characteristics of Floods on the Rivers of the Pripyat Basin

The highest water level recorded on the Pripyat River at the Mozyr monitoring station was observed in the spring of 1895, measuring 742 cm (or 113.33 m above sea level), while the lowest level was recorded in the summer of 1961 at 53 cm. The maximum amplitude of the water level fluctuations reached 6.89 m.

Long-term observations indicate that the amplitude of water levels in the Pripyat River varies from 2 to 3 m in the upper reaches, increasing to 4 to 5 m in the middle and lower reaches. The most significant changes in water levels have been documented at the Mozyr monitoring station, which can be attributed to the relatively high river banks and the corresponding lower channel capacity of the river [43].

Throughout the entire observation period, the average maximum discharge of the Pripyat River during the spring flood is approximately 1620 m³/s. The highest recorded discharges occurred in the spring of 1895 (5670 m³/s), 1932 (4220 m³/s), 1958 (4010 m³/s), 1979 (4310 m³/s), and 1999 (4150 m³/s). An overall trend indicates a gradual decline in maximum discharge values over time.

Table 6 – Maximum water discharge of spring floods on the Pripyat River at the Mozyr gauge station

Years	1845	1877	1895	1888	1889	1940	1979	1932	1970	1958
Q, m³/s	11000	7500	5670	5100	4700	4520	4310	4220	4140	4010
P, %	0.8	1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0	7.6

Table 7 – Maximum hazardous water levels during spring floods on the Pripyat River and its tributaries for the observation period

River – Gauge station	Water levels, cm			
	Hazardous high, (exceedance probability, %)	Maximum, (exceedance probability, %) / date	Maximum stream ice / date	Longest duration, days / year
Pripyat – Pinsk	250 (43)	302 (1) 29.03.1979	302 29.03.1979	50 1980, 1981
Pripyat – Koroby	420 (40)	486 (2) 20.04.1958	460 31.03.1979	32 1979
Pripyat – Turov	340 (22)	410 (1) 02-03.04.1979	405 31.03.1979	28 1979
Pripyat – Chernichi	520 (57)	637 (2) 21-22.03.1979	637 21-22.03.1999	46 1999
Pripyat – Petrikov	800 (45)	933 (1) 03-04.04.1979	924 01.04.1979	40 1999
Pripyat – Mozyr	550 (30)	742 (1) 22-24.04.1995	670 21.04.1931	31 1941
Pina – Pinsk	335 (8)	366 (2) 01.04.1979	347 29.03.1979	12 1979
Yaselda – Senin	195 (37)	247 (0,9) 27.03.1999	234 06-12.031999	127 1999
Horyn – Rechitsa	530 (52)	635 (2) 11.04.1956	635 11.04.1956	26 1979

The long-term average date for the peak of the flood is April 11; however, in recent decades, this date has been progressively shifting to an earlier timeframe. It is noteworthy that the maximum flood discharges on the Pripyat River are significantly lower than those observed during the spring floods. During the observation period, the highest flood discharge recorded at the Mozyr monitoring station (1260 m³/s) occurred in mid-August 1993, while the lowest discharge (22.0 m³/s) was recorded in November 1921, a period characterized by drought across the entire East European Plain [44].

Table 8 presents the most significant floods on the rivers of the Pripyat basin caused by spring floods during the period of instrumental observations [45].

The highest level of water on the Pripyat basin rivers is presented in Table 9.

Table 8 – Years with floods during spring floods

River – Gauge station	Scale of flood		
	Catastrophic *P* < 1 %	Outstanding *P* = 1–2 %	Big *P* = 3–10 %
Pripyat – Lyubanskii		1979	1999, 213
Pripyat – Koroby		1958	1957, 1966, 1979
Pripyat – Turov		1979	1932, 1940, 1956, 1958, 1970
Pripyat – Chernichi		1999	
Pripyat – Petrikov		1979	1931, 1932, 1940, 1956, 1958, 1966, 1970, 1999
Pripyat – Mozyr	1845	1888, 1895, 1979, 1999	1886, 1889, 1907, 1924, 1931, 1932, 1934, 1940, 1956, 1958, 1966, 1970,
Pina – Pinsk		1979	1928,1932,1940,1958
Yaselda – Senin		1999	1958, 1979, 1981
Horyn – Rechitsa		1956	1966, 1979, 1996, 1999
Ubort – Krasnoberezhye		1932	1934, 1966, 1970, 1999
Ptich – Luchitsy		1931, 1999	1895, 1896, 1900, 1907, 1917, 1956, 1958

Table 9 – Water levels on the Pripyat basin rivers (data date 01.01.2018)

River – Gauge station	Zero mark at the gauge station in Baltic Height System, m	Average level, $H_{сред}$, cm	Maximum level	
			cm	date
Pripyat – Pinsk	133.18	112	302	21.04.2013
Pripyat – Chernichi	119.23	356	637	21–22.03 1999
Pripyat – Petrikov	112.55	562	933	03–04.04.1979
Pripyat – Mozyr	110.93	224	742	22–24.04.1895
Pina – Pinsk	132.29	169	366	01.04.1979
Yaselda – Senin	134.39	126	247	27.03.1999
Horyn – Malye Vikorovichi	129.67	298	635	11.04.1956
Sluch – Lenin	129.97	114	314	20.04–21.04.1958
Ubort – Krasnoberezhye	126.26	157	390	11.04.1932
Ptich – Daraganov	150.00	186	339	13.04.1999

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Changes in Maximum Discharges of Spring Floods and Their Causes

In recent years, anthropogenic factors, alongside natural influences, have increasingly contributed to the frequency and severity of destructive flooding events. Among these factors, deforestation stands out, as it can lead to an increase in maximum surface runoff by 250 to 300 %. Other significant contributors include floodplain development, unsustainable agricultural practices, and additional human activities. The notable reduction in maximum discharges, coupled with an increase in minimum winter and summer-autumn runoff, can be attributed to both natural processes and modifications to floodplains, which act as vital natural regulators of runoff.

Since the mid-1960s, a discernible trend of decreasing maximum discharges has been observed, supported by statistical significance tests of average values across various time periods. For example, the averages for the periods from 1877 to 1965 ($\overline{Q}$ = 1770 m³/s) and from 1966 to 2021 ($\overline{Q}$ = 1270 m³/s) show statistically significant differences at the 5 % significance level. Similarly, the averages for the periods from 1877 to 1986 ($\overline{Q}$ = 1760 m³/s) and from 1986 to 2021 ($\overline{Q}$ = 1010 m³/s) also reveal significant distinctions.

In the current century, the water discharges during spring floods on the Pripyat River at the Mozyr monitoring station exceeded the normative value of $\overline{Q}$=1580 m³/s only in 2013, with a recorded discharge of Q_{2013} = 2240 m³/s. At the Lyuban Bridge monitoring station, the spring flood norm of $\overline{Q}$ = 182 m³/s was surpassed in several years: Q_{2013} = 420 m³/s, Q_{2011} = 237 m³/s, Q_{2005} = 231 m³/s, Q_{2002} = 210 m³/s, Q_{2000} = 195 m³/s, Q_{2007} = 184 m³/s, and Q_{2009} = 184 m³/s. At the Turov monitoring station, the spring flood norm of $\overline{Q}$ =1010 m³/s was exceeded, with Q_{2013} = 1320 m³/s and Q_{2005} = 1100 m³/s. On the Horyn River at the Rechitsa gauge station, the spring flood norm of $\overline{Q}$ =597 m³/s was exceeded, with Q_{2013} = 1090 m³/s, Q_{2006} = 943 m³/s, Q_{2003} = 813 m³/s, Q_{2005} = 775 m³/s, and Q_{2008} = 733 m³/s. On the Ubort River at the Krasnoberezhye gauge station, the spring flood norm of $\overline{Q}$ = 153 m³/s was surpassed, with Q_{2013} = 271 m³/s, Q_{2005} = 251 m³/s, and Q_{2006} = 204 m³/s. On the Ptich River at the village of Luchosy, the spring flood norm of $\overline{Q}$ = 213 m³/s was exceeded, with Q_{2013} = 220 m³/s.

The stability of statistical measures (means, coefficients of variation, and coefficients of autocorrelation) for the time series of maximum water discharges during spring floods was evaluated across four distinct periods (refer to Table 5).

Analysis of long-term variations in river discharge within the basin reveals persistent fluctuations in indicative discharges over the years. These fluctuations manifest as alternating sequences of high-flow and low-flow annual periods, generating cycles of varying duration and amplitude in water availability. Examination of differential integral curves constructed for 30 river gauge stations across the Pripyat River basin indicates a synchronous pattern between high-flow and low-flow phases [46].

The analysis demonstrates that the percentage difference in runoff during spring reaches its maximum in both high-flow (5 %) and low-flow (95 %) years, while minimal differences are observed during summer and autumn. This suggests that, in low-flow years, the majority of the total annual river discharge is generated in spring (50–60 %), whereas in high-flow years, runoff predominantly occurs during summer and autumn (40–50 %). Based on this, distinct low-flow and high-flow periods have been identified in the fluctuations of maximum discharge. Two hydrological regimes are clearly discernible in the maximum discharge records: a high-flow period prior to the early 1980s, characterized by pronounced maxima in 1953, 1955, 1956, 1958, 1966, 1967, 1974, 1977, 1979, and 1980; and a low-flow period from 1982 to the present, with exceptions in 1998, 1999, and 2013. Given that maximum discharges primarily reflect spring flood runoff, it can be confidently concluded that the proportion of spring runoff within the intra-annual distribution has steadily declined in recent decades.

The marked reduction in maximum spring flood discharges observed at the end of the twentieth century is attributed to an increased frequency of winter thaws, during which substantial snow reserves are converted into runoff during the winter low-flow period. This phenomenon results in elevated winter runoff, occasionally causing winter floods, and consequently diminishes peak flows in spring.

To substantiate this hypothesis, the long-term trend of minimum winter runoff is presented, revealing an increasing tendency supported by a statistically significant positive linear trend.

Significance testing of linear trends indicates that, for the Pripyat River at the Mozyr gauge station, correlation coefficients are statistically significant at the 5% level over the entire study period.

In light of the observed decreasing runoff trends, a comparative analysis of design values for maximum spring flood discharges was undertaken for the periods 1877–1965 and 1966–2021. Employing the Pearson Type III distribution, design discharge values were derived for the respective periods (see Table 10).

Table 10 – Design values of maximum spring flood discharges of the Pripyat River at the Mozyr gauge station for various periods, m³/s

Period	Exceedance probability, %			
	1	5	10	50
1877–2021	**6650**	**4200**	**3090**	**1250**
1877–1965	**7680**	**4610**	**3220**	**1470**
1966–2021	**4410**	**3400**	**2270**	**994**
Change, %	**–33.7**	**–19.0**	**–26.5**	**20.5**

The analysis presented in Table 10 reveals significant discrepancies in the design values across the periods under consideration. This underscores the necessity of accounting for the heterogeneity of the time series of maximum spring flood discharges when developing probabilistic forecasts for the rivers of the Pripyat basin.

Furthermore, the examination of the spatial structure of changes in maximum spring flood discharges indicates a general decline in spring flood runoff throughout nearly the entire Pripyat River basin.

For instance, the scale of hydromelioration efforts in the Western Dvina River basin is considerably smaller than that in the Pripyat River basin. Nevertheless, the observed reduction in maximum spring flood discharges in both river systems is consistent. It can be hypothesized that the primary driver behind the decrease in maximum spring flood discharges in the Pripyat basin rivers is of a natural origin, with lesser influence from anthropogenic factors [13].

Additionally, the long-term analysis of maximum spring flood discharges within the Pripyat basin has identified a clear trend of decreasing spring flood runoff across all rivers, particularly pronounced since the mid-1960s. To quantitatively evaluate these transformations, trend lines have been constructed for various averaging periods (see Table 5).

Minimum Flow

The Pripyat River basin is located within a region characterized by excess moisture, where groundwater discharge into the river network is relatively sustained and continuous. As a result, the baseflow contribution from groundwater to surface watercourses in this area is constant. Minimum water levels and flows during the summer period typically occur under conditions of elevated mean daily air temperatures combined with prolonged precipitation deficits; in winter, minimum flows correspond to periods of low temperatures. During drought years, drying of watercourses has been observed across 36 catchments exceeding 1000 km² in area. The summer–autumn low-flow period generally begins from late May to mid-June and persists until October. In certain years, when the spring flood recedes uniformly, the onset of low flow in the rivers can occur considerably earlier, in late April to early May. Conversely, in years with prolonged flooding or when rainfall occurs during the recession phase, the low-flow period may be delayed until late June to mid-July. In some years, in the absence of autumn floods, low flow conditions may extend until the onset of ice formation, typically from mid-November to early December. The average runoff during the summer–autumn low-flow period for small and medium rivers ranges between 3 mm and 15 mm. The most pronounced low-flow conditions within this period generally occur in July and August, less frequently in September. The duration of low flow for small and medium-sized watercourses may reach up to 130 days, whereas for the Pripyat River, it typically spans 85 to 90 days. Winter low flow usually establishes by late December.

The earliest occurrence of low flow is recorded in late October to early November, while the latest onset can be as late as January, with termination coinciding with the onset of the spring flood. The average duration of low flow on small and medium rivers varies from 49 to 100 days. Within the Polesie region, zero-flow events have been documented on 17 watercourses with catchment areas ranging from 11 to 1280 km². The average duration of zero-flow episodes can reach up to 195 days during summer and 75 to 100 days during winter [47, 48].

Table 11 summarizes the calculated minimum flow values for rivers within the Pripyat basin along with their corresponding statistical parameters.

Chronological series of minimum summer-autumn discharges of the Pripyat River at the Mozyr station is presented in Figure 5.

The main statistical characteristics of the analyzed series are presented in Table 12.

Table 11 – Calculated minimum runoff values and statistical parameters for rivers in the Pripyat basin

River	Gauge Station	Normal annual runoff		Cv	Cs/Cv
		Discharge, m^3/s	runoff module, l/s km^2		
Pripyat	Mozyr	154	1.53	0.52	4.0
Yaselda	Beryoza	1.25	1.36	0.82	2.0
Tsna	Diatlovichi	0.89	0.91	0.90	4.0
Sluch	Novodvortsy	0.45	0.50	1.02	3.0
Ptich	Luchitsy	14.3	1.63	0.49	2.5
Oressa	Andreevka	5.68	1.59	0.53	2.5

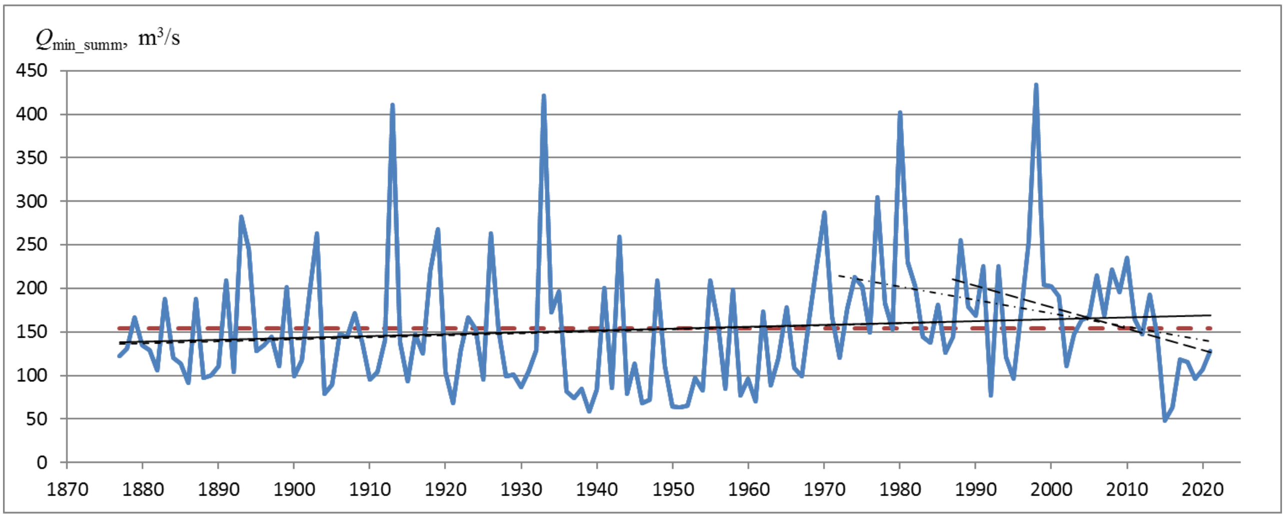

Figure 5 – Chronological series of minimum summer-autumn discharges of the Pripyat River at the Mozyr station

Table 12 – Main statistical characteristics of minimum summer-autumn discharges of the Pripyat River at the Mozyr station for various averaging intervals

Characteristics	Averaging intervals			
	1877–2021 (145 years)	1877–1986 (110 years)	1987–2021 (35 years)	1972–2021 (50 years)
Q_{cp}, m^3/s	154	149	169	176
C_v	0.47	0.48	0.42	0.41
C_s	1.49	1.59	140	1.43
$r(1)$	0.20	0.14	0.36	0.27
ΔQ 10, m^3/s	2.16	2.34	–24.76	–15.44
r	0.13	0.10	**–0.36**	**–0.31**
$r_{кр,\ p=5\ \%}$	*0.16*	*0.19*	*0.33*	*0.28*
% of Q_{cp}	1.41	1.57	–14.69	–8.75
Maximum in the period/year	434/1998	421/1933	434/1998	434/1998
Minimum in the period/year	48.0/2015	58.7/1939	48.0/2015	48.0/2015

Statistically significant differences in minimum summer-autumn water discharges between the periods of 1877–1986 and 1987–2021 were not identified. The critical value for the one-tailed Student's t-test is $t_{кр}$ = 1.67, while the calculated $t_{статистика}$ = 1.43. Additionally, no differences in variances (coefficients of variation) were observed. There were no significant changes in the coefficient of skewness or transformations of the flow gradient.

The onset of winter low flow generally occurs during the third decade of November to the first half of December. The average duration of winter low flow ranges from 60 to 80 days, with the longest durations reaching between 100 and 120 days. The conclusion of winter low flow typically falls in March, although in some years it may occur in February. For the Pripyat River, winter low flow usually establishes by the end of December and concludes in late February to early March, with an average duration of 69 days. In certain years, winter low flow may be interrupted by winter floods. The most pronounced low water period during winter low flow is typically observed in late February to early March, lasting from 7 to 18 days.

Analysis of observational data indicates that the values of the lowest average monthly summer discharges systematically decrease across the basin, trending from the northwest and north toward the south and southeast, in accordance with geographical zonation patterns in larger and medium-sized rivers. Conversely, in small rivers, an intra-zonal pattern of changes is observed, which is dependent on local hydrogeological characteristics, such as the presence and thickness of groundwater horizons, the nature of their exposure through river valleys, and the conditions governing their drainage.

The most water-rich aquifers are found in fractured and karstified carbonate-sulfate rocks of the Upper Cretaceous and Neogene periods.

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Cretaceous waters emerge within the Polesie lowland as ascending springs with discharges of up to 200 m³/h. The module of minimum average daily discharge for these rivers, at 97 % exceedance probability, varies from 0.07 to 0.18 l/s·km². Rivers that are fed by aquifers in alluvial and fluvioglacial deposits exhibit low minimum discharge modules, and during drought years, their flow can cease completely for periods ranging from 15 to 120 days. Flow cessation in these rivers can also occur during cold, thawless winters. The module of minimum average daily discharge at 97 % exceedance probability for this group of rivers ranges from 0.00 to 0.02 l/s·km² during summer low flow and from 0.00 to 0.05 l/s·km² during winter.

Research and analysis of minimum flow characteristics, based on data from several hydrological stations located in the upper reaches of the Pripyat River, indicate that human economic activities significantly influence the formation of low flow in this region. An increase in watershed area is associated with a decrease in minimum water discharges and flow modules. The primary water management facilities affecting the formation of minimum flow in the upper reaches of the Pripyat River include the Upper Pripyat drainage and irrigation system and the water intake from the Dnieper-Bug Canal, whose operation contributes to the reduction of flow. For most rivers in the Pripyat basin, a clear trend of increasing minimum flow modules with increasing watershed area is observed. This trend can be attributed to the growing proportion of groundwater contribution to the total discharge and the presence of numerous groundwater horizons that are drained by the river. In most cases, minimum water discharges in the right-bank tributaries of the Pripyat River are recorded during the autumn season. Approximately 20 to 30 % of the minimum discharges are recorded in the summer, with a similar percentage in the winter. Freezing is observed only in small rivers and for a limited duration.

Chronological series of minimum winter discharges of spring flood of the Pripyat River at the Mozyr station is presented in Figure 6.

The main statistical characteristics of the analyzed series are presented in Table 13.

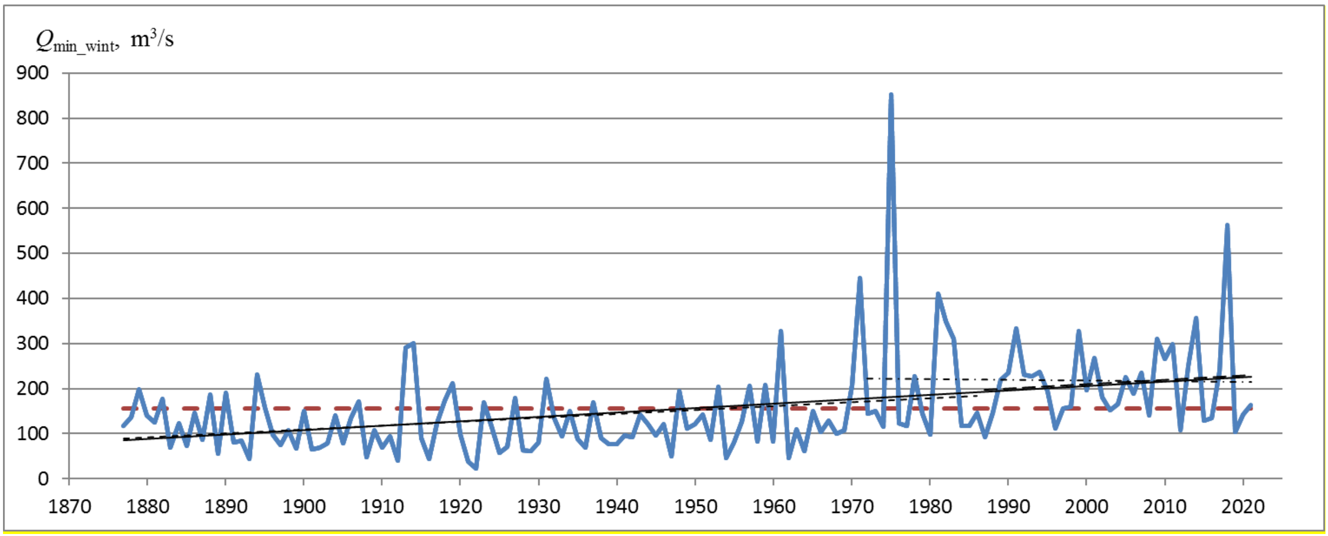

Figure 6 – Chronological series of minimum winter discharges of spring flood of the Pripyat River at the Mozyr station

Table 13 – Main statistical characteristics of minimum winter discharges of the Pripyat River at the Mozyr station for various averaging intervals

Characteristics	Averaging intervals			
	1877–2021 (145 years)	1877–1986 (110 years)	1877–2021 (145 years)	1972–2021 (50 years)
Q_{cp}, m³/s	155	136	214	218
C_v	0.68	0.75	0.43	0.60
C_s	2.87	3.83	1.65	2.79
$r(1)$	0.14	0.07	-0.06	–0.10
ΔQ 10, m³/s	9.75	8.54	9.73	–1.45
r	**0.39**	**0.27**	0.11	–0.02
$r_{кр,\ p=5\ \%}$	*0.16*	*0.19*	*0.33*	*0.28*
% of Q_{cp}	6.29	6.27	4.55	–0.67
Maximum in the period/year	852/1975	852/1975	562/2018	852/1975
Minimum in the period/year	22.0/1922	22.0/1922	92.5/1987	92.5/1987

A statistically significant increase in minimum winter water discharges has been observed for the period from 1987 to 2021, in comparison to the preceding period from 1877 to 1986. The critical value for the one-tailed Student's t-test is $t_{кр}$ = 1.68, while the calculated t-value is t = 4.22. No significant differences in variances (coefficients of variation) were detected. However, the coefficient of skewness has undergone notable changes, which should be considered when selecting probability distribution curves. Additionally, the gradient of flow changes has transformed significantly over the entire study period, as well as during the interval from 1972 to 2010, as corroborated by correlation coefficients.

Observed Climate Change

In recent decades, several changes in climate characteristics have been documented, with the average annual air temperature in this region (as well as across the entire Northern Hemisphere) exhibiting a consistent upward trend. In the Pripyat River basin, this increase has been approximately +0.7 °C to +0.9 °C over the past century. This trend is particularly pronounced during the cold season, where the rate of temperature increase is two to three times higher. In terms of atmospheric precipitation, a downward trend has been identified. Concurrently, the average height of snow cover is decreasing, primarily attributed to rising winter temperatures. These climatic shifts significantly influence the hydrological dynamics of the basin, particularly affecting the intra-annual distribution of river flow. Specifically, the proportion of spring runoff is declining, while the contribution of summer-autumn runoff is increasing. Moreover, the role of rain-induced floods in shaping runoff patterns is becoming increasingly prominent [49, 50].

For the rivers within the Pripyat basin, a comprehensive analysis of hydrological data led to the selection of seven meteorological stations and eleven hydrological posts. The selection of specific stations and posts was based on their availability in 1961 and their continuous operation through 2015 up to now, ensuring the integrity of observational data for climate and flow characteristics.

The initial climate data were sourced from various repositories, including open information resources from the World Meteorological Organization (WMO) and other organizations and centers dedicated to climate research, as well as from climate reference publications.

Figures 7 and 8 illustrate the final results of climate change within the Pripyat River basin.

Based on the assessments of climate change from 1961 to 2015, the following generalized conclusions can be drawn:

– There has been an average increase in air temperature across the basin of 1.0 °C, with the most significant increase observed during the winter season at 1.9 °C, and the least notable increase occurring in the autumn season, with a maximum rise of 0.1 °C.

– The total precipitation across the basin has not changed significantly, exhibiting a slight average increase of 0.7 %, with a maximum increase of up to 16 %.

The results of the changes in climate characteristics for the period from 1961 to 2010 are presented graphically in Figures 7 and 8.

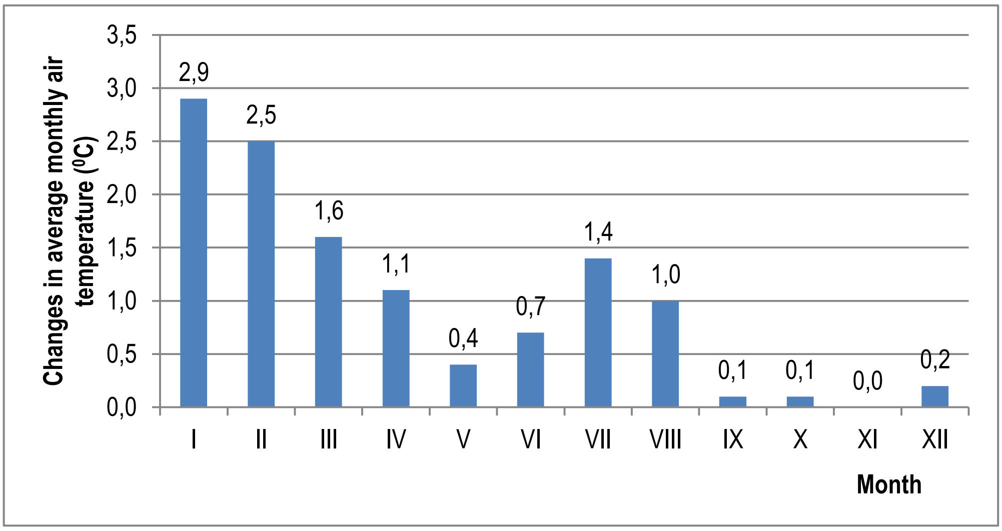

Figure 7 – Changes in average monthly air temperature (^{0}C) within the Pripyat basin (1986–2010) – (1961–1985)

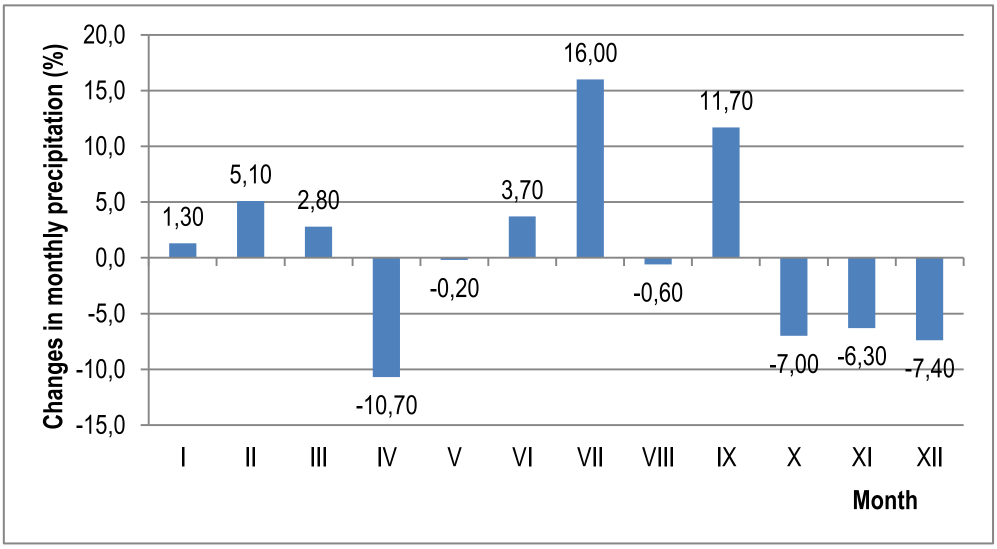

Figure 8 – Changes in monthly precipitation (%) within the Pripyat basin (1986–2010) – (1961–1985)

Observed Changes in River Flow

The assessment of changes in river flow (water discharge) has been conducted for hydrological stations, analyzing both monthly and annual averages for the period from 1986 to 2015, in comparison to the period from 1961 to 1986.

The summarized results of the river flow assessments for the Pripyat River basin, covering the period from 1961 to 2015, are presented in Tables 14 and 15 [13].

Based on the essessment of river flow changes from 1961 to 2015, the following generalized conclusions can be drawn [13]:

– The average annual river flow has experienced only a slight change, with a maximum decrease of 9 %;

– There has been a significant reduction in spring flood flow, which has decreased by 42 %, accompanied by an earlier onset of its peak;

– Winter flow has increased by 20 %;

– Summer flow has not changed significantly over the entire period from 1961 to 2015; however, in recent years (including 2015, 2016, 2017, and 2019), there has been a notable decline in flow, with measurements falling below the minimum recorded levels for the entire specified period.

Maps of changes in river flow from 1961 are provided in Appendix B [13].

Table 14 – Changes in river flow in the Pripyat River basin for the period from 1961 to 2015

River, Gauge station	Catchment area, km²	Characteristic	Water discharge values in intervals 1986–2015 and 1961–1985, m³/s, difference, %											
			January	February	March	April	May	June	July	August	September	October	November	December
Pripyat – Chernichi (Turov)	74000	$Q_{cp.}$	226	237	396	644	438	271	211	183	165	181	211	215
		$Q_{1961–1985}$	215	195	365	767	502	295	212	173	162	176	225	222
		$Q_{1986–2015}$	235	271	421	546	387	252	209	190	167	185	200	209
		Δ%	*9.4*	*39.3*	*15.2*	*–28.9*	*–23.0*	*–14.6*	*–1.6*	*10.2*	*3.6*	*5.4*	*–11.0*	*–6.2*
Pripyat – Mozyr	101000	$Q_{cp.}$	337	357	576	983	684	415	317	278	241	258	298	315
		$Q_{1961–1985}$	322	293	509	1110	723	435	318	262	232	245	303	326
		$Q_{1986–2015}$	350	410	632	879	651	398	316	291	249	268	294	306
		Δ%	*8.7*	*39.6*	*24.2*	*–20.7*	*–9.9*	*–8.6*	*–0.7*	*11.2*	*7.3*	*9.7*	*–2.7*	*–6.0*
Yaselda – Beryoza	1040	$Q_{cp.}$	4.60	4.24	6.95	8.96	4.69	3.26	3.04	3.45	4.69	4.58	4.37	4.59
		$Q_{1961–1985}$	4.27	3.60	8.63	12.5	5.33	3.07	2.31	2.13	2.37	3.33	4.47	4.86
		$Q_{1986–2015}$	4.88	4.78	5.56	6.00	4.15	3.41	3.65	4.55	6.63	5.62	4.29	4.36
		Δ%	*14.3*	*32.8*	*–35.6*	*–52.1*	*–22.1*	*11.1*	*58.0*	*114.6*	*180.0*	*68.8*	*–4.0*	*–10.3*
Yaselda – Senin	5110	$Q_{cp.}$	19.1	19.3	31.1	44.4	27.7	17.5	12.9	10.1	9.88	13.3	17.7	18.8
		$Q_{1961–1985}$	18.6	15.9	33.6	56.7	33.0	19.8	12.7	8.89	8.41	12.3	18.7	20.5
		$Q_{1986–2015}$	19.5	22.2	28.9	33.8	23.1	15.6	13.1	11.2	11.2	14.1	16.9	17.3
		Δ%	*5.0*	*39.7*	*–14.0*	*–40.5*	*–30.1*	*–20.9*	*3.7*	*25.9*	*32.6*	*14.8*	*–9.9*	*–15.3*
Tsna – Diatlovichi	1100	$Q_{cp.}$	4.04	4.02	8.07	13.3	6.29	3.51	2.85	2.19	1.76	2.39	3.45	3.63
		$Q_{1961–1985}$	3.23	2.74	7.80	15.8	6.85	3.13	1.88	1.43	1.42	2.17	3.60	3.31
		$Q_{1986–2015}$	4.72	5.08	8.29	11.1	5.82	3.83	3.65	2.82	2.03	2.58	3.33	3.91
		Δ%	*46.1*	*85.4*	*6.3*	*–29.9*	*–15.0*	*22.4*	*94.2*	*97.2*	*43.0*	*18.9*	*–7.5*	*18.2*
Horyn – Malye Viktorovichi	27000	$Q_{cp.}$	90.1	106	191	243	117	86.9	86.3	71.9	63.5	67.8	75.9	80.6
		$Q_{1961–1985}$	83.3	92.4	215	296	140	90.9	99.2	77.7	71.5	74.8	87.7	86.0
		$Q_{1986–2015}$	95.3	117	173	202	98.7	83.8	76.5	67.4	57.4	62.4	66.8	76.6
		Δ%	*14.4*	*27.0*	*–19.6*	*–31.5*	*–29.5*	*–7.8*	*–22.9*	*–13.2*	*–19.8*	*–16.6*	*–23.9*	*–11.0*
Sluch – Lenin	4480	$Q_{cp.}$	15.4	15.1	29.8	46.6	20.6	12.0	9.61	8.68	10.3	12.7	14.5	14.5
		$Q_{1961–1985}$	14.8	11.9	30.2	64.4	24.9	12.3	9.08	8.14	9.90	13.1	16.2	15.6
		$Q_{1986–2015}$	15.9	17.7	29.4	31.8	17.0	11.7	10.1	9.12	10.7	12.3	13.0	13.6
		Δ%	*7.2*	*49.5*	*–2.6*	*–50.6*	*–31.5*	*–4.5*	*10.7*	*12.0*	*7.7*	*–6.0*	*–20.2*	*–12.6*
Uborts – Krasno-berezhie	5260	$Q_{cp.}$	18.1	19.7	45.0	62.7	26.7	20.0	17.9	13.8	9.15	9.59	14.0	17.5
		$Q_{1961–1985}$	13.4	14.3	48.0	77.0	31.0	19.4	18.8	14.6	9.14	9.81	15.9	19.6
		$Q_{1986–2015}$	21.2	23.6	43.0	51.7	23.5	20.2	17.2	13.3	9.15	9.42	12.5	15.9
		Δ%	*57.8*	*65.1*	*–10.4*	*–32.9*	*–24.3*	*4.4*	*–8.5*	*–9.1*	*0.1*	*–4.0*	*–21.2*	*–18.9*
Ptich – Luchitsy	8770	$Q_{cp.}$	40.5	39.0	64.6	99.6	58.9	37.0	29.8	25.7	27.0	31.9	38.3	40.5
		$Q_{1961–1985}$	38.6	32.6	65.4	125	67.7	39.3	30.9	28.0	28.4	33.1	42.1	44.5
		$Q_{1986–2015}$	42.0	44.3	63.9	78.6	51.5	35.1	28.9	23.9	25.9	30.9	35.2	37.1
		Δ%	*8.9*	*35.6*	*–2.2*	*–37.0*	*–24.0*	*–10.6*	*–6.4*	*–14.6*	*–8.6*	*–6.6*	*–16.2*	*–16.6*
Shats – Shatsk	208	$Q_{cp.}$	1.00	1.06	2.08	2.91	1.25	1.03	0.96	0.85	0.77	0.76	0.94	0.95
		$Q_{1961–1985}$	0.75	0.81	2.11	3.70	1.31	1.15	1.23	1.11	0.95	0.81	0.95	0.88
		$Q_{1986–2015}$	1.20	1.26	2.04	2.26	1.21	0.92	0.74	0.63	0.63	0.71	0.94	1.00
		Δ%	*60.0*	*55.6*	*–3.3*	*–38.9*	*–7.6*	*–20.0*	*–39.8*	*–43.2*	*–33.7*	*–12.4*	*–1.1*	*13.6*
Oressa – Andreevka	3580	$Q_{cp.}$	16.8	17.2	25.6	31.6	18.2	13.9	12.3	11.6	13.9	15.6	16.4	16.8
		$Q_{1961–1985}$	16.2	15.0	25.7	37.4	20.7	15.4	12.9	12.9	14.7	16.4	18.2	18.7
		$Q_{1986–2015}$	17.3	19.1	25.4	26.8	16.1	12.6	11.8	10.4	13.3	14.8	14.9	15.1
		Δ%	*6.9*	*27.2*	*–1.2*	*–28.3*	*–22.2*	*–180*	*–8.1*	*–19.4*	*–9.1*	*–9.7*	*–17.9*	*–19.2*

Scenarios and Projections of Climate Change

Climate change scenarios for the river basins of the Dnieper and Pripyat rivers, extending to the year 2035, have been developed using materials presented in the Atlas of Global and Regional Climate Projections, which serves as an appendix to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [51]. For the overarching climate and hydrological projections up to 2035, a multimodel ensemble consisting of four scenarios – RCP8.5, RCP6.0, RCP4.5, and RCP2.6 – has been employed alongside cartographic representations created by the IPCC using global climate models, as detailed in the atlas.

The climate change scenarios have been formulated based on two greenhouse gas emission pathways (widely recognized in global practice and frequently utilized for climate change assessments) [52, 53]:

Scenario I: A1B (Relatively High-Emission Scenario) – This scenario is characterized by relatively high greenhouse gas emissions resulting from rapid economic development and population growth until the mid-21st century. Following this period, it anticipates a deceleration in population growth, the swift adoption of modern technologies, and a balanced approach to energy resource utilization.

Table 15 – Changes in water discharge (numerator m³/s and demoninator %) within the Pripyat River basin from 1961 to 2009

River – Gauge station	Catchment area, km²	Average	Maximum spring flood	Minimum summer-autumn low flow	Minimum winter low flow
Pripyat – Chernichi (Turov)	74000	282/–6.8	973/–18.3	120/2.3	141/–1.8
Pripyat – Mozyr	101000	422/–0.6	1410/–30.0	179/–0.8	205/2.6
Yaselda – Beryoza	1040	4.79/1.7	20.8/–66.0	1.72/98.2	2.63/39.4
Yaselda – Senin	5110	20.2/–12.4	67.6/–47.1	6.20/20.0	10.9/12.1
Tsna – Diatlovichi	1100	4.62/6.8	22.6/–42.8	0.94/16.3	1.96/31.7
Horyn – Malye Viktorovichi	27000	107/–16.7	631/–45.7	40.9/–6.9	49.8/3.9
Sluch – Lenin	4480	17.5/–16.5	79.5/–39.0	4.34/–33.0	8.58/–5.3
Uborts – Krasnoberezhie	5260	22.8/–10.5	162/–49.6	4.23/8.7	8.47/14.6
Ptich – Luchitsy	8770	44.4/–13.5	152/–44.6	17.6/–10.7	24.3/3.8
Shats – Shatsk	208	1.21/–13.7	8.76/–53.6	0.39/–31.9	0.49/13.0
Oressa – Andreevka	3580	17.5/–11.7	53.9/–26.9	6.72/–24.8	10.0/–1.1

Scenario II: B1 (Low-Emission Scenario) – This scenario presents a more "lenient" outlook, characterized by low greenhouse gas emissions. It suggests a probable sudden onset of globalization, with population dynamics mirroring those outlined in Scenario A1. However, it envisions a rapid transformation of the economic system into an information-driven model, with society becoming less consumer-oriented and a significant emphasis on the adoption of new clean technologies.

For the Pripyat basin, a more detailed climate forecast has been constructed, accounting for regional variability as identified through meteorological station data from 1961 to 2015. This forecast employs the most unfavorable (conservative) scenarios projecting the highest temperature increases and reductions in precipitation. Additionally, it incorporates linear interpolation and delineates climate change scenarios utilizing the regional model CCLM, with outputs derived from the global climate model ECHAM5, as illustrated in Figures 9 and 10.

Under the most conservative climate change scenarios, the average annual temperature in the Pripyat basin is projected to increase by up to 1.9 °C, with the greatest seasonal rises occurring in winter (up to 2.53 °C), followed by summer (2.1 °C), and approximately 1.7 °C during spring and autumn. Annual precipitation is expected to undergo minimal change, with an overall decrease of approximately 2.2 %. Seasonal variations include a slight reduction in winter precipitation (less than 1 % on average), a pronounced increase in summer precipitation (approximately 6.2 %), a moderate rise in spring (3.3 %), and a minor decrease in autumn (around 1.6 %).

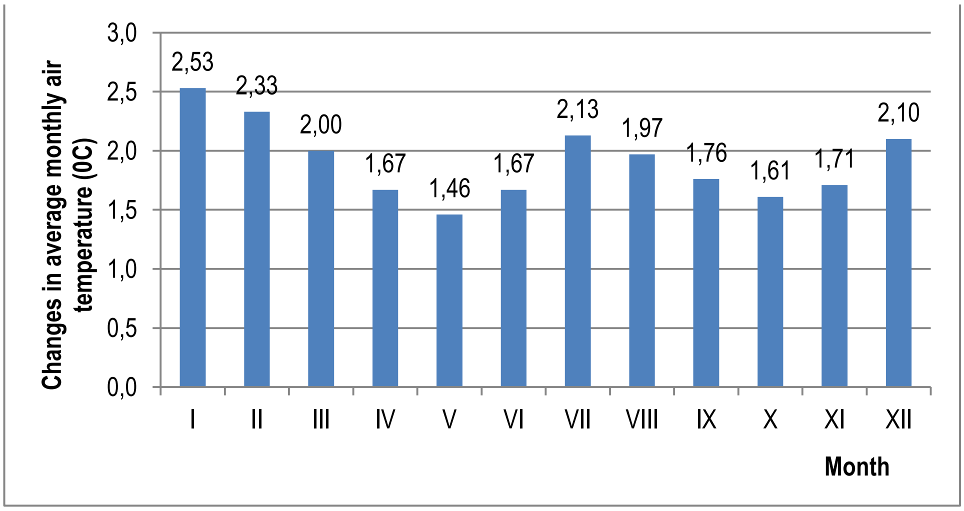

Figure 9 – Forecast of changes in average monthly air temperature (⁰C) within the Pripyat basin up to 2035. (mean value for 2021 – 2050)

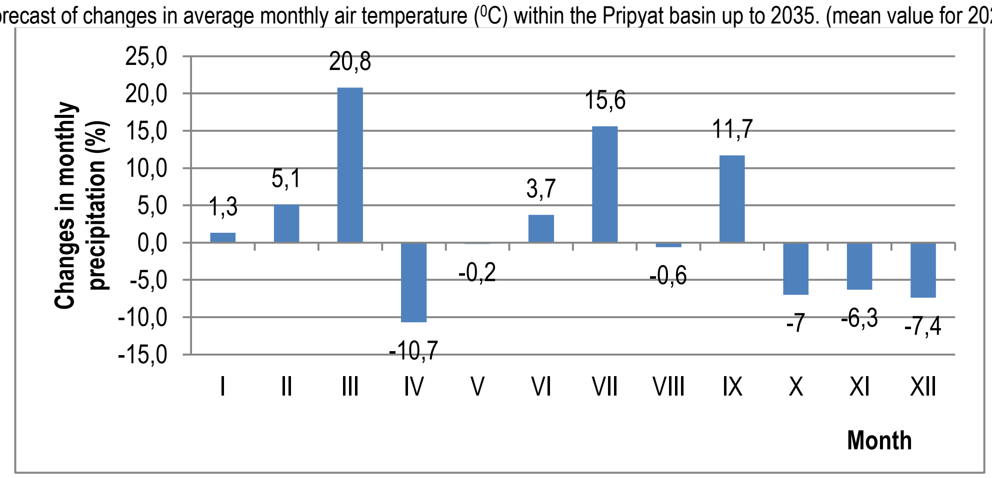

Figure 10 – Forecast of changes in average monthly precipitation (%) within the Pripyat basin up to 2035 (mean value for 2021–2050)

https://doi.org/10.36773/1818-1112-2025-138-3-141-158

Runoff Change Projections

Applying the hydrological and climatic calculation methodology outlined previously, projections of river runoff changes in the Pripyat basin have been developed for the period up to 2035. These projections integrate observed climate and river discharge data from 1961 to 2015, alongside refined climate forecasts for the basin based on a multimodel ensemble comprising four scenarios recommended by the Intergovernmental Panel on Climate Change (IPCC), incorporating regional climate variability.

A synthesis of the projected runoff changes for rivers within the Pripyat basin through 2035 is presented in Table 16 and illustrated in the cartographic schemes of Appendix G [13].

Key findings from the runoff projections for the Pripyat basin rivers by 2035 include:

A decline in mean annual runoff;

A slight reduction in winter runoff across most rivers;

A likely decrease in spring runoff, with some exceptions;

A substantial and the most pronounced reduction in runoff during summer compared to other seasons;

A decrease in runoff during autumn, particularly in early autumn (up to mid-October).

Table 16 summarizes the anticipated changes in river runoff for the Pripyat basin, based on a combination of the A1B and B1 emission scenarios, further refined using a multimodel ensemble of four CMIP5 scenarios as outlined in the IPCC's Fifth Assessment Report (2013) [54].

Table 16 – Projected changes in surface runoff by 2035 for rivers in the Pripyat basin, expressed as a percentage of current condition, %

River – Gauge station	Winter	Spring	Summer	Autumn	Average annual
Pripyat – Chernichi (Turov)	4.9	5.5	–19.2	0.6	–2.1
Pripyat – Mozyr	0.2	1.6	–20.6	–2.4	–5.3
Yaselda – Beryoza	–0.3	–27.0	–41.7	–23.3	–23.1
Yaselda – Senin	–3.9	–10.6	–37.7	–11.8	–16.0
Tsna – Diatlovichi	–3.7	–8.9	–26.9	–19.9	–14.9
Horyn – Malye Viktorovichi	–4.0	–11.8	–20.1	–16.7	–13.2
Sluch – Lenin	10.1	5.7	–15.8	1.6	0.4
Uborts – Krasnoberezhie	–13.4	–5.6	–25.2	–38.8	–20.8
Ptich – Luchitsy	10.3	–0.2	–24.0	16.7	0.70
Shats – Shatsk	–0.2	–9.2	–10.7	–4.4	–6.1
Oressa – Andreevka	–14.7	–10.7	–28.4	5.4	–12.10
Average in catchment:	***–1.3***	***–6.5***	***–24.6***	***–8.5***	***–10.2***

Conclusion

The assessment of changes in river runoff within the Pripyat Basin, as well as across Belarus as a whole, over the period from 1961 to 2015 indicates that, on average, these changes have been modest. Nevertheless, climate change has contributed to increased spatial and seasonal variability in runoff patterns, as well as differences related to catchment area size. Specifically, rivers in the Pripyat Basin have experienced runoff reductions in nearly all seasons except winter, during which runoff has increased. Notably, significant alterations have occurred in the spring period, characterized by a decline in spring flood runoff and an earlier onset of the flood season. Divergent trends in runoff changes are evident across spring, summer, and autumn, with summer showing a particularly marked decrease.

Projections extending to 2035 largely corroborate the observed trends from 1961 to 2015. Forecasts suggest a pronounced differentiation in runoff volumes between small and medium-sized rivers. Although average annual runoff may change only slightly, there is a high likelihood of increased seasonal and monthly variability, with summer months expected to experience especially substantial declines across all rivers in the Pripyat Basin. Moreover, the magnitude of projected runoff changes in the Pripyat Basin is anticipated to exceed those for rivers located in northern Belarus.

It is important to emphasize that these runoff projections under changing climatic conditions should be interpreted probabilistically, reflecting inherent uncertainties arising from several sources, including:

– Limitations in detecting trends of meteorological and hydrological variables, accounting for their statistical significance.

– Ambiguities and uncertainties inherent in climate change scenarios.

– Uncertainties in hydrological model outputs due to model imperfections, calibration challenges, and data limitations.

– Unpredictability of anthropogenic influences on water resources under evolving climate conditions.

The value of runoff assessments and forecasts lies in their critical role for informing water management and protection strategies aimed at enhancing governance of the Pripyat Basin.

Among the most significant adverse impacts of climate change on river runoff is the potential increase in the frequency and intensity of extreme hydrometeorological events. These include heavy precipitation, droughts, late frosts, and floods driven by snowmelt and rainfall, especially when wet snow and rain coincide, potentially prolonging flood durations.

Enhanced intra-annual runoff variability and elevated flood risks – due to abrupt winter thaws, earlier spring floods, and intensified rain-induced flood events – may substantially increase the occurrence of extreme hydrological phenomena.

The issue of low-flow periods is particularly pertinent for rivers in the Pripyat Basin. Although current and near-future conditions do not indicate an imminent water resource deficit, the probability of extended low-flow episodes is rising. Such periods may lead to ecological degradation and diminished recreational value of surface water bodies and adjacent lands, altered groundwater regimes, and soil depletion in floodplain areas.

Furthermore, increased frequency and duration of droughts elevate the risk of significant runoff reductions in small rivers, resulting in lowered water levels, deteriorated water quality, and diminished recreational potential.

Consequently, the development and implementation of adaptive measures aimed at optimizing water resource management in response to climate change represent an urgent priority.

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