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THE CLIMATE CHANGE IMPACT ON THE HYDROLOGICAL REGIME OF THE RIVERS IN BELARUS

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Abstract

The article evaluates the changes in the parameters of the annual runoff, the maximum spring flood runoff and the main runoff-forming factors for the period 1988−2018 in relation to the period 1949-1987. The observed over the past decades climatic changes significantly change the situation of the spatio-temporal variability of the maximum runoff. Changes in the annual runoff for most catchments of Belarus are statistically insignificant. The main climatic factors determining the spring flood runoff are precipitation during the winter and spring periods, and the air temperature of the winter period. Taking into account the multi model ensemble of four climate change scenarios, the forecast estimates of the annual and maximum runoff for the period up to 2035 are obtained.

Keywords: river flow rates, precipitation, air temperature, forecast estimates, climate warming, long-term variability.

ВЛИЯНИЕ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ НА ГИДРОЛОГИЧЕСКИЙ РЕЖИМ РЕК БЕЛАРУСИ

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Реферат

В статье выполнена оценка изменений характеристик годового стока, максимального стока весеннего половодья и основных стокоформирующих факторов за период 1988−2018 гг. по отношению к периоду 1949−1987 гг. Установлено, что отмечаемые за последние десятилетия климатические изменения существенно меняют картину пространственно-временной изменчивости максимального стока. Изменения же годового стока для большинства водосборов Беларуси носят статистически незначимый характер. Основными климатическими факторами, определяющими сток весеннего половодья, являются осадки за зимний и весенний периоды, температура воздуха зимнего периода. С учетом мультимодельного ансамбля из четырех сценариев изменения климата получены прогнозные оценки годового и максимального стока на период до 2035 г.

Ключевые слова: расходы речного стока, осадки, температура воздуха, прогнозные оценки, потепление климата, многолетняя изменчивость.

Introduction

Rational management of water resources in modern conditions is one of the priority tasks in the field of water resources not only in Belarus, but also throughout the world. Reliable provision of water to the population and sectors of the economy, early warning of natural hazards is a necessary condition for the sustainable development of society. In the process of developing a water resources management strategy, planning and implementing water management measures, solving problems of optimal regulation of river runoff, it is necessary, first of all, to have scientifically based assessments of the changes in hydrological characteristics occurring and expected in the future under the influence of continuous and increasing anthropogenic impact and changing climate. The complexity of solving these issues at the present stage of society's development is largely due to the peculiarities of socio-economic and climatic conditions of the last three decades. In the last 30 years, significant dynamics of climatic indicators has been observed in the territory of Belarus, as well as throughout the world, which causes a response in hydrological processes [1-3]. Since river runoff refers to climatically conditioned renewable water resources, a change in the regime of river runoff affects not only the possibility of its use as a source of water supply, but also the preservation (or violation) of the ecological balance of water bodies.

River runoff is a complex multifactorial process. The works [4, 5] provide a detailed analysis of the influence of each of them. Despite the large amount of factors forming the runoff, in the present conditions it is the climatic factor that comes to the fore. A lot of works have been devoted to the study of the regularities of the river runoff formation in Belarus, the variability of the runoff characteristics in the spatio-temporal aspect [6, 7]. However, these studies do not cover the last years of observations when global climate change occurred. The methods of probability theory and mathematical statistics used in earlier studies to assess the long-term variability of the runoff and the factors forming the runoff are mainly applicable to homogeneous data. The occurring abrupt, stepwise changes in the series of characteristics of the runoff make them heterogeneous, or non-stationary, and require other approaches to analysis. In conditions of non-stationary climate, anthropogenic load on catchments, uneven placement of hydrological stations, as well as their amount decrease, assessment of long-term variability of runoff, establishment of quantitative links between the characteristics of runoff and the totality of its determining factors, assessment of runoff changes in the future is undoubtedly one of the most pressing problems solved by modern scientific and applied hydrology.

The purpose of the study is to assess the current transformation of the annual runoff, the maximum spring flood runoff of the rivers in Belarus, as well as to obtain forecast estimates of their changes under probable climatic scenarios in the future.

To achieve these goals, we had to solve a number of tasks:

- Assessment of changes in the main runoff characteristics for the period 1949-1987 (base period) in relation to the period 1988–2018 (modern period);
- Analysis of changes in the main climatic factors of the annual and maximum runoff formation;
- Obtaining forecast estimates of changes in river runoff up to 2035.

Materials and methods

The study used the observation materials of the State Institution "Republican Center for Hydrometeorology, Control of Radioactive Contamination and Environmental Monitoring" of the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus for the current hydrological stations for the period of instrumental observations published in the materials of state cadasters. To identify the spatial and temporal variability in river runoff, air temperature and precipitation, time series for the period from 1949 to 2018 were processed (n = 70 years). The observations of monthly and annual precipitation amounts, average monthly and average annual atmospheric air temperatures at 50 weather stations, average monthly river runoff rates at 84 hydrological stations evenly located across the territory of Belarus were used as initial hydro meteorological information. The reduction of series with short duration of observation periods for the selected hydro stations for the study was carried out using the computer software complex "Hydrologist-2" [8].

The methodology of the study was based on the systematization and analysis of long-term series of observations of the average annual and maximum spring flood runoff of the rivers in Belarus. The analysis of the long-term variability of the runoff characteristics of the studied rivers was

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carried out differentially, since the hydrological regime of medium and especially small rivers is not identical to large rivers. Small rivers are particularly sensitive to the conditions of their formation and serve as an integral indicator of complex natural and anthropogenic processes occurring in their catchments. Conventionally, rivers are classified into the following groups:

- Rivers with a catchment area of more than 30,000 km^2;
- Rivers with a catchment area from 10,000 km2 to 30,000 km^2;
- Rivers with a catchment area from 2,000 km2 to 10,000 km^2;
- Rivers with a catchment area of up to 2,000 km^2.

Due to the fact that climate is one of the main factors determining the total amount and intra-annual distribution of runoff, it is advisable to study the entire hydrological cycle in the river basin, including changes in time and space in the amount of precipitation and air temperature.

Results and discussion

Observed climate changes

During the period 1949-2018 the average temperature increase in Belarus was about 0.31 °C/10 years, whereas during the period from 1969 to 2018 it increased to 0.46 °C/10 years.

To identify the peculiarities of air temperature fluctuations in the basins of large rivers in Belarus, differential integral curves for 1949–2018 for 8 weather stations were constructed (Figure 1).

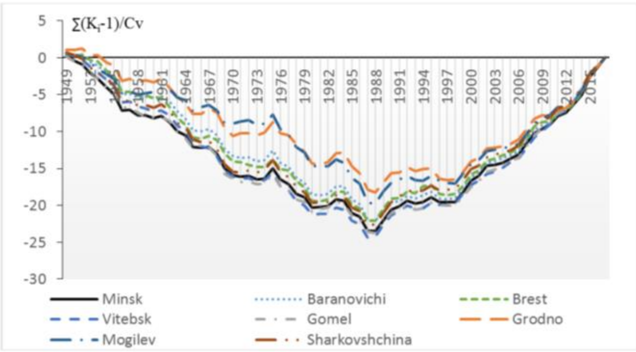


Figure 1 – Differential integral curves of average annual air temperatures at weather stations in Belarus

The ordinates of the differential integral curves are calculated as an increasing sum $\sum(K_i - 1)/c_v$, where $K_i = Q_i/\bar{Q}$ is the modular coefficient, Q_i is the average annual air temperature, *i* is the number of the calculated term of the sequence, $\bar{Q}$ is the average annual value of air temperature, c_v is the coefficient of variation.

The constructed differential integral curves of the average annual atmospheric air temperature show that the calculated period of 1949-2018 includes periods of temperature decrease and increase, and since 1988 it has been in the positive phase of the upward trend. Figure 1 shows that 1988 corresponds to the beginning of an intensive increase in average annual air temperatures. To assess climate change in accordance with the recommendations of the World Meteorological Organization, the initial series was divided into two periods of 30 years or more: 1) from 1949 to 1987; 2) from 1988 to 2018.

Analysis of air temperature for the period 1988-2018 compared to the period 1949-1987 indicates its growth throughout the territory of Belarus. The increase in the average annual temperature on the territory of Belarus for the second study period was 1.31 °C.

Since the temperature change is uneven both within the year and in space, further study of atmospheric air temperatures was carried out according to the groups shown in Figure 2.

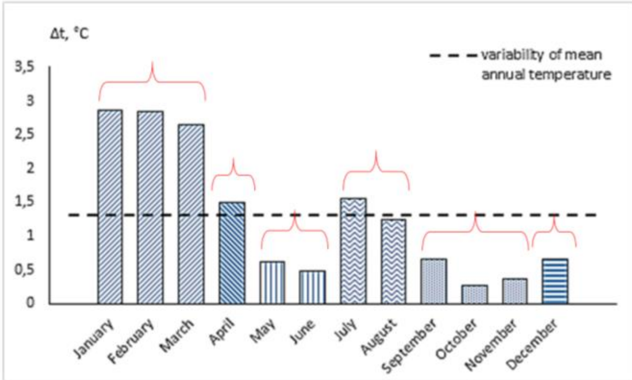


Figure 2 – The change in the average annual and average monthly air temperatures for the period 1988-2018 in relation to the period 1949-1987, °C

The results of spatial generalization of air temperature changes by selected groups are presented in the form of maps prepared in ArcGIS (Figure 3).

Unlike the change in air temperature, there was no significant change in the total amount of precipitation in the annual context (Figure 4). It is worth noting that the change in precipitation, as well as temperature, is characterized by ambiguity by basins and months. The greatest positive dynamics in precipitation changes (ΔP) is observed in February, March, and July. In October an increase in precipitation is observed in the basins of the Berezina, Dnieper, Western Dvina and Sozh rivers. A negative trend in precipitation changes is typical for April and August (except for the Western Dvina River basin).

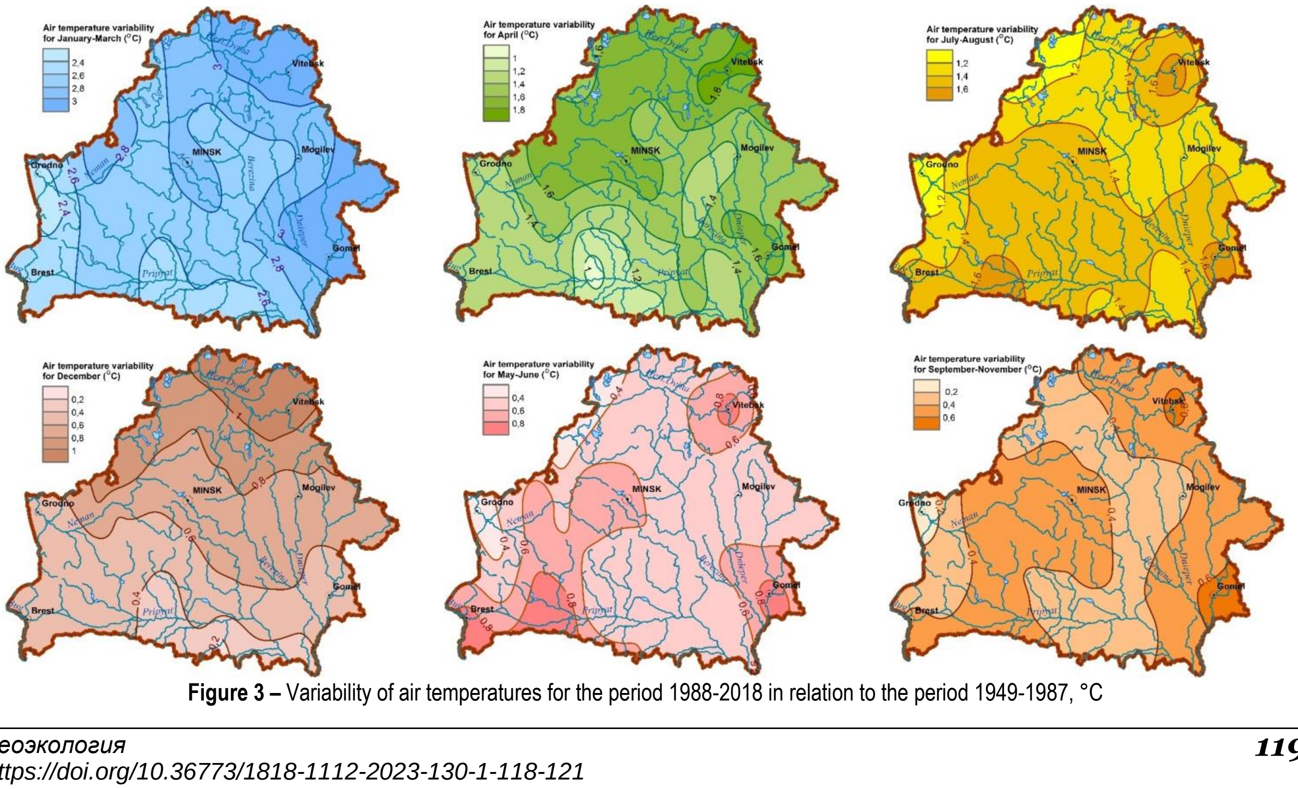


Figure 3 – Variability of air temperatures for the period 1988-2018 in relation to the period 1949-1987, °C

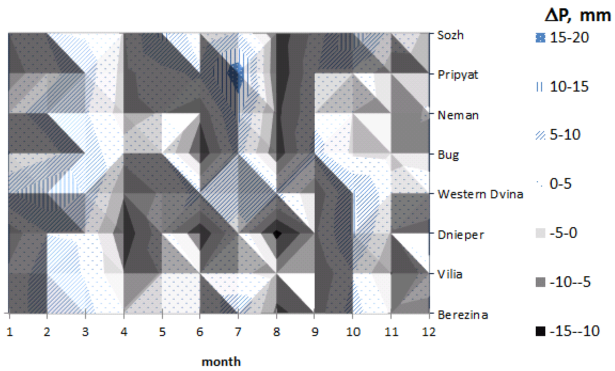


Figure 4 – The change in the amount of precipitation by month for the basins of the rivers in Belarus for the period 1988-2018 in relation to the period 1949-1987

Changes in annual and maximum runoff

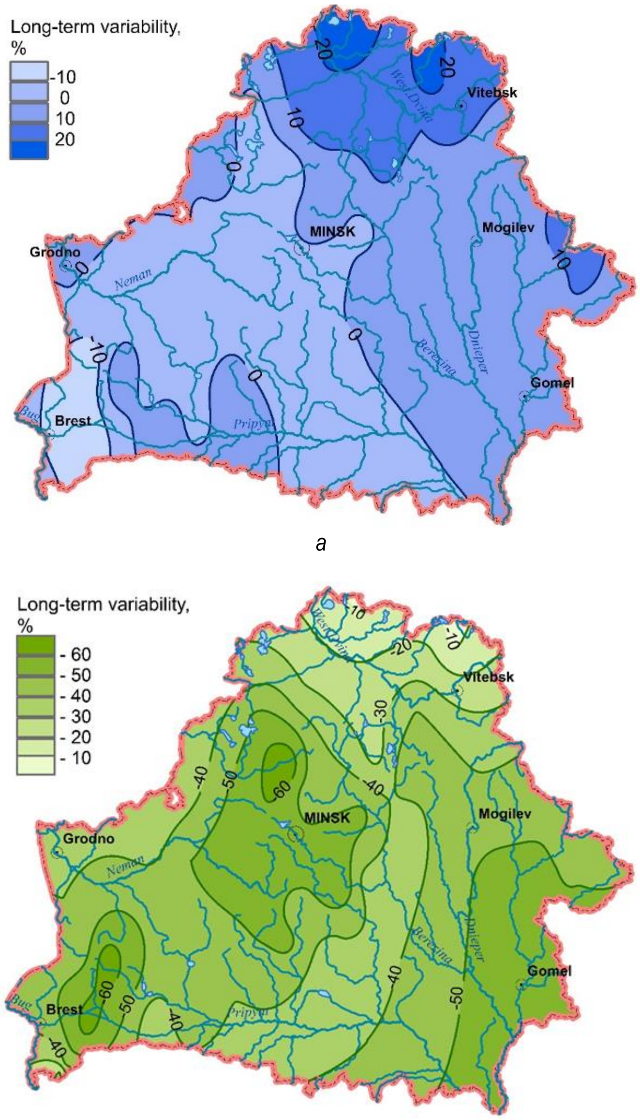
Quantitative indicators of runoff variability for the two studied periods are shown in Table 1.

Table 1 – Variability of the studied types of river runoff in Belarus for the modern period in relation to the base period, %

River − Station	Catchment area, km^2	Annual	Maximum spring
	rivers with catchment area > 30 000 km^2		
Pripyat − Mozyr	101000	11	-33
Dnieper − Rechitsa	58200	6	-42
Western Dvina − Polotsk	41700	12	-19
Sozh − Gomel	38900	8	-49
Neman − Grodno	33600	4	-44
	rivers with catchment area > 10 000 km^2		
Berezina − Bobruisk	20300	-2	-53
Dnieper − Orsha	18000	12	-31
Sozh − Slavgorod	17700	13	-48
Neman – Belitsa	16700	-8	-53
Vilia – Michalishki	10300	-6	-57
	rivers with catchment area > 2 000 km^2		
Mukhavets – Brest	6590	-18	-64
Berezina – Borisov	5690	2	-42
Yaselda – Senin	5110	-4	-49
Disna – Sharkovshchina	4720	-2	-38
Neman – Stolbtsy	3070	-8	-59
	rivers with catchment area ≤ 2 000 km^2		
Vilia – Steshitsy	1230	4	-52
Tsna – Dyatlovichi	1100	1	-4
Yaselda – Bereza	1040	6	-67
Uza – Pribor	760	9	-55
Polota – Yankovo	618	15	-18

The analysis of the runoff changes at the studied gauging stations showed that the highest change in the average annual runoff occurred for large rivers (the average in Belarus is 6%), and the change in the maximum runoff is most pronounced for small and medium-sized rivers (a decrease in runoff by an average of 43%). For large rivers, the decrease in maximum runoff reaches 37%. The results of spatial generalization of changes in the average annual runoff and maximum spring flood runoff are presented in Figure 5. Analysis of the obtained maps allows us to conclude that an increase in annual runoff occurred for the basins of the Western Dvina and Dnieper rivers. The rest of Belarus is mainly characterized by a slight decrease in annual runoff.

The considered climatic changes have a direct impact on the water regime of the rivers in Belarus. To assess the relationship between the values of runoff, air temperatures and precipitation, correlation coefficients within the framework of correlation matrices between these values were determined. The analysis of the relationship closeness of river runoff with meteorological parameters showed that the main climatic factors determining the runoff of the spring flood are precipitation for winter and spring periods and air temperature for January−March and August. The correlation coefficients of average annual expenditures with the total amount of precipitation for January−September are statistically significant for most runoff series and reach the highest values.

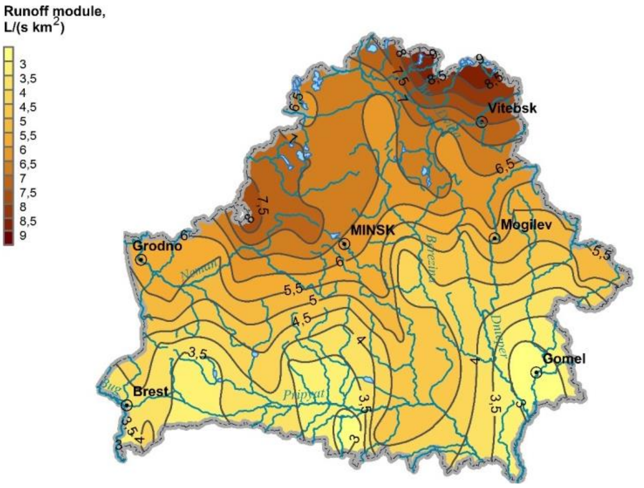


a – annual runoff, *b* – maximum spring runoff

Figure 5 – Change in runoff (%) for the period 1988-2018 in relation to the period 1949-1987:

Estimates of the possible river runoff changes in Belarus in the XXI century based on climate models

To obtain forecast estimates of changes in the river runoff in Belarus for the period up to 2035, the method of hydrological and climatic calculations proposed by V.S. Mezentsev, based on the joint solution of the equations of water and heat and energy balances, has been adapted [10]. The developed model is used to assess possible changes in river water resources depending on climatic fluctuations and anthropogenic impacts on watershed characteristics. Generalized forecast estimates of runoff changes were obtained taking into account a combination of scenarios A1B and B1 of climate change, as well as refinements using a multi model ensemble of four CMIP5 scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC) in 2013 in the Fifth Report on Climate Change [11]. Maps of forecast estimates of the river runoff in Belarus for the period up to 2035 are shown in Figure 6.



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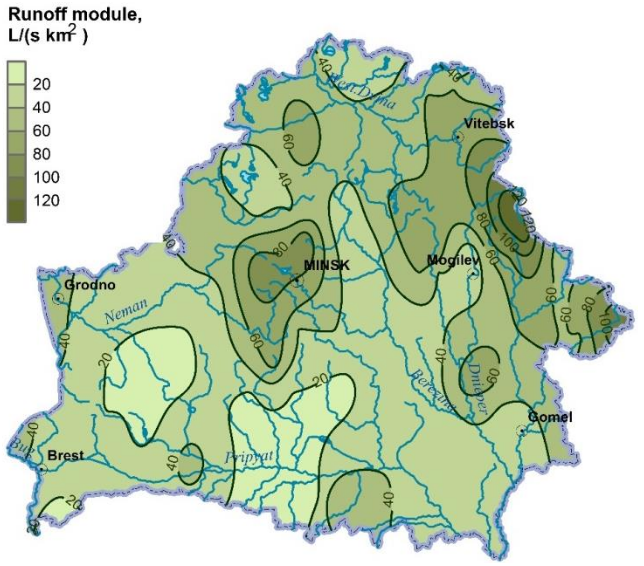

b

a – annual runoff, *b* – maximum spring runoff

Figure 6 – Forecast estimates of changes in the river runoff in Belarus until 2035:

Conclusion

From the results of trends assessments in climate parameters it follows that over the period 1988-2018 an average increase of 1.3 °C in air temperature occurred in the territory of Belarus. At the same time, there was a significant unevenness in the intra-annual distribution of the air temperature increase with a maximum increase in winter (up to 3.2 °C in the basin of the Western Dvina River and up to 2.4 °C in the south-west of Belarus), with a minimum increase in autumn (up to 0.8 °C). In contrast to the change in air temperature, there was no significant change in the total amount of precipitation in the annual context.

As a result of the performed studies on the runoff dynamics, it was found that the maximum spring flood runoff of the rivers in Belarus for the period 1988-2018 decreased by an average of 41% compared to the runoff of the base period 1949-1987, and the average annual runoff increased by an average of 3.5%.

Based on the results of the forecast estimates, the following conclusions can be drawn about the river runoff changes in Belarus until 2035:

- The average value of the annual river runoff in Belarus will change from -10% (in the Pripyat River basin) to 10% (in the Western Dvina River basin);
- The average annual values of the maximum river runoff in Belarus are characterized by a decrease of up to 5% for the basins of the Dnieper and Pripyat Rivers, an increase of 5% in the basins of the Western Dvina and Neman Rivers.

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