Changes of mean and peak river runoff in Belarus during the 20th century

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1. Changes of mean river runoff

The purpose of this research is the estimation of changes of mean and extreme river runoff in Belarus during the 20th century for the Neman River, the West Dvina River and the Bug River. Long-term monthly mean and peak observations of runoff are used as input. The data were received from the Republican Meteorological Center of the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus.

A comparative analysis of hydrographs of the Neman River runoff was executed using the following indices: percent of variation in the runoff for separate periods and seasons; date of passing of the peak of the spring high water; amount of high waters in one year.

On average for the period 1961 to 2005, runoff of the Neman River in spring accounts for 41% of the annual runoff. During the summer-autumn season, 37 % of the total annual runoff is observed and 22% is observed during the winter season. The November runoff is higher than in October, except for years with exceptionally high runoff. The greatest water flow in the winter season occurs in January.

Comparative analysis of the water regime of the Neman River for the period of observations during 1961 to 2005 has shown that there were systematic changes These include a significant decrease of the peak flow during the spring freshet and a moderate increase of the flow in summer-autumn and especially in winter seasons. These changes are connected to appropriate climatic variations observed in the same period. Frequent prolonged winter thaws have increased the infiltration of snowmelt water into the soil, and consequently lead to increase of minimum (winter) flow, reduction of the stream flow during the spring high water period, and the earlier passage of the peak flow.

An increase of minimum stream flow in the summer-autumn period was caused (in addition to, climatic factors) by human impact in the form of wide-scale melioration projects. Though the scale of these projects in the Neman River Basin are much less than to those implemented in Polesye, nevertheless, they cannot be ignored. In the last years, the number of freshet periods for very high -flow years has increased up to 4, for the high-flow years this number increased from 2 to 3 per year to 3 to 4 per year, and did not change for other years. Similar runoff variations were observed on other rivers of the Baltic Sea Basin in the Republic of Belarus. So the runoff variations in the West Dvina River Basin are characterized by increase in winter and decrease in the summer-autumn season. Observations of the runoff variations in the Vilia region show a runoff decrease in the spring and summer-autumn seasons and an increase in the winter time. However in the small watersheds where large anthropogenic impact has occurred (offloading, pumping and/or the discharging the ground waters etc.), natural runoff was significantly disturbed and its tendencies deviate from observed over the large river basins.

For correct runoff quantification it is necessary to partition it into anthropogenic and natural components using expression:

$$M_{est.} = M_{izm.} \pm \Delta M_{aper.} \pm \Delta M_{k\,lim.} \pm \Delta M_{antr.}, \qquad (1)$$

where $M_{est.}$ – total runoff, which would be observed without global climate and local anthropogenic disturbances; $M_{izm.}$ – the measured amount of the runoff at given period; $\Delta M_{aper.}$ – the “natural” runoff fluctuations of the runoff caused by climate variations; $\Delta M_{k\,lim.}$ – the runoff changes caused by global warming; $\Delta M_{antr.}$ – the runoff changes caused by local anthropogenic impact.

The size of $\Delta M_{aper.}$ is usually estimated as an anomaly from the average runoff amount during for the study period (i.e., as an anomaly from its long-term normal value). The size of $\Delta M_{k\,lim.}$ can be estimated using regression analysis (if the element $\Delta M_{antr.}$ is absent), or with the help of regional «precipitations – temperature – runoff» models.

Usually, the natural runoff fluctuations ($\Delta M_{aper.}$) are spatially asynchronous, while the runoff changes caused by global climate change ($\Delta M_{k\,lim.}$) have a more coherent systematic character for the large areas. This allows us to separate the contribution of these two factors to the river runoff.

The element $\Delta M_{antr.}$ shows cumulative influence on the runoff by human activity. Its estimation may be associated with big errors due to the absence of mass measurements.

The need to use of formula (1) emerged from analyses of initial hydrometeorological data observed by various methods. When we discovered statistically significant deviations in the runoff time series that lead to a significant influence of the last term of (1), our procedure was amended to include additional statistical methods. Specifically:

– to reveal changes in the flow tendencies, we used integrated difference curves;

– systematic changes in hydrological time series were estimated using linear and quadratic trend analyses;.

– to test our hypotheses about differences in statistical parameters, Student and Fisher criteria were used.

After all hypotheses about influence on the runoff of warming climate were tested, the impact of large-scale land use was assessed.

The analysis of hydrographs in West Dvina River Basin provided estimates of the time series homogeneity and revealed the rivers where anthropogenic influence were substantial and are visually appreciable (e.g., due to the change of the basin area, redistribution of the runoff, etc.). Thereafter, statistical analyses provided estimates of the impact of hydraulic engineering, land use, and climatic warming. The analysis of the intra-seasonal changes in the West Dvina River runoff showed an increase in annual river runoff in the river basin during the 1981 - 2005 period compared to the 1960-1980 period by 23.6% (at the Polotsk hydrological station) to 27.2 % (at the Vitebsk hydrological station).

The minimal runoff increased in the summer-autumn on average by 23 % and in winter by 52%. We should repeat that the winter runoff increase can be associated with prolonged winter thaw periods in the last years and an intensive snowmelt that recharged subsurface water reservoirs. This development also caused a depletion of the water available for the maximal runoff in the spring high water season by approximately 11.5 %.

2. Changes of peak river runoff

The longest period of instrumental observations for peak runoff is available on the Neman River at station Grodno (since 1878). For other rivers the period of supervision is much shorter. Expansion of the hydrological network had begun in the 1920–1930's, and then continued, especially in the second half of the 20th century.

The greatest peak flows on the Neman River were reported in 1885, 1903, 1920–1930, 1950, 1962 and 1985. The rivers in the Bug River Basin have a shorter period of river gauge observations. Therefore, we can report here only peak flow during the last 50 years. In this period, the greatest peak flows were reported in the second half of 1970's years (1974, 1975, 1979 and 1980).

Thus, on the rivers of the Neman River and the Bug River Basins (within the Belarus territory), the greatest peak flows were reported during the 1970's of the century. Since the middle of 1980's, the size of the maximum peak flow in the rivers of these basins has significantly decreased.

To reveal the changes in maximum peak flow, quantitative estimates were made. To avoid errors related to recurrence and spatially inhomogeneous nature of formation of the peak flow, we assessed for all rivers the same period (1966 – 2005). This period was divided into 2 intervals: 1966–1985 and 1986–2005. For each of the 20-year-long periods, we defined average values of the maximum peak runoff. If the observation period at a particular river was less than 15 years at least in one of these intervals, the river was not included in our assessment. This procedure left us with 25 runoff time series for which we estimated the change in the maximum peak flow. The estimates are presented in the form of factors of the runoff:

$$k_i = (Q_{av2} - Q_{av1})/Q_0, \qquad (2)$$

where Q_{av1} and Q_{av2} are the mean values of the maximum peak flow during 1966–1985 and 1986–2005 respectively and Q_0 is an average value of the maximum peak runoff for the entire 1966–2005 period. Factors k_i were mapped using the coordinates of the river basin centers (Figure 1). This figure shows a spatial structure of change of maximum peak flow at the rivers in the Neman River and the Bug River Basins in the 1986–2005 period compared to the 1966–1985 period. Positive factors (that are absent in this figure) would indicate an increase in the mean sizes of the maximum peak runoff during the last 20 years, while the negative k_i -values show its reduction.

Figure 1 shows a significant reduction of maximum peak runoff in 1986–2005 in comparison with the 1966–1985 period over the rivers of the western part of Belarus. The values of changes vary. The largest reduction of the maximum peak runoff is reported for the Bug River Basin where the decreases average 60–70 % or more. A smaller peak flow reduction is found at the rivers of the Neman River Basin (30–40 %).

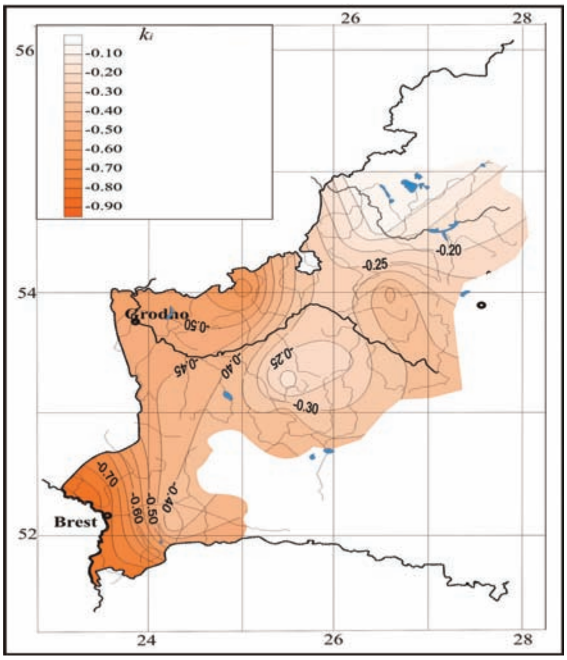

Figure 1. The spatial structure of change of the maximum peak runoff during 1986–2005 as compared to the previous 20 years.

The average long-term value of the maximum peak flow over the entire Belorussian territory is equal to 30–35 *l/(s·km²)*. The size of the maximum peak runoff in the Neman River Basin is equal to 25–30 l/(s·km^2), and its smallest changes were documented at the left-bank tributaries. The average long-term values of the maximum peak flow in the Bug River Basin are close to country averages [25–35 l/(s·km^2)].

3. Conclusion

Analyses of the river gauge data during the period of instrumental observations, revealed different runoff changes across the Republic of Belarus as well as within different hydrological seasons. The latest changes in the Belarusian rivers' runoff to the Baltic Sea show a decrease in the peak of spring high water, an increase of minimum summer-autumn and winter water discharges, and also some increase in the autumn and winter mean flow. There was a large change in the maximum peak runoff at the rivers of the western part of Belarus during the last decades of the 20th century. The causes of changes have mostly a climatic origin but in some watersheds the role of regional human impact was found to be also quite considerable.

References

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