Changes in the annual and intra-annual river runoff of the Votkinsk reservoir’s catchment

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Abstract. The assessment of the long-term variability of the rivers water content in the catchment area of the Votkinsk Reservoir for gauge stations (g/s) with the longest observation series (1939–2018) has been carried out. During the period under review, almost all g/s showed the presence of a statistically significant positive linear trend. The difference-integral curves revealed a violation of the stationarity of long-term observation series, and an analysis of the intra-annual distribution of monthly and seasonal runoff in% of the annual for two periods was carried out: 1956–1976 and 1977–2018. For the period 1977–2018 a decrease in the share of spring runoff (by an average of 7%), as well as an increase in the share of summer-autumn runoff and winter runoff by 18.4 and 24%, respectively, were found for almost all rivers in the study area.

1. Introduction
Long-term variability of the annual and seasonal river runoff is determined by the influence of runoff-forming factors, mainly by the climate, which determines the type of river water regime and the features of runoff distribution within the year [1].

The factors that determine the variability of the water balance and the river’s regime are related to human economic activity [2], and are of great interest in the study of the hydrological consequences of climate changes, planning of water supply to the population and production, justification of major water management measures, hydrotechnical and water management construction [3].

Fu Q, Feng S obtained the dependence of the increase in air humidity and, as a result, precipitation, on the increase in air temperature. In some regions of the world, both an increase and a decrease in precipitation can be observed. It depends on changes in atmospheric circulation. On average for the Globe, with an increase in global air temperature by 1°C, precipitation increases by 1.7% [4].

Since the beginning of the XX century, there has been an increase in the global surface air temperature, while the rate of warming is heterogeneous [5]. There were identified three periods: the warming of 1910-1945, the relative constancy of 1946-1975, and the most intense warming after 1976.

Numerous studies of climate change confirm their significant impact on the river runoff [1; 6–8]. Positive trends in average annual water discharge are determined by the observed trends in climatic characteristics changes. For the European part of Russia, there are two periods: until 1977, when there was no directional change in water content, and since 1978, with a significant change in the rivers water content [7; 8]. In addition, the mid-1970s were repeatedly considered as the years of the "climate shift" [9-11].
The features of the changes of the annual and seasonal river runoff which have been occurred in the Votkinsk Reservoir’s catchment were considered. For the study area, the boundaries of the seasons are set in [12]: spring IV-VI, summer-autumn VII-X, winter XI-III.

The catchment area (184240 km²) is located in the North-East of the European part of Russia and covers the basin of Upper and Middle Kama. The right-Bank part of the catchment is on the Russian plain (70%), the left-Bank – in the foothills and on the Western slope of the Urals (30% of the total area). The extent from North to South is 640 km (61°57’N– 56°05’N) and from West to East about 530 km (51°35’E – 60°27’E) [1].

The territory is characterized by pronounced latitudinal zonation in climate change on the plane and altitudinal zonality in Urals [13]. The territory is composed mainly of sedimentary rocks, with the presence of igneous rocks in the Eastern part of the catchment. The largest area is occupied by Paleozoic rocks, especially the Permian system [13-14]. The podzolic soils (about 78% of the catchment) are dominated, and the mechanical composition is divided into heavy (clay, loamy) and light (sandy) [15]. Forest (dark coniferous, small-leaved and broad-leaved), which occupy about 85% of the catchment, is the main type of vegetation [16].

The hydrological regime of the rivers in the Votkinsk Reservoir’s catchment area belong to the Eastern European type with a pronounced spring flood, rain floods in the summer-autumn period and winter low water. The predominant river's feed is snow melt water [17].

2. Materials and methods

To select the initial data, the average annual and average monthly water flow rates for 185 g/s on the rivers in the Votkinsk Reservoir’s catchment area for the entire observation period were analysed. It should be noted that the hydrological series of observations on rivers have different durations and mismatch of their beginnings. The analysis of these data showed that on 86 g/s observations were conducted only for 1-5 years, on the remaining 99 – for more than 5 years. Of these, on the 67 g/s there are more than 20 years of observations and on the 27 g/s – more than 40 years.

To estimate the long-term changes in annual and seasonal runoff, the series with the longest duration of observations, mostly without omissions, are of particular interest. These include the following seven g/s with a duration of observations from 71 to 90 years: Kama-Gainy (1931-2018), Vishera-Ryabinino (1930-2018), Kolva-Petretsovo (1934-2018), Inva-Kudymkar (1936-2018), Usva-Usva (1932-2018), Sylva-Podkamennoe (1936-2018), Chusovaya-Kyn (1939-2018). Restoring individual passes the average annual water discharge (1-5 years) for the g/s: Kama-Gainy, Vishera-Ryabinino, Kolva-Petretsovo and Chusovaya-Kin conducted by rivers-analogs in accordance with SP 33-101-2003 [18].

To determine intra-row changes in the annual and seasonal runoff data processing analysis were performed using correlation, regression analysis and difference-integral curves methods. The assessment of changes in seasonal runoff for the observation period (1956–2018) on the rivers in the Votkinsk Reservoir’s catchment area was performed for 27 active g/s.

3. Results

The presence of a statistically significant positive linear trend (figure 1) is typical for six g/s: Kama-Gainy, Vishera-Ryabinino, Kolva-Petretsovo, Inva-Kudymkar, Usva-Usva, and Sylva-Podkamennoe. The highest increase in the average annual runoff over the entire observation period is typical for the g/s Vishera-Ryabinino, the lowest for the Inva-Kudymkar. For the g/s Chusovaya-Kyn the presence of a significant trend in the average annual runoff was not noted (figure 1).

The long-term variability of the water content of the rivers, using the difference-integral curves of the average annual runoff for the observation period (1939-2018) are studied (figure 2). It should be noted that the g/s Chusovaya-Kyn and Sylva-Podkamennoe are characterized by a shorter duration of long-term cycles – 58 years, while for the other g/s this value is at least 66 years. On average for all g/s the change of the low-water phase to the high-water phase occurs in 1977.
Climate change, as one of the main runoff-forming factors, is characterized not only by changes in long-term characteristics, but also by intra-annual runoff redistribution between seasons. After identifying the stationarity violation in the long-term cycle of the observation series, the monthly and
seasonal runoff as a percentage of the annual runoff was estimated for two periods: 1956–1976 and 1977–2018. It makes possible to identify the runoff redistribution between seasons and determine the season with the greatest runoff increase, which determines the overall positive trend of annual runoff.

| River-g/s            | Seasonal runoff distribution for periods | Difference between periods, % |
|----------------------|----------------------------------------|------------------------------|
|                      | 1956-1976   | 1977-2018   |                             |
| Kama-Gayny           | 0.62 (VII-X) | 0.61 (VII-X) | -0.01 |
| Kama-Bondyug         | 0.64 (VII-X) | 0.62 (VII-X) | -0.02 |
| Kosa-Kosa            | 0.70 (VII-X) | 0.66 (VII-X) | -0.04 |
| Lolog-Sergeyevskiy   | 0.68 (VII-X) | 0.67 (VII-X) | -0.01 |
| Vishera-Ryabinino    | 0.57 (VII-X) | 0.58 (VII-X) | -0.01 |
| Yazva-NizhnyayaYazva | 0.61 (VII-X) | 0.62 (VII-X) | -0.01 |
| Kolva-Petretsovo     | 0.61 (VII-X) | 0.62 (VII-X) | -0.01 |
| Yayva-Baza           | 0.54 (VII-X) | 0.53 (VII-X) | -0.01 |
| Yayva-UstIgum        | 0.62 (VII-X) | 0.62 (VII-X) | -0.01 |
| Inva-Kadykmak        | 0.73 (VII-X) | 0.65 (VII-X) | -0.08 |
| Inva-Shudka          | 0.74 (VII-X) | 0.63 (VII-X) | -0.11 |
| Kuva-Kuva            | 0.76 (VII-X) | 0.71 (VII-X) | -0.05 |
| Velva-Oshib          | 0.76 (VII-X) | 0.69 (VII-X) | -0.07 |
| Kosva-Ostanino       | 0.56 (VII-X) | 0.56 (VII-X) | -0.00 |
| Obva-Karagay         | 0.74 (VII-X) | 0.63 (VII-X) | -0.11 |
| Chusovaya-Staroutkink| 0.68 (VII-X) | 0.57 (VII-X) | -0.11 |
| Chusovaya-Kyn        | 0.63 (VII-X) | 0.61 (VII-X) | -0.02 |
| Chusovaya-Lyaminino  | 0.68 (VII-X) | 0.63 (VII-X) | -0.05 |
| Serebryanaya-Serebryanka| 0.65 (VII-X) | 0.60 (VII-X) | -0.05 |
| Usva-Usva            | 0.66 (VII-X) | 0.62 (VII-X) | -0.04 |
| Sylva-Shamary        | 0.71 (VII-X) | 0.64 (VII-X) | -0.07 |
| Sylva-Podkamennoye  | 0.60 (VII-X) | 0.55 (VII-X) | -0.05 |
| Vogulka-Shamary      | 0.70 (VII-X) | 0.65 (VII-X) | -0.05 |
| Gayva-Plotinka       | 0.67 (VII-X) | 0.57 (VII-X) | -0.10 |
| Mulyanka-Subbotino   | 0.65 (VII-X) | 0.55 (VII-X) | -0.10 |
| Ocher-Kazymovo       | 0.54 (VII-X) | 0.46 (VII-X) | -0.08 |
| Tulva-Barda          | 0.62 (VII-X) | 0.59 (VII-X) | -0.03 |

In general, on the rivers in the Votkinsk Reservoir’s catchment area the entire period of observations (1956–2018) are characterized by the following distribution of annual runoff shares by seasons: spring (IV-VI) – 0.63 summer-autumn (VII-X) – 0.23, winter (XI-III) – 0.14. For small and medium rivers in the central and lowland parts of the catchment area (Kosa, Lolog, Inva, Kuva, Velva, Obva), a large share of the spring season (on average0.70 or more) is determined, summer-autumn – 0.19, winter (XI-III) –0.11. For mountain rivers the share of spring runoff is 0.62, summer-autumn – 0.25, winter –0.13. While comparing the intra-annual runoff for two periods: 1956-1976 and 1977-2018, the following distribution of the annual runoff shares by season was revealed. For the period 1956-1976: spring (IV-VI) – 0.65, summer-autumn (VII-X) – 0.22, winter (XI-III) – 0.13. For the period 1977-2018: spring (IV-VI) – 0.61, summer-autumn (VII-X) – 0.24, winter (XI-III) – 0.15.

A comparison two periods revealed a decrease in the share of spring runoff for most g/s on average 7.0%, except Vishera, Kolva and Yazva rivers, where the share of spring runoff increased on average 1.4% (table 1). The summer-autumn runoff decreases in its share from -1.7% to -6.8% for rivers: Kama, Vishera, Kolva, Yayva and Kosva were revealed. At the other g/s there is an increase in the
share of summer-autumn runoff on average 18.4%. The entire study area is characterized by an increase in winter runoff on average 24%. The highest value was on the Inva River – 59.2%, and on Obva, Gaiva, Mulyanka and Ocher rivers it was 45.4%. It is due that during the period 1977-2018, an increase the average air temperature in winter season was noted [6], which contributed the thaws formation, snow melting and an increase in surface runoff.

4. Conclusion
Based on the analysis of annual and seasonal runoff for seven g/s with the longest data observations (more than 70 years), significant positive linear trends of average annual runoff were identified for six of them, except g/s Chusovaya-Kyn.

The considerable length of the data observations allowed us to identify long-term cycles and water content phases for g/s located in different parts of the Votkinsk Reservoir’s catchment area. The change of the low-water phase to the high-water phase for these g/s occurs on average in 1977. Almost all rivers in the study area showed a decrease in the share of spring runoff and a significant increase in the share of winter runoff for the period 1977-2018.

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