Main regularities of changes in the river Ural run-off in relation to the influence of natural and anthropogenic factors (on the example of the upstream flow)

A Gareev \(^1\) ORCID 0000-0002-5517-7909, V Baryshev \(^{1,2}\) ORCID 0000-0002-3756-1683, M Gainanshin \(^3\) ORCID 0000-0002-9619-449X

\(^1\)Department of Geosciences, Bashkir State University, Ufa, Russia
\(^2\)Federal State Budgetary Institution Bashkir UGMS, Ufa, Russia
\(^3\)Faculty of General Sciences, Ufa State Aviation Technical University, Ufa, Russia

E-mail: mansur5701@mail.ru

Abstract. The article provides research findings on the spatial-temporal variability of water resources in the river Ural basin within the boundaries of the Republic of Bashkortostan. The multiannual characteristics of changes in the river runoff are reflected with the identifying of low-flow and high-flow phases. It is established that the decreasing river runoff observed during the recent years is accounted for by the cyclical fluctuations in hydrometeorological conditions of the river basins coupled with the consequences of climate changes. The main trends in the changes of the annual, maximum and minimum runoff in relation to the impact of natural and anthropogenic factors are identified.

1. Introduction
River runoff in the basin of the river Ural is marked by considerable spatial and temporal variability. Among the factors predetermining the given regular pattern we can mention the Ural Mountains due to their playing a barrier role in the movement of the western moisture-laden air masses as well as a fairly clear-cut manifestation of the conditions of zonal variability of natural factors. The corresponding local runoff values are shaped by the limited amount of atmospheric precipitation, the annual average being 350 to 400 mm in the north and up to 200 mm and lower in Kazakhstan, as well as by the high evaporation rates from the surface of river catchments.

Consequently, while in the forest-steppe zone pertaining to the eastern slopes of the Southern Urals the runoff of small rivers is to be observed throughout the year, a surge in its values is traced in the within-year variation of the river runoff when moving southward along the steppe zone. Under these circumstances many small rivers tend to dry up in summer and to freeze in winter. The drainage network density is sharply decreasing, the same is observed in the characteristics of water resources used for satisfying various needs in the sectors of economy as well as for utility purposes and drinking water supply. The annual runoff values are also moulded by the factors governed by the regional peculiarities of the global climate change manifestations. This results in an impact on the conditions of formation and variability of hydrological and ecological characteristics of watercourses of various orders. Special attention should be paid to the fact that over the past decades a rather sharp decrease in river runoff has been observed, which manifests itself in the emergence of problems in meeting the needs of water use both in the regions of the Russian Federation and Kazakhstan [1, 2].
2. Methodology

Given the great economic and ecological significance of water resources distribution in the long-term view, special attention should be paid to analyzing multiannual cyclical and interdecadal fluctuations of annual, minimum summer-autumn and winter runoff values, as well as to identifying trends in their variability in the long-term view in relation to the influence of natural and anthropogenic factors.

The article features a long-term analysis of runoff changes of small and medium rivers with their basins located within the upper reaches of the river. This is due to the fact that the river Ural and its tributaries account here for a significant part of the river runoff of the whole basin, which in turn affects both the hydrological-ecological and water-resource indicators of the river in the middle and lower reaches. The rivers basins for which long-term surveillance data can be found have been analyzed: the river Mindyak (the village Novobayramgulovo), the river Maly Kizil (the village Murakaev), the river Bolshoy Kizil (the village Burangulovo), the river Tanalyk (the village Samarskoe), the river Sakmara (the village Akyulovo), the river Zilair (the village Zilair), the river Bolshoy Ik (the village Mrakovo). Their basins are confined to the eastern slopes of the Southern Urals, as well as to the Zilair plateau which have undergone human economic activity of various degrees.

It should be noted that the existing regular patterns in the river runoff variability are identified on the basis of analyzing the difference integral curves clearly reflecting the patterns of interdecadal river runoff fluctuations. The advantage of this method lies in the fact the extrapolation of trends makes it possible to conduct an approximate predictive assessment of changes in river runoff for the future, observing the established regularities of changes in the identified trends.

As can be seen from figure 1, given the fairly synchronous fluctuations in the variability in the yearly average values of river runoff for the river basins, low-flow and high-flow phases can be distinguished. E. g., during the period from 1964-1965 to 1982-1984 a low-flow phase was observed, which was succeeded by a high-flow phase lasting until 2001-2003. The latter was subsequently replaced by a low-flow-water phase, which testifies to the currently observed substantial decline of river runoff due to the influence of natural factors. It should be emphasized that the low-flow phase, the onset of which dates back to 2002-2008, could proceed in the short term, for at least 10-15 years. Hence, under such conditions a further decrease in river runoff will be traced, resulting especially in the minimum water discharge, which may lead to a subsequent decline of water management and aggravation of the water-ecological situation in the river basin as a whole.

![Figure 1. Difference integral curves of yearly average water discharges of the studied rivers for 1961-2015.](image-url)
As it is known, within the framework of finding solutions to specific water management issues, it is necessary to take into account both trends and absolute indicators of variability in the maximum, as well as the minimum summer-autumn and winter runoff. In view of the above-mentioned, we have provided an analysis of the combined graphs reflecting the variability of the yearly average and the maximum water discharge in terms of the analyzed (boundary) river stations. The trends of changes in river runoff along the river Tanalyk – the village Samarskoe (figure 2) are provided as an example. From the figure it can be concluded that both the yearly average water discharge values and the maximum water discharge values of spring floods in the long-term view display cyclical fluctuations under the conditions of a clear-cut synchrony observed since 1977.

![Figure 2. Graphs of the five-year moving averages of the maximum and yearly average water discharges for the stream gauge riv. Tanalyk – vil. Samarskoe.](image)

### 3. Results and Discussion

It should be noted that due to the sharp aridity of the territory within the Trans-Ural peneplain coupled with the need for obtaining stable and high yields of agricultural crops, a multitude of water reservoirs were built on many small and medium-sized rivers during the times of the former USSR. At that period, water management systems were effectively operating; water was obtained for irrigating agricultural lands by redistributing river flow in multiannual and intra-annual timeframes.

Many irrigation systems were actually destroyed after the collapse of the USSR, while the existing reservoirs belong to the property managed by various government agencies. Thus, at present they are largely inoperative, since water intake for irrigating agricultural fields is not exercised at most waterworks facilities. Given the above-mentioned, we have analyzed the peculiarities of the impact posed by artificial regulation towards the characteristics of the annual, maximum and minimum river runoff. Basins of small and medium rivers characterized by the highest indicators of artificial regulation of river runoff were selected as the analyzed ones: riv. Maly Kizil – vil. Murakaev, riv. Bolshoy Kizil – vil. Burangulovo, riv. Mindyak – vil. Novo-Bayramgulovo, riv. Karagayly – vil. Staro-Sibaev, riv. Tanalyk – vil. Samarskoe.
To assess the values of absolute and relative changes in river runoff, in relation to the effect of artificial regulation, the method of running (integral) sums was selected as the main method, which, in contrast to the methods of statistical analysis applying the Fisher’s F-test, the Student’s T-test, the Wilcoxon signed-rank test etc., features a number of advantages. This is observed primarily in a clear-cut reflection of the occurring changes and in the possibility of determining the absolute and relative values of changes in river runoff in relation to the influence of the factors taken into account.

The established regular patterns can be shown in a fairly full-scale on the example of the river Tanalyk (the village Samarskoe). Thus, based on the analysis of the graphs reflecting the variations in the average annual and maximum water discharge, it can be concluded that they are not subject to significant deviations from the trends in the long-term view (figure 3). This characterizes the fact that the artificial regulation of river runoff by means of reservoirs does not lead to a decrease in either the annual or the maximum runoff, which is largely due to the low values of the total river runoff regulation (reservoir capacity) in comparison to the values of the yearly average and maximum water discharges.

![Figure 3. Running sums of the yearly average and maximum water discharges on the stream gauge riv. Tanalyk – vil. Samarskoe.](image)

In contrast to the yearly average and maximum characteristics of river runoff, a significant deviation was identified in summer-autumn and winter minimum water discharge values. This deviation is especially vivid in the example shown in figure 4 leaving no doubt as to the an increase in the minimum summer-autumn and winter water discharge values subject to the artificial regulation of river runoff. Thus, with respect to the analyzed river Tanalyk (the village Samarskoye), an increase in the minimum water discharge has been observed since 1987, which is associated with waterworks facilities being brought into service. On the whole, it should be emphasized that the indicators of increasing minimum water discharges of small and medium rivers within the study area, depending on the coefficient of artificial regulation of river runoff, reach significant values.
Figure 4. Running sums of the minimum water discharges for the winter and summer-autumn low-water periods on the river Tanalyk – the village Samarskoe.

According to the data shown in table 1, the relative increases in the minimum 30-day summer runoff values for observation points of numerous rivers amount to 29-32 per cent and higher. On the river Karagayly (the village Staro-Sibaev) the average 23% increase in the minimum runoff is associated with the discharge of mine waters [3, 4].

Proceeding from the above-mentioned, it should be emphasized that there is no denying the fact that the corresponding increase in the minimum water discharges of small and medium rivers in the summer and winter periods under the conditions of their regulation by means of impoundments and reservoirs is a positive factor from both the economic and environmental points of view.

Table 1. Variations in the minimum 30-day summer-autumn water discharge of various rivers under the conditions of artificial runoff regulation by means of reservoirs.

| River-station          | Catchment area F, km² | Mean-square error | Relative runoff variation, E_y, % | Absolute runoff increase, m³/s | Remark                     |
|------------------------|-----------------------|-------------------|----------------------------------|-------------------------------|----------------------------|
| riv. Maly Kizil – vil. Murakaev | 503                   | 10                | 29                               | 0.41                          | Row uniformity is broken   |
| riv. Bolshoy Kizil – vil. Burangulovo | 212                   | 10                | 29                               | 0.19                          | Row uniformity is broken   |
| riv. Mindyak – vil. Novo-Bayramgulovo | 785                   | 12                | 32                               | 0.66                          | Row uniformity is broken   |
| riv. Karagayly – vil. Staro-Sibaev | 54.4                  | 13                | 23                               | 0.05                          | Row uniformity is broken   |

On the whole, analysis of quantitative and morphometric characteristics of impoundments and reservoirs in the basin of the river Ural points out that they are mostly confined to areas characterized by plain land and aridity. This is a distinctive feature of the current water management conditions,
reflecting the intake and use of water from water sources without incurring unnecessary costs. However, the given approach to water management results in the emergence of a controversial situation associated with the occurrence of water shortages in low-water years, taking into consideration the spatial differentiation of water usage in terms of the subjects the Russian Federation, as well as the economic interests of Russia and Kazakhstan.

Taking into account the aforementioned, the article seeks to analyze peculiarities in the location of artificial water bodies in the basin of the river Ural and their influence on the characteristics of river runoff within the borders of the Russian Federation: in the Republic of Bashkortostan, the Chelyabinsk and Orenburg regions. Thus, the territory of the Republic of Bashkortostan comprises about 30 small and medium water bodies, their total surface area being 43.9 km². In Chelyabinsk Oblast, including the areas of the Verkhneuralsk and Magnitogorsk reservoirs, the total area of water bodies amounts to more than 107.0 km². In Orenburg Oblast the total area of the Irikinsky and Kumaksy reservoirs and water bodies of a smaller order exceeds 272.7 km². Thus, the total area of artificial reservoirs in the basin of the river Ural within the Russian borders amounts to 423.7 km². In relative terms (%) and in respect to Russia’s subjects mentioned above, the values amount to 10.4%, 25.2%, 64.4% respectively. This indicates that the greatest value of the total area of reservoirs and impoundments is confined to the territory of the Orenburg region (64.4%), while on the territory of the Republic of Bashkortostan it reaches only 10.4%.

While making hydroeconomic calculations, the most indicative data was found in the values of irretrievable losses leading to a decrease in river runoff and, consequently, to the occurrence of shortages and the aggravation of water management problems. Taking into account the aforementioned, we calculated the values of water loss caused by evaporation from the water surface of artificial reservoirs. The results are to be found in table 2.

According to the data supplied in table 2, the overall additional losses resulting from evaporation from the surface of reservoirs and impoundments in the basin of the river Ural within the Russian Federation as a whole amount to 97.5 million m³, of which in relative terms the Republic of Bashkortostan accounts for 8.1%, Chelyabinsk Oblast is responsible for 21.9%, while the Orenburg region accounts for 70.0%. The given figures reflect, on the whole, the groundless character of assumptions on the retention of river runoff within the Republic of Bashkortostan. The occurring changes covering the shallowing rivers, the emergence of unfavorable water management and hydrological-ecological conditions in the basin of the river Ural are largely the implications of the ongoing low-water phase. At the same time, we shouldn’t disregard the increasing aridity of the climate, which leads to increasing amounts of additional water losses from evaporation from the surface of artificial water bodies. Meanwhile, a pronounced growth of the minimum water discharge (see figure 4), associated with to the artificial regulation of river runoff, is undoubtedly an important factor preventing the occurrence of extremely unfavorable water management and hydrological-ecological conditions.

Table 2. Additional river runoff losses resulting from evaporation from the surface of reservoirs and impoundments in the basin of the river Ural, in respect to Russia’s subjects.

| №  | Subjects of the Russian Federation within the basin of the river Ural | Total surface area, km²/% | Evaporation losses, mm | 10⁶ m³/% |
|----|---------------------------------------------------------------------|---------------------------|------------------------|----------|
| 1  | the Republic of Bashkortostan                                       | 43.9/10.4                 | 180.0                  | 7.9/8.1  |
| 2  | Chelyabinsk Oblast                                                  | 107.1/25.2                | 200.0                  | 21.4/21.9|
| 3  | Orenburg Oblast                                                     | 272.7/64.4                | 250.0                  | 68.2/70.0|
|    | **Grand total**                                                     | **423.7/100**             | **97.5/100**           |          |

In respect to the analysis of peculiarities in the formation of hydrological, ecological and economic consequences arising from the artificial regulation of river runoff and the occurrence of water
shortages in low-water and extremely dry years, the following provisions should be emphasized (table 3).

**Table 3.** Some hydrological and ecological issues of water bodies of the river Ural.

| №  | Unfavorable hydrological and ecological processes | Causes                                                                 |
|----|--------------------------------------------------|------------------------------------------------------------------------|
| 1  | Lack of information on changes in the river runoff of small river basins | Lack of funding and data reporting                                      |
| 2  | Deterioration of hydrological and ecological characteristics of rivers of various categories under the conditions of artificial regulation | Lack of scientifically-substantiated provisions for executive and supervising authorities in terms of optimal water management activities based on ecological and economic criteria |
| 3  | A sharp deterioration in the conditions of migration of higher aquatic organisms | Absence of fish-breeding facilities at the venues                      |
| 4  | Intensive eutrophication of lakes, ponds and reservoirs | Lack of mechanisms for optimal environmental management in the basins |
| 5  | Lack of coordinated mechanisms for water management throughout the Ural River basin | Lack of a unified (optimal) basin mechanism for water management taking into account the requirements of the geosystems approach as well as the basin principle |

4. **Conclusion**

Having summarized and analyzed the research data comprising the calculations and assessments, the following should be emphasized.

1. The variability of yearly average, maximum and minimum water discharges of the analyzed rivers is characterized by cyclical long-term and interdecadal fluctuations. Originating in 2001-2007 and lasting up to the present day, a phase reflecting the declining characteristics of river runoff has been identified.

2. Artificial regulation of river runoff under the influence of the factor of global warming leads to the occurrence of significant water losses from evaporation from the surface of impoundments and reservoirs. However, the values reflecting the increase in the minimum water discharge herein by far exceed the values of water losses for additional evaporation. Beyond any doubt, this provides a positive impact in solving water management and water-ecological issues in the basin of the river Ural.

3. Water usage conditions in river basins of various categories tend to be constrained due to the lack of information on absolute and relative changes in runoff in the basins of small and medium rivers.

4. Artificial regulation of river runoff results in sharp deterioration in the condition of migration of anadromous and semi-anadromous (including valuable) fish species, which is of greatest significance in the Ural-Caspian basin.

5. Reservoirs and impoundments per se tend to create conditions contributing to their eutrophication and, consequently, leading to the formation of a number of unfavorable ecological and water management conditions.

The suggested provisions should receive practical manifestation in the justification of uniform and optimized water management mechanisms in the river basin. In that respect, the scale of reservoir construction should be standardized in arid areas, where they could be transformed into evaporation
basins in low-water and extremely dry years, contributing to the drying up of small rivers in accordance with the cascade regulation of river runoff with the anticipation of the corresponding unfavorable hydrological, ecological and economic consequences.

References
[1] Surface water resources of the USSR (Leningrad: Gidrometeoizdat) p 512
[2] Chibilev A A 2008 The river Ural basin: history, geography, ecology (Yekaterinburg: URO RAN) p 312
[3] Gareev A M, Galiullina Yu V and Baryshev V I 2020 Long-term dynamics of changes in the river runoff of the Southern Urals and the Cis-Urals (within the Republic of Bashkortostan) Bulletin of Academy of Sciences of the Republic of Bashkortostan 35(2) pp 35-43
[4] Shiklomanov I A 1979 Anthropogenic changes in the water content of rivers (Leningrad: Gidrometeoizdat) p 302