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The role of anthropogenic and climatic factors in the transformation of loads on water resources in the Volga river basin

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The role of anthropogenic and climatic factors in the transformation of loads on water resources in the Volga river basin

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Abstract. It is shown that over the past 30-40 years, the Volga River basin has experienced a significant increase in its minimum flow in the winter low flow period. Data on water intake from surface and underground sources for 1985-2017 is given for the main tributaries. It is revealed that climatic and anthropogenic factors cause an almost similar effect on the change in the water resource utilization coefficient.

1. Introduction

The Volga Basin is experiencing an acute problem of providing the population and economic facilities with adequate water quality and in the required mode. High indirect (areal) impact on water bodies is manifested in the form of anthropogenic loads on the catchment area associated with the settlement of the territory and the economic activities of its residents. Almost half of the gross regional product and industrial products of Russia as well as more than a third of agricultural products are produced here. In 2016, 60.8 million people lived in the basin (42% of the total population of the Russian Federation), of which 48.8 million lived in cities [1].

The load on the water resources of any region is characterized by the water resource utilization rate Q_{util} , equal to the percentage ratio of the total water consumption to that of the renewable water resources. State Hydrological Institute specialists posit that to assess the actual load on water resources, the minimum (for the observation period) average annual value of water resources for the three consecutive low-water years should be used. To analyze the state of water resources in any region, the following classification can be applied as per the Q_{util} or load on water resources [2].

1st category: $Q_{util} < 10\%$ – low load on water resources; usually, these regions do not experience any serious water supply problems (except for pollution problems).

2nd category: $Q_{util} = 10\text{--}20\%$ – moderate load on water resources. The water supply level becomes a factor limiting the development of the region.

3rd category: $Q_{util} = 20\text{--}40\%$ – high load on water resources. Supply and demand for water must be regulated for sustainable development.

4th category: $Q_{util} = 40\text{--}60\%$ – very high load on water resources. There is a serious water shortage and there is need to regulate and limit water consumption, attract additional water supply sources.

5th category: $Q_{util} > 60\%$ – critically high load. Lack of water resources is becoming a critical factor in the development of the economy and livelihoods.



RosNIIVH experts define the Qutil as the ratio of water intake for economic needs to the minimum water content of rivers in the limiting winter period [3].

The most important practical tasks of regulating the flow and water supply of the territory are connected with the calculations of the minimal flow parameters. Since the occurrence of a minimal water content limits water utilization, it is almost always regarded as an extreme event. The problems of water scarcity and quality are directly associated with minimal runoff.

2. Materials and methods

The study of modern changes in the minimum flow of the Volga river basin is based on a comprehensive statistical analysis of long-term series of observations of the minimum flow of rivers with a duration of observations of more than 50 years and a small number of gaps in the observations. For selected posts (table 1), data on average runoff for 30 days within low water periods for the winter period was analyzed. The value of the underground supply during the low-flow period, to which a certain amount of surface runoff is added, is of fundamental importance for the formation of a minimum 30-day flow [2].

Sufficiently reliable data on water consumption began to be published after 1980, with the introduction of the statistical report on Form No. 2-TP (Water Management). Data for the relatively small rivers is available for 1994-2016, while that for the Belaya and Vyatka rivers is for the period starting 1985. In addition to the intake of water from surface sources, we took into account damage to the river runoff due to water intake from underground sources. The river runoff damage coefficients were taken as per State Hydrological Institute data. They vary from 0.30 for the Vyatka River to 0.49 for the Belaya River.

Table 1. Change in the average multi-year minimum flow in fractions (K) and the increment of the minimum flow module Δq relative to the previous period (before 1978) in the Volga River basin.

No.	Post code	River	Point	Monitoring period	K	Δq , l s/km ²
1	75128	Mologa River	Ustyuzhna	1934-2009	1.64	0.95
2	75241	Kostroma River	Buy	1897-2016	1.41	0.46
3	75286	Unzha River	Manturovo	1950-2016	1.54	0.82
4	75311	Oka River	Belyov	1937-2016	1.83	1.30
5	75328	Oka River	Gorbatov	1936-2016	1.70	1.19
6	76180	Chusovaya River	Kyn Town	1953-2016	1.44	0.52
7	76190	Chusovaya River	Lyamino Town	1932-2016	1.28	0.40
8	76275	Belaya River	Arskiy Kamen'	1932-2016	1.27	0.19
9	76295	Belaya River	Birsk	1938-2016	1.88	1.59
10	76550	Vyatka River	Krasnoglinye	1942-2016	1.24	0.38
11	76553	Vyatka River	Usatievskaya (Nagorsk Village)	1938-2016	1.29	0.46
12	77250	Samara River	Elshanka	1934-2016	1.87	0.36

3. Results and discussion

It is obvious that in the Volga river basin, the last 30-40 years have been associated with an actual increase in the minimum flow in the winter [4, 5, 6, 7]. The main factor of such changes is considered

to be the increase in winter air temperature, which led to an increase in thaws and more intensive supply of groundwater in the winter lowland due to snowmelt [5, 8]. Climate warming causes a substantial increase of the river runoff during low-water periods on the European Russia leading to significant strengthening the natural regulation of flow, its scale being comparable with the effect of seasonal regulation reservoirs [5, 8]. In this work, the available minimum runoff series compared with the previous work [9] was supplemented with data for 2016 inclusive. Extension of the series has not revealed any new trends in changes in the minimum runoff in the basin, neither does it allow us to confidently assert that the minimum runoff is continuing to increase, or that its characteristics are returning to the values of the stationary period (up to 1978-1980).

For the 1994-2017 period, water intake from surface sources in the Mologa and Unzha river basins decreased by 5-7 times, in the Samara River basin by 9 times, and in the remaining basins by 1.5-2.5 times [2, 10,11, 12]. In the Mologa, Vyatka, and Samara river basins, the drop in water intake from underground sources was smaller than from surface sources. The cumulative damage to the river flow as a result of water intake from all sources has decreased in 23 years from 1.5 times in the Belaya and Chusovaya river basins to 6.5 times in the Samara River basin.

Before the 1990s crisis, the agro-industrial sector was developed in the Mologa, Unzha, Vyatka and especially Samara river basins. Here, the utilization of water for agricultural purposes (irrigation, agricultural water supply, pond fish farming) was comparable or higher than the volume of water consumption for other needs (figure 1). However, agriculture during the crisis years suffered the most damage, from which it has not yet recovered. Financial support of the industry has been greatly reduced. In most regions, 70-90% of the land designated for irrigation is not irrigated [13].

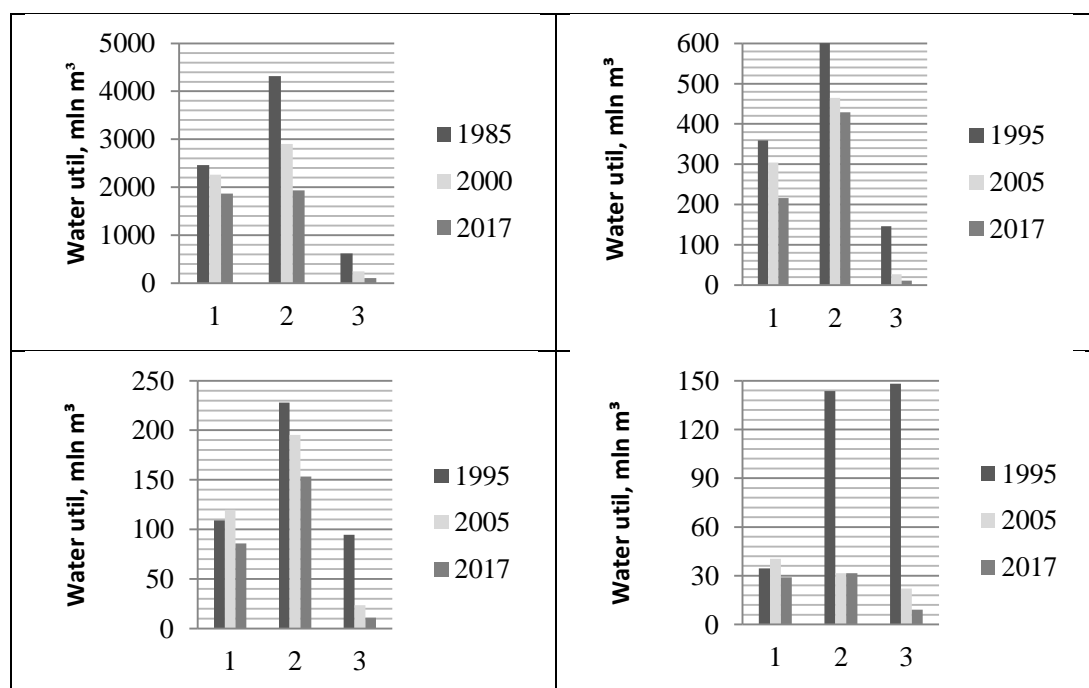


Figure 1. Dynamics of water utilization for economic needs (million m³) in the Oka (a), Belaya (b), Vyatka (c), Samara (d) river basins in the period 1995-2017.

Legend: 1 – drinking and household; 2 – production; 3 – agricultural

In this regard, as well as a sharp drop in the volume of livestock, the volume of water utilization for agricultural purposes in the Oka and Vyatka river basins for the period 1995-2017 decreased by 7-8 times, in the Kostroma and Belaya river basins by 13-16 times, in the Mologa and Samara basins by 18-20 times and in the Unzha river basin by more than 200 times.

Among the economic sectors of the Volga River basin is the most water-intensive – the production industry. In the 1990s, the volume of fresh water used for production purposes declined due to the general economic destabilization in the country, the decrease in the region's industrial output and the transition of many enterprises to part-time operations or their closure [14]. Industrial water consumption for the 22 years from the main rivers decreased by 1.5-3 times, from the Kostroma, Unzha and Samara river basins by 3.5-4.5 times, and from the Mologa river basin by 10 times.

The integral indicator of the population's water supply is the utilization of water for household needs. Its maximum value in the Volga basin was observed in the early 1990s. It steadily declined in the subsequent years. In most regions of the basin, due to the decrease in population, increase in water tariffs and more economical utilization of water in the housing stock, water consumption for household and drinking needs has declined by 20-40% over two decades, and in the Kostroma and Unzha river basins by 2-4 times.

For each represented river of the Volga Basin, for the corresponding periods, there were volumes of non-returnable water consumption, which allowed to calculate the values of the minimum restored flow for the winter low-water season of each year. The decrease in water intake against the background of the growth of the minimum runoff in the winter period led to a noticeable drop in the Qutil for the Belaya and Samara river basins (figure 2).

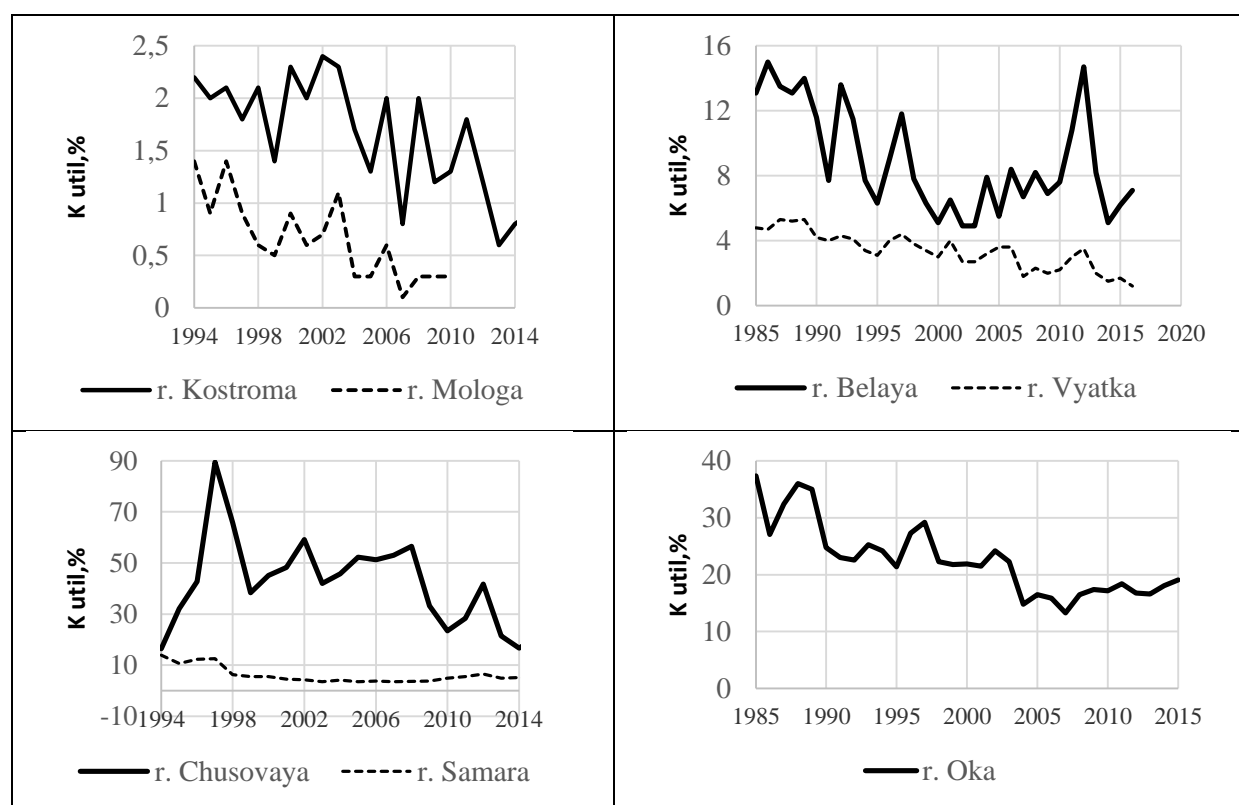


Figure 2. Dynamics of changes in the water resource utilization coefficient (%) on the rivers of the Volga Basin.

These rivers have moved from the category of rivers with a moderate load on water resources to the category of rivers with a low load. In the Mologa, Unzha and Vyatka river basins, the Qutil also decreased by approximately 2 times, but they remained in the category of rivers with a low load. In the Chusovaya river basin, after the reduction of the volume of water transfer to the Iset basin in 2009-2010, the Qutil dropped to 20-40%. The Qutil for the Oka river basin in the 1980s was at the 30-35%

level, but after 2004 did not exceed 20%. The Oka River has moved from the category of rivers with a high load on water resources to the category of rivers with a moderate load.

The dependences of the water resource utilization coefficient in the rivers of the Volga Basin (U) on the values of the 30-day minimum restored runoff during the winter period (X_1 – climatic factor) and damage to the surface runoff due to water intake from surface and underground sources (X_2 – anthropogenic factor) were analyzed and multiple regression equations were obtained. For example, the following regression equation was obtained for the Vyatka River

$$U = 2.94 - 0.00739X_1 + 0.2704 X_2 \quad R = 0.982 \pm 0.006$$

However, a direct comparison of the regression coefficients may give an incorrect idea of their effect on the change in the function, since the magnitude of the effect depends on the magnitude of the factor variation. Therefore, it is more reasonable to use standardized regression coefficients that show an increase in Q_{util} (in the form of the magnitude of the change in its standard deviation) when the magnitude of the factors changes by one standard deviation (table 2). The calculations results show that both factors have approximately the same effect on the change of Q_{util} on all Volga tributaries, except for the Samara River (table 2).

Table 2. Standardized regression coefficients.

<i>Rivers of the Volga Basin</i>	<i>Standardized regression coefficient</i>	
	<i>X_1 – Climatic factor</i>	<i>X_2 – Anthropogenic factor</i>
Mologa River	0.473	0.689
Kostroma River	0.687	0.644
Unzha River	0.232	0.452
Chusovaya River	0.509	0.801
Vyatka River	0.508	0.664
Belaya River	0.595	0.804
Samara River	0.334	1.111

4. Conclusion

The average long-term minimum flow in the winter grew 1.3-1.9 times for the last 30-40 years on tributaries of the r. Volga. Water withdrawal from surface sources as a result of a downturn in the economy decreased from 1.5 to 9 times during 1994–2017 in different parts of the basin, and the cumulative damage to river flow declined from 1.5 to 6.5 times. The simultaneous action of these factors has led to a marked reduction in the load on water resources. It has been revealed that the climatic and anthropogenic factors have approximately the same effect on reducing the utilization of water resources.

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