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# REDUCTION OF WATER RESOURCES IN THE REGION AS A CONSEQUENCE OF DEGRADATION OF GLACIERS OF THE NORTH CAUCASUS UNDER THE INFLUENCE OF CLIMATE CHANGE (TRANSLATION OF THE ORIGINAL PUBLICATION INTO ENGLISH)

Research article

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**Abstract**

Translation of the original publication *Ташилова А.А. УМЕНЬШЕНИЕ ВОДНЫХ РЕСУРСОВ РЕГИОНА КАК СЛЕДСТВИЕ ДЕГРАДАЦИИ ЛЕДНИКОВ СЕВЕРНОГО КАВКАЗА ПОД ВОЗДЕЙСТВИЕМ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ / Ташилова А.А., Кешева Л.А., Теунова Н.В. // Международный научно-исследовательский журнал. — № 1 (127). — DOI: 10.23670/IRJ.2023.127.70.*

The end of the 20th and the beginning of the 21st centuries are characterized by many large-scale natural changes, including in mountain cryosystems. The highland cryosystem responds to climate change and, above all, to the long-term increase in summer surface air temperature, which has increased by 0.5-0.7°C over the past 60 years in the Caucasus Mountains. This work shows that over the past 20 years, summer temperatures have been supplemented by an increase in winter and spring temperatures at a significant level, which, against the background of a slight decrease in the amount of all seasonal precipitation, leads to the melting of glaciers and a decrease in water balance reserves. According to the results of calculations, it was found that over the last ~20 years, which amounted to a third of the entire period from 1957 to 2020, the decrease in the water balance of the Bolshoi Azau glacier amounted to 260 million tons, which is more than half of the entire period – 476.25 million tons.

**Keywords:** water balance, climate change, glacier degradation, North Caucasus.

# УМЕНЬШЕНИЕ ВОДНЫХ РЕСУРСОВ РЕГИОНА КАК СЛЕДСТВИЕ ДЕГРАДАЦИИ ЛЕДНИКОВ СЕВЕРНОГО КАВКАЗА ПОД ВОЗДЕЙСТВИЕМ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ (ПЕРЕВОД ОРИГИНАЛЬНОЙ ПУБЛИКАЦИИ НА АНГЛИЙСКИЙ ЯЗЫК)

Научная статья

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**Аннотация**

Перевод оригинальной публикации *Ташилова А.А. УМЕНЬШЕНИЕ ВОДНЫХ РЕСУРСОВ РЕГИОНА КАК СЛЕДСТВИЕ ДЕГРАДАЦИИ ЛЕДНИКОВ СЕВЕРНОГО КАВКАЗА ПОД ВОЗДЕЙСТВИЕМ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ / Ташилова А.А., Кешева Л.А., Теунова Н.В. // Международный научно-исследовательский журнал. — № 1 (127). — DOI: 10.23670/IRJ.2023.127.70.*

Конец 20-го и начало 21вв. характеризуются многими крупномасштабными природными изменениями, в том числе в горных криосистемах. Криосистема высокогорья реагирует на изменение климата и прежде всего – на долговременный рост летней температуры приземного воздуха, которая увеличилась за последние 60 лет в горах Кавказа на 0,5-0,7°С. В данной работе показано, что за последние 20 лет к летним температурам добавился рост зимней и весенней температур на значимом уровне, что на фоне незначительного снижения количества всех сезонных осадков приводит к таянию ледников и уменьшению запасов водного баланса. По результатам расчетов получено, что за последние ~20 лет, составившие треть от всего периода с 1957 до 2020 гг., уменьшение баланса воды ледника Большой Азау составило 260 млн. тонн, что больше половины за весь период – 476,25 млн. тонн.

**Ключевые слова:** водный баланс, климатические изменения, деградация ледников, Северный Кавказ.

## Introduction

One of the most characteristic indicators of climate change is the melting of glaciers: since the beginning of the 20th century, more than 20% of European glaciers have disappeared over the past 30 years [1].

Understanding what is happening to glaciers is necessary in order to predict changes in the water balance of territories. This is especially true for regions where melting glaciers are a source of fresh water.

The IPCC report [2] notes that, with a high degree of confidence, local warming rates vary by season. For example, warming in the European Alps has been found to be greater in summer and spring [3], [4], as well as in the Caucasus [5], while in the Tibetan Plateau warming is greater in winter [6], [7].

In this regard, of particular interest is the study of modern changes in seasonal and regional climate and its impact on the processes occurring in the cryosphere, leading to the melting of glaciers in the high mountain regions of the Caucasus.

**Research methods and principles**

To determine the climatic characteristics (seasonal temperatures, precipitation) affecting the glaciers of the Baksan River basin (Bolshoi Azau, Irik, Shkhelda, etc.), series of observations at the Terskol weather station (2144 m) were used as the main source of information (archive of the Elbrus anti-avalanche team of the North Caucasian paramilitary service for active influence on hydrometeorological processes).

The assessment of the coefficients of linear trends of meteorological parameters was obtained by the least squares method and expressed in °C/10 years and in mm/month/10 years. The significance of the trend is determined by the value of the coefficient of determination *R2* (or the contribution of the trend to the explained variance *D* (%)) according to the Fisher criterion.

$$F=(R2 / (1 - R2))\cdot ((n - m - 1) / m),$$

where $n$ – the number of observations;

$m$ – number of parameters at factor $x$.

The tabular value of the Fisher criterion ($F$-test) determines its maximum value at which random factors influence. If the actual criterion is less than its tabular value $F_{fact.} < F_{tabl.}$, then the established behavior of the value and its change are not influenced by random factors. This value depends on the degree of freedom ($df = n-m-1$) and the selected significance level *Sig.* (0.05).

**Main results**

According to the Terskol weather station (Kabardino-Balkaria, 2144 m above sea level, a high-mountain region with a pronounced continental climate and vertical zonation), the average annual temperature for 1961-2021 was 2.64°C with a climatic norm of 2.54°C (average for 1961-1990). Unlike the winter, spring and autumn seasons, in the summer seasons 1961-2021 average temperatures in Terskol had a positive significant trend. The rate of increase in summer temperatures for the period 1961-2021 was 0.32°C/10 years (D=39%), increasing from 1976 to 0.43°C/10 years (D=44%, the maximum of all seasonal trends). It is noted in [5] that according to data from the Terskol weather station, from the mid-90s to the present, positive temperature anomalies predominate in the series of summer temperatures. If we consider the season of accumulation of ice masses (October-April), then against the background of a long-term slight increase in precipitation since 1961 (1.83 mm/year mm/month/10 years, D = 4.8%), since the beginning of the 2000s there has been a decrease in winter precipitation amounts, which continues into the present period.

In the period since 1976 there has been a statistically significant rate of increase in average annual temperature by b=0.2°C/10 years with a high contribution to the explained variance of D=17%. With the increase in the duration of the subperiods (1976-2013, 1976-2014,….., 1976-2021), the rate of increase in the annual temperature of the Terskol weather station increased, approaching statistically significant: in 1976-2013 by 0.06 °C/10 years (D=3%); in 1976-2014 by 0.11°C/10 years (D=4%);…; in 1976-2021 by 0.20°C/10 years (D=17%).

When highlighting the sub-period 2001-2021, characterized by increased melting of the Caucasus glaciers, from Figure 1 it can be noted that the rate of increase in annual temperature in Terskol increased to 0.70°C/10 years (D=32.9%, $F_{fact.}$=8 .97> $F_{theor.}$=4.67 for df =20, which defines the trend of average annual temperatures as statistically significant). There was also an increase in the increase in winter (0.16°C/year, D=25.1%) and spring (0.08°C/10 years, D=23.4%) temperatures to a statistically significant level. Summer temperatures continue to rise, but the trend is statistically insignificant (0.04°C/year, D=14.3%). Thus, over the past 20 years, in the winter, spring and summer seasons, there has been an increase in temperatures at a significant level of warming, comparable to other climatic zones.

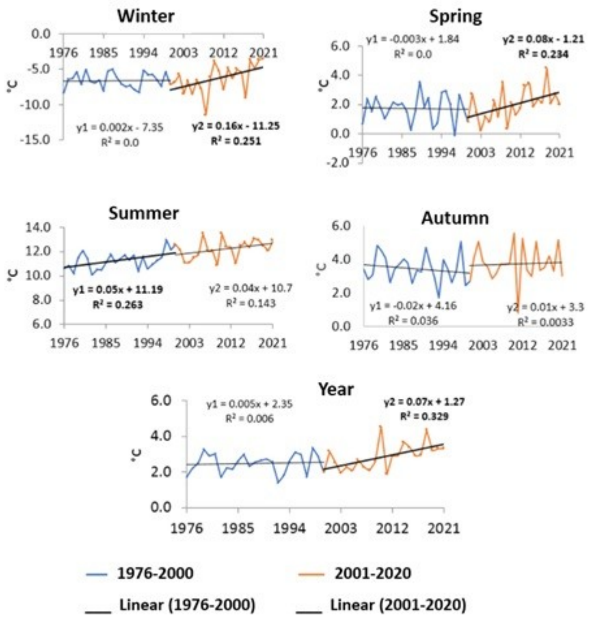


Figure 1 - Average temperature graphs (Terskol) with trends in sub-periods 1976-2000 (y1) and 2001-2021 (y2)
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*Note: significant trends at the 5% level are highlighted in bold*

The Terskol weather station is characterized by a fairly large amount of annual precipitation (970.7 mm). From 1961 to 2021 in Terskol, a statistically insignificant increase in the amount of annual precipitation b= 16.9 mm/month/10 years (D = 3.1%) remained in 1976-2021. The growth rate of annual precipitation decreased to b=16.5 mm/ month/10 years. Over the long observation period from 1961 to 2021, there were no trends in winter and summer precipitation amounts; spring and autumn precipitation amounts increased slightly.

From Table 1 it can be seen that in the period from 2001 to 2021 against the background of a significant increase in seasonal temperatures, changes in the amount of precipitation, both seasonal and annual, had negative trends, all trends were statistically insignificant (Table 1).

Table 1 - Parameters of changes in precipitation, Terskol
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| Seasons | Period 1976-2021 | | Sub-periods 1976-2000 | | Sub-periods 2001-2021 | |
|---|---|---|---|---|---|---|
| | *b*, mm/month/year* | *D**, %* | *b, mm/month/year* | *D, %* | *b, mm/month/year* | *D, %* |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Winter | -0.31 | 0.3 | 0.2 | 12.3 | -2.12 | 5.6 |
| Spring | 1.71 | 6.9 | -0.02 | 2.2 | -2.26 | 2.7 |
| Summer | -0.31 | 0.4 | -0.36 | 0.12 | -1.02 | 2.5 |
| Autumn | 0.27 | 1.7 | 1.85 | 2.1 | -2.74 | 4.0 |
| Annual | 1.64 | 1.6 | -0.22 | 0.0 | -6.2 | 4.6 |

*Note: * the negative trend is highlighted in gray;*

*** significant trend at the 5% level (Sig.<0.05) is highlighted in bold*

For the region under study, in the formation of water resources in the modern period, not only a long-term (60 years) significant increase in summer temperature plays a particularly important role, but also a significant increase in winter, spring, summer and annual temperatures over the past 20 years, occurring against the background of practically unchanged or insignificant a decrease in precipitation, which leads to intensive melting of glaciers that feed rivers.

To calculate changes in the water balance during the degradation of valley glaciers in the Central Caucasus, glaciers of the Baksan River basin were selected in order to assess the impact of mountain climate change according to data from the Terskol weather station, located in the Baksan Gorge. From data on the degradation of valley glaciers of the Greater Caucasus, given by Dokukin M.D. in [8], the values of the decrease in glacier areas (ΔS, km$^2$) were used to calculate the average, minimum and maximum values of changes in the water balance (tons of water) as a result of the loss of the ice shell of glaciers over the past ~60 years.

According to the recommendation of the authors [8], the calculations used the thickness of valley glaciers in the river basin. Baksan h=75 m. Then the decrease in the average volume of the Bolshoi Azau glacier was:

$\Delta V = \Delta S.h = 6.35\ km^2 \cdot 0.075\ km = 0.47625 \cdot 10^9\ m^3$

or taking into account the fact that 1 $m^3$ = 1 ton of water,

mass of water: m=476250000 tons.

Thus, over the past 60 years, as a result of the melting of the Great Azau glacier (Central Caucasus, Baksan River basin), the water balance has decreased by 476.25 million tons.

To compare the rate of melting, we present the results of calculations on changes in the water balance of the Bolshoy Azau and Terskol glaciers over the past 20 years (from 1997 to 2017), using data on changes in the volume of the ice shell ($\Delta V$, $km^3$) from the paper of Kutuzov S.S. [9].

Decrease in water balance as a result of the melting of the Greater Azau glacier from 1997 to 2017 the average amounted to 260 million tons, which is more than half the value of 476.25 million tons (decrease from 1957 to 2020).

For the remaining glaciers of the River Baksan basin, the decrease in their water balance as a result of melting from 1957 to 2020 is presented in Table 2. From Table 2 it can be seen that the second-largest reduction in the water balance for the period 1957-2020 occurred due to the melting of the Kayaartybashi glacier. The average value was 92.25 million tons, with a maximum decrease of 98.25 million tons and a minimum of 86.25 million tons. From 1957 to 2020 on the Chegetkarachiran glacier, the average decrease was 2.26 million tons of water (from a maximum of 2.40 million tons to a minimum of 2.10 million tons). Shhelda Glacier lost an average of 93 million tons of water reserves for the period from 1960 to 2020, and the Bolshoi Tyutyu glacier – 44.25 million tons (from 1962 to 2020).

Table 2 - Decrease in the water balance of glaciers as a result of melting

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| № | Name of glacier | Reduction of water reserves, million tons | | |
|---|---|---|---|---|
| | | average | maximum | minimum |
| 1 | 2 | 3 | 4 | 5 |
| 1957 - 2020 | | | | |
| 1 | Big Azau | **476.25** | 491.25 | 461.25 |
| 2 | Irik | 59.25 | 63.00 | 55.50 |
| 3 | Chegetkarachiran | 2.26 | 2.40 | 2.10 |
| 4 | Yusengi | 16.50 | 18.00 | 15.00 |
| 5 | Shhelda (from 1960 to 2020) | 93.00 | 96.00 | 90.00 |
| 6 | Bashkara | 27.75 | 29.25 | 26.25 |
| 7 | Yunomsu | 33.00 | 34.50 | 31.50 |
| 8 | Big Tyutyu (from 1962 to 2020) | 44.25 | 47.25 | 41.25 |
| 9 | Kayaartybashi | 92.25 | 98.25 | 86.25 |
| | Sum | **844.51** | **879.9** | **809.1** |
| 1997 - 2017 | | | | |
| 10 | Big Azau | **260** | 380 | 140 |
| 11 | Terskol | 80 | 130 | 30 |

Thus, over the last ~20 years, which amounted to the last third of the entire period from 1957 to 2020, the decrease in the water balance of the Great Azau glacier (260 million tons) amounted to more than half of the balance for the entire period (476.25 million tons). Probably, the same distribution of decrease in water balance due to glacier melting occurred for other glaciers.

**Discussion**

The problem with such intense glacier melting is its consequences. As glaciers shrink in response to a warming climate, water is released from long-term glacial reserves. At first, glacial runoff increases, but after a few years or decades there will be a tipping point, often called "peak water," after which glacial runoff, and therefore its contribution to downstream streamflow, will decrease.

Global modeling results show that peak water was reached before 2019 for 55-67% of glaciers in Central Europe and the Caucasus [10]. The Third Assessment Report on climate change and its consequences on the territory of the Russian Federation notes that taking into account the trends in changes in annual river flow in recent decades, there is a high probability of worsening the problem of water supply in a number of southern regions of the European territory of Russia, which is already low and could become catastrophic low [11].

**Conclusion**

Climate change and the resulting glacier degradation continue, and the pace of these processes is increasing. Since the beginning of the current century, in Terskol in the winter, spring and summer seasons there has been an increase in temperatures at a significant level of warming, comparable to other climatic zones. This seasonal increase in temperature has generated a statistically significant increase in the average annual temperature at the Terskol station in the last 20 years

(0.07°C/year, D=32.9%). Between 2001 and 2021 against the background of a significant increase in seasonal temperatures, the total precipitation, both seasonal and annual, had negative trends, all trends were statistically insignificant.

The prevailing thermal and precipitation regimes in recent decades have been the main component of many factors leading to a reduction in the area of glaciers and changes in the water balance.

In total, over the past 60 years, the glaciers of the river basin Baksan have lost 844.51 million tons of water, of which the Bolshoi Azau glacier accounted for 476.25 million tons of water. Over the past 20 years, Greater Azau has lost 260 million tons of water, which accounted for more than half of the losses in a third of the time of the entire studied period, which probably happened with all other glaciers of the Caucasus.

**Конфликт интересов**

Не указан.

**Conflict of Interest**

None declared.

## Список литературы / References

1. Glaciers // Grind. — URL: www.grid.unep.ch/glaciers (accessed 07.10.2022)
2. МГЭИК, 2019 г.: Резюме для политиков. В: Специальный отчет МГЭИК об океане и криосфере в условиях меняющегося климата / Под ред. Н.-О. Пёртнер, Д.С. Робертс, В. Массон-Дельмотт и др.
3. Auer I. HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region / I. Auer et al. // Int. J. Climatol. — 2007. — 27(1). — p.17-46. — DOI: 10.1002/joc.1377.
4. Ceppi P. Revisiting Swiss temperature trends 1959–2008 / P. Ceppi, S.C. Scherrer, A.M. Fischer et al. // Int. J. Climatol. — 2012. — 32(2). — p. 203–213. — DOI: 10.1002/joc.2260.
5. Tashilova A.A. Analysis of climate change in Terskol over the last 60 years / A.A. Tashilova // IOP Conf. Ser.: Earth Environ. Sci. — 840(2021). — p. 012038. — DOI: 10.1088/1755-1315/840/1/012038.
6. Liu X. Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings / X. Liu, Z. Cheng, L. Yan et al. // Glob. Planet. Change. — 2009. — 68(3). — p. 164–174. — DOI: 10.1016/j.gloplacha.2009.03.017.
7. Xu Y. Observed high-altitude warming and snow cover retreat over Tibet and the Himalayas enhanced by black carbon aerosols / Y. Xu, V. Ramanathan, W.M. Washington // Atmos. Chem. Phys. — 2016. — 16(3). — p. 1303–1315. — DOI: 10.5194/acp-16-1303-2016.
8. Беккиев М.Ю. Современная деградация долинных ледников Центрального Кавказа / М.Ю. Беккиев, М.Д. Докукин, Р.Х. Калов и др. // Фундаментальная и прикладная климатология. — 2021. — Т. 8. — 3. — с. 113-141. — DOI: 10.21513/2410-8758-2021-3-113-141
9. Kutuzov S. Volume Changes of Elbrus Glaciers From 1997 to 2017 / S. Kutuzov, I. Lavrentiev, A. Smirnov et al. // Front. Earth Sci. — 2019. — 7. — p. 153. — DOI: 10.3389/feart.2019.00153.
10. Huss M. A new model for global glacier change and sea-level rise / M. Huss, R. Hock // Front. Earth Sci. — 2015. — 3. — p. 54. — DOI: 10.3389/feart.2015.00054.
11. Третий оценочный доклад об изменениях климата и их последствиях на территории Российской Федерации. Общее резюме. — СПб.: Наукоемкие технологии, 2022. — 124 с.

## Список литературы на английском языке / References in English

1. Glaciers // Grind. — URL: www.grid.unep.ch/glaciers (accessed 07.10.2022)
2. IPCC 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate / H.-O. Pörtner, D.S. Roberts, W. Masson-Delmotte, P. Zay, M. Tignor, E. Polochanska, K. Mintenbeck, A. Alegria, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. M. Weier ( ed.)
3. Auer I. HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region / I. Auer et al. // Int. J. Climatol. — 2007. — 27(1). — p.17-46. — DOI: 10.1002/joc.1377.
4. Ceppi P. Revisiting Swiss temperature trends 1959–2008 / P. Ceppi, S.C. Scherrer, A.M. Fischer et al. // Int. J. Climatol. — 2012. — 32(2). — p. 203–213. — DOI: 10.1002/joc.2260.
5. Tashilova A.A. Analysis of climate change in Terskol over the last 60 years / A.A. Tashilova // IOP Conf. Ser.: Earth Environ. Sci. — 840(2021). — p. 012038. — DOI: 10.1088/1755-1315/840/1/012038.
6. Liu X. Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings / X. Liu, Z. Cheng, L. Yan et al. // Glob. Planet. Change. — 2009. — 68(3). — p. 164–174. — DOI: 10.1016/j.gloplacha.2009.03.017.
7. Xu Y. Observed high-altitude warming and snow cover retreat over Tibet and the Himalayas enhanced by black carbon aerosols / Y. Xu, V. Ramanathan, W.M. Washington // Atmos. Chem. Phys. — 2016. — 16(3). — p. 1303–1315. — DOI: 10.5194/acp-16-1303-2016.
8. Bekkiev M.Yu. Sovremennaya degradaciya dolinnyh lednikov Central'nogo Kavkaza [Modern Degradation of Valley Glaciers in the Central Caucasus] / M.Yu. Bekkiev, M.D. Dokukin, R.Kh. Kalov [et al.] // Fundamental'naya i prikladnaya klimatologiya [Fundamental and Applied Climatology]. — 2021. — Vol.8. — № 3. — p. 113-141. — DOI: 10.21513/2410-8758-2021-3-113-141 [in Russian]
9. Kutuzov S. Volume Changes of Elbrus Glaciers From 1997 to 2017 / S. Kutuzov, I. Lavrentiev, A. Smirnov et al. // Front. Earth Sci. — 2019. — 7. — p. 153. — DOI: 10.3389/feart.2019.00153.
10. Huss M. A new model for global glacier change and sea-level rise / M. Huss, R. Hock // Front. Earth Sci. — 2015. — 3. — p. 54. — DOI: 10.3389/feart.2015.00054.

11. Tretij ocenochnyj doklad ob izmeneniyah klimata i ih posledstviyah na territorii Rossijskoj Federacii. Obshchee rezyume [Third Assessment Report on Climate Change and Its Consequences on the Territory of the Russian Federation. General summary]. — St. Petersburg: Science-intensive technologies, 2022. — 124 p. [in Russian]