Comparative assessment of the rate of change in the amount of precipitation in the North Caucasus region for 1961-2019 and 1976-2019

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Abstract. Global climate change and the impact of these changes on the environment, ecology, economy at the end of the twentieth century, became one of the main problems of human life. Since climatic changes are not synchronous in time and space, regional studies are necessary fragments in building an overall picture of climate change.

The purpose of this article is to assess changes in the precipitation regime in the North Caucasus region for the periods 1961-2019 and 1976-2019 for different climatic zones.

It was found that in all climatic zones of the North Caucasus region, both an increase and a decrease in seasonal and annual precipitation were observed, mainly these trends are statistically insignificant. In all climatic zones, with the exception of the alpine one, in the period 1976 to 2019, a negative trend in the amount of precipitation was observed, which increased in comparison with the entire observation period.

Keywords: North Caucasian region, climatic zone, modern period, precipitation amount, trend, rate of change.

Introduction

Climate is a generalization of weather changes in a given area of space at a given time interval. To characterize the climate, a statistical description is used in terms of averages, extrema, indicators of variability of the corresponding values and the frequency of occurrence of phenomena for a selected period of time. The most important and popular climatic variables used to estimate climate change are air temperature at the surface of the earth and precipitation.

Atmospheric precipitation in the form of rain, snow and hail are common natural phenomena. Abundant atmospheric precipitation increases the likelihood of floods, avalanches, rockfoils, mudflows, landslides, landslides, contributes to the accumulation of a critical amount of water in mountain lakes and unexpected breakthrough of dams, river overflow, destruction of roads, power lines, buildings, destruction of farmland [1].

According to the results of the forecast [2] in the XXI century, the amount of precipitation on the territory of Russia, as a whole, will increase, and the most significant in the winter. The distribution and intensity of future precipitation changes are highly seasonal.

Purpose of the study - to establish the nature of the change in the precipitation regime in different climatic zones of the North Caucasus region for the observation period 1961-2019 and for the period of modern warming 1976-2019.

Materials and methods

According to climatic characteristics, the North Caucasian region can be divided into 4 zones depending on the height above sea level: plain, foothill, mountain and high-mountain.

The flat zone occupies most of the region's territory and stretches from its northern borders to the south, to the Terek River. Plains are territories with a slight elevation difference (up to 200 m), they are low-lying up to 200 m, elevated from 200 to 500 m and higher than 500 m, such plains are called plateaus.

The foothill zone (500-1000 m above sea level) is located to the south and stretches in a small strip from northwest to southeast. The mountainous zone is located at an altitude of over 1000 and alpine at an altitude of over 2000 m above sea level. The physical and geographical characteristics of the meteorological stations in the North Caucasus region are shown in Table 1.

Table 1 - Physical and geographical characteristics of meteorological stations in the North Caucasus region

№ n/n	Weather stations	Longitude (°N), Latitude (°E)	Height above the sea level, (m a. s. l.)
Plain stations (< 500 m a. s. l.)			
1	Prokhladnaya (Kabardino-Balkaria)	43.46° N; 44.05° E	198
2	Izobil'nyi (Stavropol region)	45.22° N; 32.42° E	194
3	Makhachkala (Dagestan)	42.59° N; 47.31° E	173
4	Mozdok (Republic of North Ossetia - Alania)	43.44° N; 44.39° E	126
5	Derbent (Dagestan)	42.04° N; 48.17° E	30
6	Izberg (Dagestan)	42.34° N; 47.45° E	21
7	Kizlyar (Dagestan)	43.51° N; 46.43° E	-17
Foothill stations (500–1000 m a. s. l.)			
8	Kislovodsk (Stavropol region)	43.54° N; 42.43° E	819
9	Vladikavkaz (Republic of North Ossetia - Alania)	43.21° N; 44.40° E	680
10	Buinaksk (Dagestan)	42.49° N; 47.07° E	560
11	Stavropol (Stavropol region)	45.03° N; 41.58° E	540
12	Cherkessk (Karachay-Cherkessia)	44.17° N; 42.04° E	526
13	Nalchik (Kabardino-Balkaria)	43.22° N; 43.24° E	500
Mountain stations (1000–2000 m a. s. l.)			
14	Teberda (Karachay-Cherkessia)	43.45° N; 41.73° E	1280
15	Akhty (Dagestan)	41.28° N; 47.44° E	1054
High-mountain station (> 2000 m a. s. l.)			
16	Terskol (Kabardino-Balkaria)	43.15° N; 42.30° E	2144

To study changes in the precipitation regime, averaged values, anomalies and trends for calendar seasons and the year as a whole were used.

The time series were investigated by the methods of mathematical statistics and supplemented by linear trends characterizing the trend of the value under consideration for the

periods 1961-2019 and 1976-2019. Average values and norms of annual and seasonal precipitation were calculated for each climatic zone and the region as a whole.

Results and discussion

In different climatic zones of the North Caucasus region, climate change can vary significantly. Figure 1 shows the course of annual precipitation amounts according to data from 16 m/stations in the North Caucasus region. Figure 1 shows that changes in the precipitation regime in different climatic zones are not synchronous. The greatest amount of precipitation is observed in the high-mountainous zone, and the least in the lowland zone.

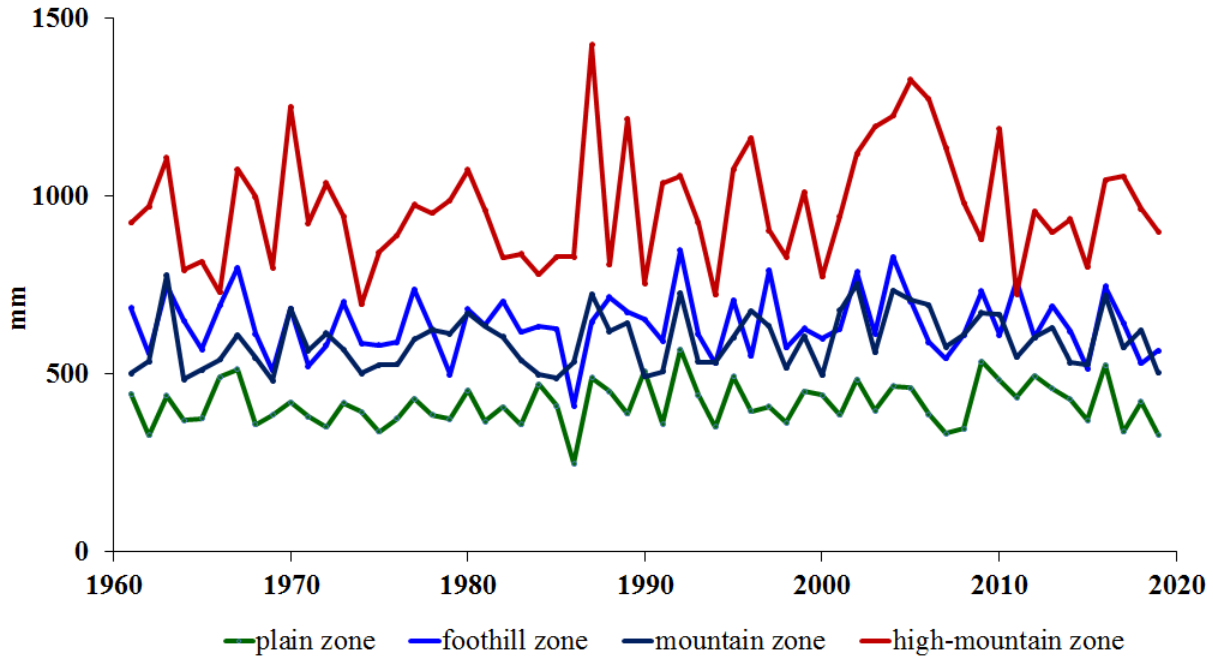

Figure 1 - The course of annual precipitation totals according to data from 16 m/stations of the North Caucasus region.

To study changes in the precipitation regime, as in previous works [3, 4], we used averaged values and trends for calendar seasons and the year as a whole.

The time series were investigated by the methods of mathematical statistics and supplemented with linear trends characterizing the trend of the value under consideration for the periods 1961-2019 and 1976-2019. Average values and norms of annual and seasonal precipitation were calculated for each climatic zone and the region as a whole.

Throughout the North Caucasus region in the period from 1961 to 2019 there was a statistically insignificant increase in annual precipitation. Table 1 shows the averaged values of precipitation amounts and their climatic norms in different climatic zones and on average for the region for the periods 1961-2019 and 1976-2019.

Table 2 shows that in all climatic zones in the period 1976-2019 the excess of the climatic norm is higher than in the period 1961-2019.

Table 2 - Climatic norms and annual precipitation for the periods 1961-2019 and 1976-2019 in the North Caucasus region

Climatic zones	**Plain**	**Foothill**	**Mountain**	**High-mountain**	**Average for the North Caucasus**
Climatic norm (1961-1990), mm	405	631	576	936	637
Average annual precipitation, 1961-2019, mm	416	640	594	969	655
ΔP exceeding the climatic norm	11	9	18	33	18
Average annual precipitation, 1976-2019, mm	421	642	605	983	662
ΔP exceeding the climatic norm	16	11	29	47	25

Table 3 shows the summary characteristics of the linear trend (slope b (mm/10 years) and contribution to the total variance *D* (%)). The slope *b* characterizes the rate of change of the meteorological parameter, and the strength of the trend, its significance, describes the value of the contribution to the total variance (*D*,%). Table 3 shows that in all climatic zones, both an increase and a decrease in seasonal and annual precipitation were observed, these trends are mainly statistically insignificant. In the plain zone, from 1976 to 2019, there was a slight decrease in the growth rate of annual precipitation amounts from 5.4 mm/10 years to 5.32 mm/10 years. Winter and spring seasons, the growth rate has increased, the autumn and especially summer season (from -3.2 mm/10 years for the entire period to -4.45 mm/10 years in the modern period) is characterized by a decrease in precipitation. All trends are statistically insignificant, with the exception of a steady increase in winter precipitation. In the foothill zone, the growth rate of annual precipitation amounts in the modern period decreased compared to the entire observation period and amounted to 0.93 mm/10 years, the trend is statistically insignificant. This is due to the strengthening of the negative trend in summer precipitation amounts and a decrease in precipitation in the autumn season. In the mountainous zone, there is also a tendency towards a decrease in annual precipitation amounts to 6.55 mm/10 years. The main contribution to this change is made by the winter season, where the growth rate decreased from 1.34 mm/10 years to 0.042 mm/10 years, summer and autumn seasons, where the growth rate has a negative

trend (-2.25 mm/10 years and -0.66 mm/10 years respectively). In the mountainous zone, only the spring season is characterized by an increase in the amount of precipitation (from 5.5 mm/10 years for the entire period to 10.01 mm/10 years in the modern period). At the high-mountain meteorological station Terskol, the growth rate of annual precipitation totals was 15.25 mm/10 years (D =1.36%), which is lower than the annual precipitation totals for the entire observation period. In the winter season, there was a negative trend in the change in the amount of precipitation, and in the modern period the growth rate was -3.02 mm/10 years. Spring and summer seasons are characterized by a slight increase in the growth rate of seasonal precipitation amounts.

Table 2 - Comparative estimates of the rate of change in the amount of precipitation in different climatic zones of the North Caucasus region for 1961-2019 and 1976-2019

Season	**Year**		**Winter**		**Spring**		**Summer**		**Autumn**	
years	**1961-2019**	**1976-2019**	**1961-2019**	**1976-2019**	**1961-2019**	**1976-2019**	**1961-2019**	**1976-2019**	**1961-2019**	**1976-2019**
Plain zone										
b	5,4	5,32	2,69	5,21	1,53	2,27	-3,2	-4,45	5,2	3,12
D(%)	2,26	1,12	4,6	**9,62**	1,2	1,64	2,9	3,0	5,8	1,08
Foothill zone										
b	1,1	0,93	8,82	2,47	3,0	7,27	-4,4	-7,95	2,5	-0,34
D(%)	0,05	0,01	0,6	2,87	2,0	6,04	1,4	2,75	1,5	0,01
Mountain zone										
b	10,36	6,55	1,34	0,042	5,5	10,01	0,2	-2,25	4,3	-0,66
D(%)	5,1	1,2	0,3	0,0	5,8	8,9	0,0	0,6	2,4	0,03
High-mountain zone										
b	16,31	15,25	0,3	-3,02	9,1	12,89	-0,4	0,57	8,8	5,7
D(%)	2,9	1,36	0,0	0,25	3,8	3,52	0,0	0,01	2,6	0,66
Average values for the North Caucasus region										
b	8,55	6,96	1,3	1,18	4,4	7,46	-1,9	-3,52	5,2	1,96
D(%)	3,3	1,38	0,4	0,23	4,3	5,57	0,7	1,3	4,4	0,35

b – the value of the slope of the linear trend (mm / 10 years), ***D***(%) – the contribution of the trend to the total variance. Bold indicates trends that are statistically significant at the 5% level.

In general, in the North Caucasus region, we can talk about a decrease in the growth rate, both in annual precipitation amounts and seasonal, with the exception of the spring season, where the growth rate in the modern period has increased to 7.6 mm in 10 years. All trends are statistically insignificant.

Separately, I would like to note the change in the amount of precipitation in the summer season. In all climatic zones, with the exception of the alpine one, in the period 1976 to 2019, a negative trend in the amount of precipitation was observed, which increased in comparison with the entire observation period. Only in the alpine zone, in which there was a negative trend in the

change in the amount of precipitation over the entire observation period, there was an increase in the amount of precipitation in the modern period, although this trend is statistically insignificant.

Since the plain and foothill zone of the North Caucasus region is the most important producer of agricultural products, a decrease in summer precipitation may negatively affect the production of agricultural products.

In contrast to the forecast given in [2], in the region under consideration, there is a tendency towards a decrease in annual and seasonal precipitation amounts in all seasons, except for spring.

Conclusion

During the study of changes in the precipitation regime in the North Caucasus region, both an increase and a decrease in annual and seasonal precipitation were observed.

In the plain zone of the North Caucasian region, an increase in winter and spring precipitation and a decrease in summer and autumn were observed, due to which there was a tendency to a decrease in annual precipitation as well.

In the foothill and mountainous zones in the winter, summer and autumn seasons, as well as in the year as a whole, there was a decrease in seasonal precipitation amounts in the modern period, compared to the baseline, in contrast to the spring season, characterized by their growth.

The alpine zone is the only zone where there is an increase in summer precipitation.

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