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Characteristics of the contemporary spatiotemporal distribution of atmospheric precipitation in the northeastern part of the Lesser Caucasus region

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ABSTRACT

Problem definition. Global warming observed on Earth in recent times is manifested with numerous impacts in mid-latitude regions. The rise in air temperature affects the long-term dynamics of many climatic elements. Consequently, the potential increase in evaporation leads to a reduction in precipitation, which in turn results in decreased freshwater resources and an expansion of health-related risks.

Formulation of the purpose. The purpose of the study is to determine the contemporary spatiotemporal distribution characteristics of atmospheric precipitation in the northeastern part of the Lesser Caucasus region, as well as the effects of climate changes on the long-term precipitation amounts, based on the initial precipitation data for the period 1961–2023.

Research methods. The analyses utilized precipitation data (monthly, seasonal, annual, and long-term) from six hydrometeorological stations operating in this region during the specified period. The study was conducted using mathematical-statistical, cartographic, and physical methods. To determine the spatial distribution pattern, the variation of annual precipitation amounts with elevation was mapped using GIS technology.

The main material. The results of the study indicate that 65% of the annual precipitation occurs during the warm period, while 35% falls in the cold period of the year. In the region, precipitation amounts increase from the lowlands toward the high mountains. Precipitation, which rises up to the upper boundary of the mid-mountain zone, tends to decrease again above approximately 2800 m. The period when precipitation decreases most in the region corresponds to June–September, during which the demand for drinking water reaches its maximum level. In the multi-year period, 90% of the 10 years with lower precipitation occurred after 1995. However, during that period, an increase in extreme precipitation amounts was recorded. This confirms that the majority of the annual precipitation occurred during such events, while drought conditions expanded during other phases of the year.

Conclusions. The long-term average of atmospheric precipitation in the northeastern part of the Lesser Caucasus region (1991–2023) was 451 mm, which is 15% (71 mm) lower than the norm (1981–2010). Maximum precipitation is recorded primarily in Gadabay (up to 1000 mm). The wettest period in the region occurred between 2001 and 2010, while the driest period was after 2010. The sharp decrease in precipitation during

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summer significantly affects crop cultivation and horticulture in the lowlands, as well as hay farming and livestock breeding in the mountainous areas. It is recommended to plant drought-resistant crops and to use modern irrigation technologies (sprinkler and drip systems) in agriculture. Determining the contemporary spatiotemporal distribution of precipitation in this region is essential for climate change mitigation, adaptation strategies, and the assessment of alternative energy sources.

Introduction

The formation of water resources on Earth is regulated by the large and small water cycles. In each of these cycles, the primary driving factors are evaporation, cloud formation, and precipitation [17, 18]. Atmospheric circulation, latitude, relief and orography, proximity to water basins, origin of air masses, temperature regime, and surface characteristics play a crucial role in the uneven distribution of precipitation over the Earth's surface [9, 16].

The amount of atmospheric precipitation varies over time. These variations manifest seasonally throughout the year and on a multi-year scale under the influence of global factors. Nevertheless, differences exist between seasonal and long-term (multi-year) variations [4, 15, 21, 23].

In recent years, with the rise in global temperatures, changes have been observed in the characteristics of the main factors influencing precipitation, with the exception of latitude [2, 5].

Onyutha (2020) found that, compared to 1961-1990, the frequency of extreme precipitation events in various regions of East Africa has increased in recent decades [14]. Elizbarashvili et al. (2025) showed that, using data from 63 meteorological stations for 1950-2022, higher temperature anomalies were detected in high-mountain and subalpine zones. Their study also indicated statistically significant trends, including increased precipitation during the cold season in humid regions and decreased spring precipitation in arid areas [3].

Huseynov et al. (2025) observed a decrease in precipitation on the southern slopes of the Greater Caucasus from 2011 to 2024 in all months except January, March, and May. Consequently, the reduction in precipitation during spring and summer overlaps with the growing season of agricultural crops [6].

The Republic of Azerbaijan stands out among other countries in the South Caucasus, a region where the effects of global warming are particularly pronounced, due to its physical-geographical location [10]. The complexity of the country's relief limits the possibility of conducting comprehensive climate studies across the entire territory; therefore, investigating its constituent regions separately is considered a significant approach [4, 11, 15].

In Azerbaijan, the first comprehensive classification of the surface distribution of

precipitation in the southern and southeastern parts of the Lesser Caucasus region was carried out by A.M. Shikhlinski and A.A. Madatzada [1]. In subsequent years, numerous researchers-including N. Sh. Huseynov, F. A. Imanov, R. N. Mahmudov, Surxay H. Safarov, Said H. Safarov, A. S. Mammadov, Kh. Sh. Rahimov, U. R. Taghiyeva, Y. J. Hadiyev, J. S. Huseynov, and others-have conducted extensive studies to determine changes in various precipitation characteristics under the influence of climate change.

In recent years, the effects of climate change on air temperature have been established in the northeastern part of the Lesser Caucasus region. Specifically, compared to 1961-1990, air temperature in the region increased by 1.1 °C during 2006-2020, and compared to 1981-2010, it increased by 1.1 °C during 2011-2023. These changes necessitate a re-evaluation of the contemporary characteristics of atmospheric precipitation in this region [6, 7].

The contemporary state of atmospheric precipitation and the specific effects of climate change on precipitation in the northeastern part of the Lesser Caucasus region have not been extensively studied in previous research. Additionally, the increase in hydrometeorological time series and the recording of new temperature extremes during 2011-2024 necessitate an assessment of their impact on precipitation amounts in the region.

The aim of this study is to determine the contemporary spatiotemporal distribution characteristics of atmospheric precipitation in the northeastern part of the Lesser Caucasus region under the influence of climate change, based on initial precipitation data for 1961-2023.

Materials and methods. The study utilized precipitation data from 1961-2023 collected at six hydrometeorological stations under the National Hydrometeorological Service in the northeastern Lesser Caucasus region: Dashkasan, Goygol, Gadabay, Shamkir, Agstafa, and Ganja. The key characteristics of these stations are presented in Table 1. Primary data were obtained from the Ministry of Ecology and Natural Resources, the State Statistical Committee, and periodic scientific publications [4, 5, 21, 22].

To assess the most recent regional impacts of climate change, we conducted a comparative analysis of precipitation indices between the WMO-recommended climate normal period (1981-2010) and the recent period (2011-2023)

Table 1

Main characteristics of hydrometeorological stations

Station	Elevation, m	Observation periods used at work, year	Climate norms: Precipitation amount (1981-2010), mm
Dashkasan	1614	1961-2023	666
Goygol	1585	1961-1999, 2005-2023	608
Gadabay	1480	1961-2023	699
Shamkir	404	1961-2023	298
Agstafa	331	1961-2023	372
Ganja	312	1961-2023	269

[19, 20]. Additionally, we quantified the annual frequency distribution of precipitation events across different intensity thresholds (< 10 mm, 11-20 mm, 21-30 mm, 31-40 mm, 41-50 mm, 51-60 mm, 61-70 mm, and >70 mm) expressed as percentage occurrence.

Multiple methods exist for analyzing precipitation dynamics across different time periods [8, 12, 15]. However, conventional approaches like graphical representations of annual precipitation and trend curves often prove inadequate due to the high variability inherent in this stochastic variable, making it challenging to discern multidecadal tendencies. Therefore, modern analytical techniques-articularly moving averages and anomaly integral curves-are employed in atmospheric precipitation studies.

For long time series of random variables, sharp deviations in the instantaneous time phase (individual years) can distort the trend, so a moving average is commonly used to smooth the curve. A 3-year moving average reflects short-term fluctuations (interannual variability), while a 5-year moving average provides an optimal balance. Although it shows the trend, it does not fully capture long-term variability. A 10-year moving average, however, better represents the effects of climate change while masking local variations. Therefore, this study uses 10-year moving averages [7, 13]. The moving average is calculated using the following formula (1):

$$XA_k = \frac{1}{n} \sum_{i=0}^n x_{k-i} \quad (1)$$

Here, (XA_k) is the moving average for year (k) , (n) is the interval length (10 years), and (x) represents the precipitation value for the current year.

To monitor the long-term dynamics of atmospheric precipitation and assess the representativeness of the series, difference-integral curves are also employed. In the analyses, graphs featuring these difference-integral curves have been constructed. The difference-integral is defined by the following formula (2) [7].

$$= \frac{(\sum K_i - 1)}{C_v} \quad (2)$$

Here, f_i represents the difference-integral, and K_i is the ratio of the annual precipitation amount (Q_i) to the long-term (1991-2023) mean precipitation (Q_{or}) of the series. In the formula, K_i equals Q_i/Q_{or} .

To determine the spatiotemporal distribution patterns of atmospheric precipitation, the analysis employed mathematical-statistical, physical, and cartographic methods. The resulting graphs, tables, and histograms were generated using MS Excel, while the map was created in ArcMap (part of the ArcGIS software suite). Statistical calculations were performed using the StokStat program.

Discussion

The northeastern part of the Lesser Caucasus region is located in the northwestern section of the republic. The area features a combination of mountainous and flat terrain. The primary landforms include the mountain ranges of the Lesser Caucasus-Shahdag, Qashlur, Bulagdag, Pant, and Murovdag-as well as the Ganja-Gazakh plain. The highest peaks above sea level are Shahdag (2901 m), Gochadag (3318 m), Greater Hinaldag (3367 m), and Gamishdag (3927 m). A significant portion of the region lies above the annual snow line. The rivers in the area primarily belong to the Kura River basin, with groundwater, rainfall, and snowmelt playing a crucial role in their sustenance [11].

In the Ganja-Gazakh region and the low mountainous areas, the climate is characterized by a semi-desert and dry steppe type, with mild winters and hot, dry summers. In the mid-mountainous areas, the climate is moderately warm with dry winters, while in the high mountainous areas, a cold climate with dry winters prevails. The distribution of precipitation increases with elevation up to about 800-1400 meters. Beyond this elevation, the amount of precipitation begins to decrease [10].

Table 2

Results of the long-term trend analysis of precipitation amounts

Stansiya	Trend	Kendall tau	p-value	Sen's slope (mm/il)
Dashkasan	Decreasing	-0.12	0.18	-0.7
Goygol	Decreasing	-0.15	0.1	-1.1
Gadabay	Increasing	0.1	0.22	0.8
Shamkir	No trend	-0.03	0.75	-0.2
Agstafa	Decreasing	-0.18	0.05	-1.4
Ganja	No trend	0.02	0.8	0.1

Air masses arriving from the west contribute to year-round precipitation in the region. During transitional seasons, intense insolation in the lowland and low mountainous areas leads to the development of strong convective processes in the mid- and high mountainous zones. Thus, due to orographic influence, the formation of atmospheric precipitation intensifies from early summer to mid-autumn. Additionally, large-scale mesoscale and synoptic processes further enhance precipitation throughout the year. Typically, at the end of spring and during the early summer and autumn months, convective activity increases across the region, resulting in heavy, short-duration (convective) rainfall [6, 11].

In this study, the non-parametric Mann-Kendall test was applied to the meteorological station time series for 1961-2023 to detect the presence and direction of trends. The trend magnitude was estimated using Sen's slope method. The results are presented in the following table (Table 2).

The results of the Mann-Kendall and Sen's slope analyses presented in Table 2 indicate that, over the study period, the long-term variation of precipitation at the hydrometeorological stations shows a significant decrease at Agstafa station. At the other stations, the decrease is less pronounced.

Although negative Kendall tau and Sen's slope values at Dashkasan and Goygol stations indicate a declining precipitation trend, the high p-values

suggest that these changes are not statistically significant. At Agstafa station, the decreasing trend is more clearly observed, and the p-value is close to the threshold, indicating a higher probability of precipitation decline in this area. A weak increasing trend is observed at Gadabay station, but it is also not statistically significant. Statistical tests demonstrate that significant precipitation decreases are already evident in lowland areas (Agstafa).

Mathematical and statistical analyses of precipitation in the northeastern part of the Lesser Caucasus region for 1991-2023 indicate that the long-term average precipitation in the region is 451 mm (Table 3). Across individual hydrometeorological stations, this value ranges between 252 mm and 689 mm. In the mid-mountainous zone, precipitation increases and fluctuates between 550-700 mm (547-689 mm). Toward the lowland areas, the long-term average precipitation ranges from 250 to 350 mm (252-329 mm). Of the total annual precipitation in the region, approximately 64 % falls during the warm season, while the remaining 36 % occurs in the cold season.

In the northeastern part of the Small Caucasus region, the amount of atmospheric precipitation is almost evenly distributed within the 1400-1600 m area. The maximum precipitation in the region is observed at higher altitudes (where observational data is available) in this area, with 689 mm recorded in Gadabay. The amount of precipitation continues to increase upwards, reaching 2500 m.

Table 3

Annual distribution of atmospheric precipitation in the northeastern part of the Lesser Caucasus region

Station	Season, mm					Annual percentage, %	
	Winter	Spring	Summer	Autumn	Annual	Warm	Cold
Dashkasan	76	210	183	134	604	65	35
Goygol	63	183	178	123	547	66	34
Gadabay	76	236	231	145	689	68	32
Shamkir	41	97	77	68	282	61	39
Agstafa	48	117	85	80	329	61	39
Ganja	35	87	66	64	252	61	39
Region	57	155	137	103	451	65	35

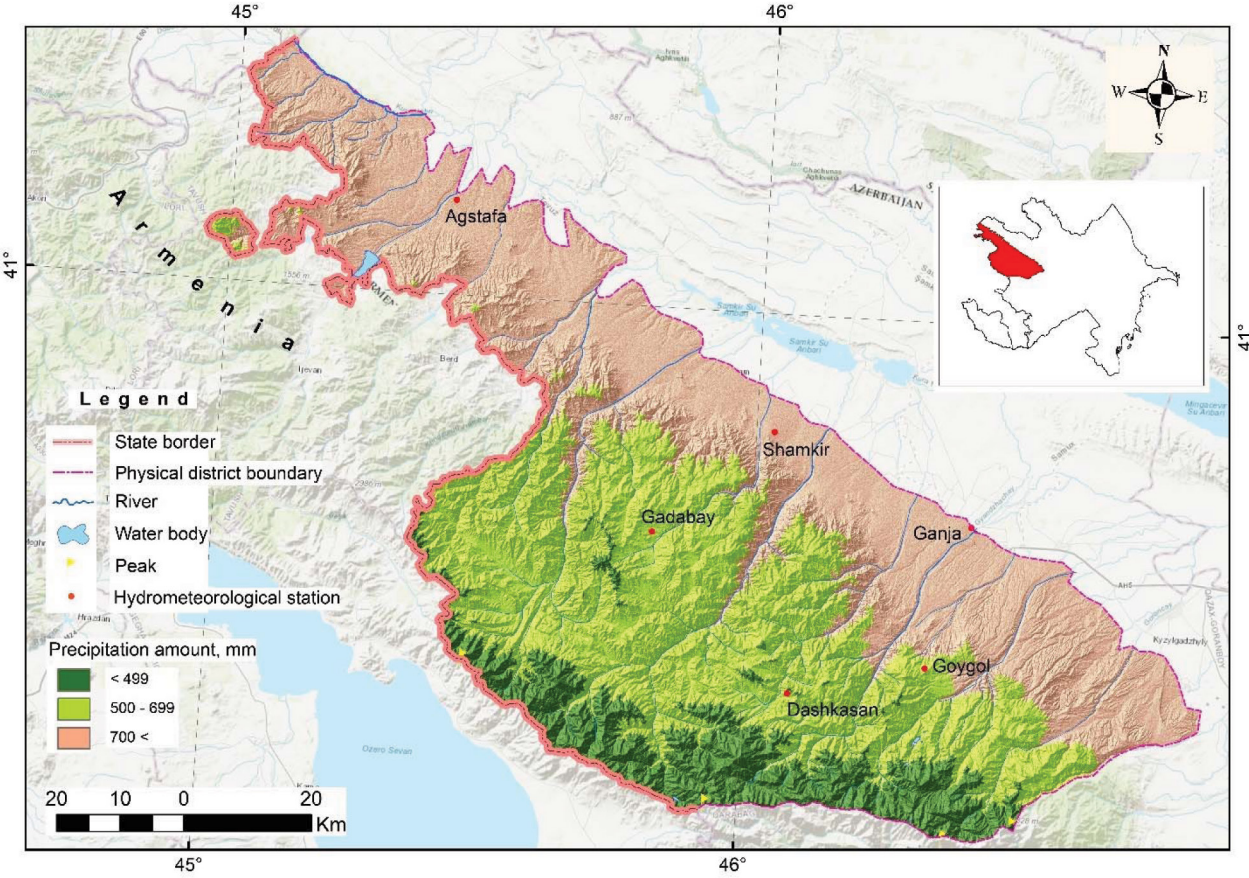


Fig. 1. Average Annual Precipitation Indicators (1991-2023)

However, above 2800 m, in the mountainous area extending to 3600-3700 m, the amount of precipitation decreases again, dropping to around 600 mm [1]. The lowest precipitation in the region occurs in the east, along the boundary with the Kura-Araz lowland, where it falls in the 300-400 m altitude range. Here, the precipitation amount is 252 mm in Ganja.

In the region, the least amount of precipitation is observed in the winter season (57 mm). The wettest season is spring (155 mm). In summer, this value is 137 mm and in autumn, it is around 103 mm. While this distribution holds true for five hydrometeorological stations, there are differences in Goygol. In Goygol, the highest precipitation occurs not in spring, but in summer, with 246 mm recorded

Table 4

Monthly and annual mean precipitation anomalies (mm, %-bold)

Station	Month												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Dashkasan	-4	-7	-2	-18	-10	-28	-21	-14	-5	-6	-12	-1	-127
	-14	-21	-4	-26	-10	-26	-33	-32	-11	-10	-30	-2	-19
Goygol	0	3	7	-1	-15	-31	-29	-26	-5	2	2	5	-87
	0	13	19	-2	-15	-30	-43	-48	-11	4	7	25	-14
Gadabay	4	6	4	-8	8	-12	-20	-14	-2	1	-6	6	-38
	20	23	10	-11	7	-10	-26	-28	-5	2	-16	29	-5
Shamkir	-2	4	-1	-5	-3	-11	6	-9	-1	-3	-9	0.2	-34
	-18	24	-3	-14	-8	-28	31	-40	-6	-9	-39	2	-11
Agstafa	-3	-4	-5	-11	-12	-18	-1	-17	-9	-6	-14	-6	-104
	-20	-17	-15	-28	-22	-36	-2	-62	-34	-15	-50	-41	-28
Ganja	1	5	-1	-8	-4	-10	-6	-3	-1	-1	-6	0	-33
	11	37	-6	-25	-9	-25	-31	-17	-5	-4	-32	0	-12
Region	-1	1	1	-9	-6	-18	-12	-14	-4	-2	-8	1	-71
	-3	5	2	-17	-8	-24	-25	-38	-11	-5	-26	4	-15

A precipitation map has been created to show the spatial distribution of average multi-year precipitation in the northeastern part of the Small Caucasus region (Figure 1). The map was processed using the Digital Elevation Model (DEM) in a GIS environment. The map, processed in 3D format, depicts both the vertical and horizontal distribution of precipitation across the area. The application of hillshade effects on the map allows for clearer differentiation of color gradients representing precipitation distribution. Observing the spatial distribution of precipitation, we can identify a consistent pattern: rainfall amounts increase from the Ganja-Gazakh lowlands toward the high mountain zones.

In the region's low mountain zone (0-500 m), precipitation amounts are minimal. As elevation increases into the mid-mountain zone (up to 1400-1600 m), precipitation shows a marked increase. Although permanent glaciers do not form above the snow line (3000 m) in the study area, persistent snow patches that survive through the following summer are observed in high-altitude zones (Murovdag, Shahdag).

The study statistically assessed the impacts of climate change on long-term precipitation amounts in the northeastern part of the Lesser Caucasus region (Table 4). For this purpose, a comparative analysis was conducted between observed precipitation indices and the climatic norm (1981-2010).

To evaluate the impacts of climate change on precipitation in the region, the average monthly precipitation indices were compared with the climatic norm (1981-2010). In January, precipitation amounts remained unchanged in Goygol, increased in Ganja (11 %) and Gadabay (20 %), while other stations showed decreases of 14-20 %. In February, this indicator decreased

in Dashkasan (21 %) and Agstafa (17 %), but increased by 13-37 % at other stations. Compared to the climatic norm, March saw increased precipitation in Goygol (19 %) and Gadabay (10 %), while other stations recorded decreases of 3-15 %. In April, this indicator decreased at all stations, ranging between 2-28 %. In May, while Gadabay showed a 7 % increase, other stations observed precipitation decreases of 8-22 %. During June (10-36 %), August (17-62 %), and September (5-34 %), all stations in the region recorded significant decreases in precipitation compared to the climatic norm. In July, while precipitation in Shamkir increased by 31 % compared to the climatic norm, other stations experienced 2-43 % less rainfall.

In October, precipitation increased by 2-4 % in Goygol and Gadabay, while other stations recorded decreases of 4-15 %. November saw a 7 % increase in Goygol, but other stations experienced reductions ranging from 16-50 %. Compared to the climatic norm, December values decreased in Dashkasan (2 %) and Agstafa (41 %), remained unchanged in Ganja, and showed increases of 2-29 % at other stations.

The annual fluctuations of precipitation in the northeastern part of the Lesser Caucasus region for 2011-2023, compared to the climate norm (1981-2010), are shown in Figure 2. The long-term average precipitation in the region was 415 mm, while the climate norm was 485 mm, representing a decrease of 71 mm or 14 %. Comparing the 2011-2023 precipitation values with 1961-1990, greater changes are observed in the recent period. During 2011-2023, the highest precipitation amounts occurred in July-August, accounting for 30-40 % of the monthly norm. Compared to 1961-1990, the long-term average precipitation for the region in 2011-2023 decreased by 86 mm or 17 %.

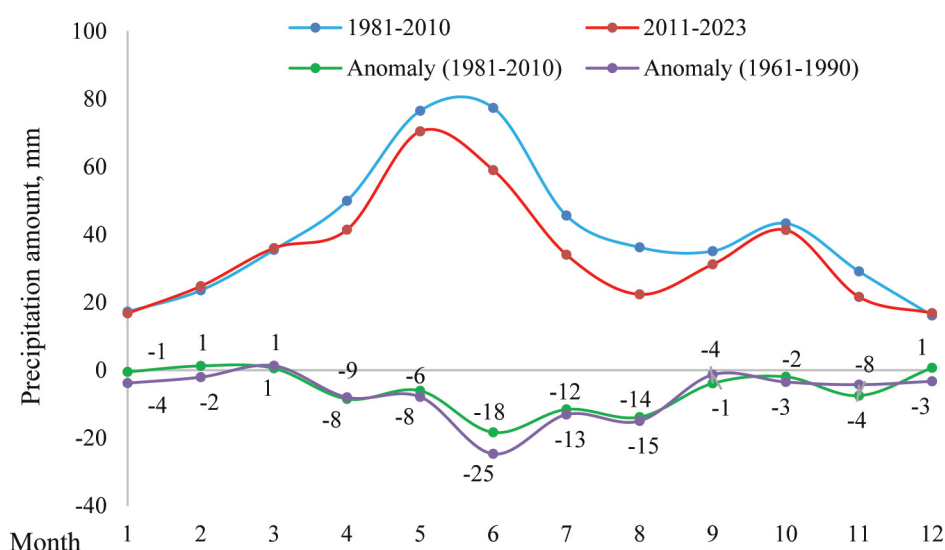


Fig. 2. Variability of mean monthly precipitation amounts in the northeastern Lesser Caucasus region

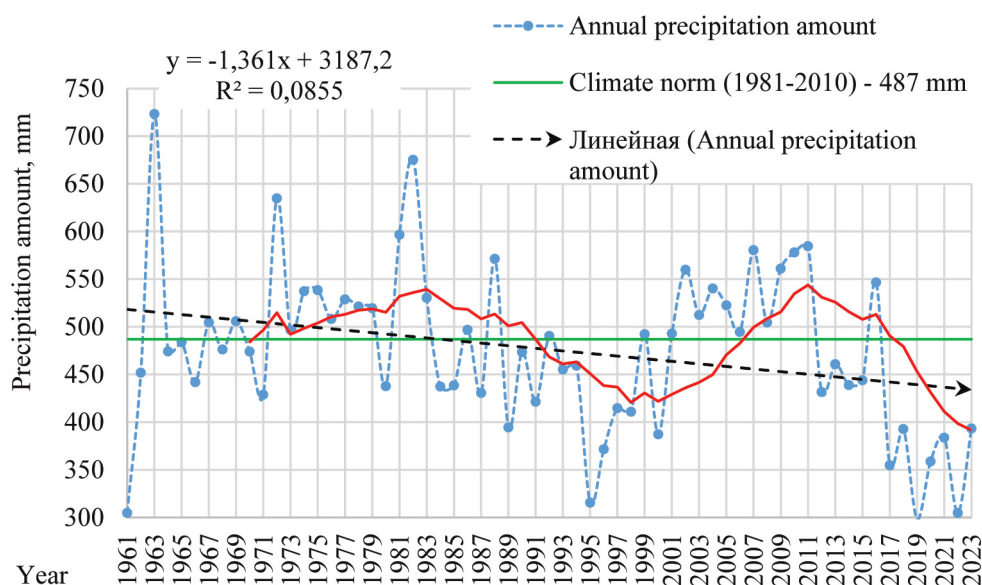


Fig. 3. The multi-year dynamics of precipitation in the northeastern part of the Lesser Caucasus region

The highest annual decrease in precipitation was recorded in Agstafa (28 %), while the lowest was observed in Gadabay (5 %). Looking at the graph, we can see that the most significant reductions occurred from mid-spring to the end of summer. Specifically, in the region, precipitation decreased by 17 % (9 mm) in April, 24 % (18 mm) in June, 25 % (12 mm) in July, 38 % (14 mm) in August, and 26 % (8 mm) in November. Compared to the normal levels, the precipitation amount decreased by 3 % (1 mm) in January, 8 % (6 mm) in April, 11 % (4 mm) in September, and 5 % (2 mm) in November. However, slight increases in this indicator (4-5 %) were recorded in December and February. Although there were reductions in the fall, they were of minor significance.

The sharp declines in precipitation during the summer months negatively affect productivity in the agricultural sector. Additionally, due to the impacts of climate change, the intensity of torrential rains and hail events has shifted over time, and their increasing frequency causes severe damage to agricultural areas.

A graph has been constructed to determine the dynamics of annual precipitation indicators over an extended period in the northeastern part of the Lesser Caucasus region (Figure 3). The graph includes the multi-year trend of precipitation, the trend line, the moving average, and the climate norm. Upon examining the graph, we can observe that the precipitation amount in the region fluctuates between 300-750 mm.

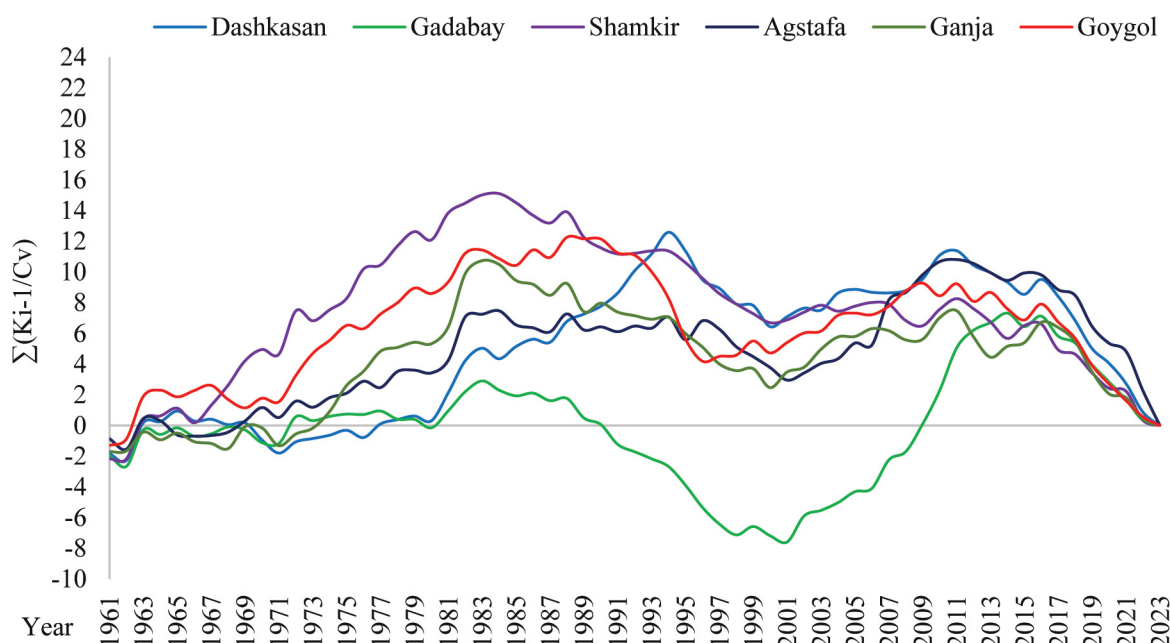


Fig. 4. Dynamics of the precipitation difference integral (1961-2023)

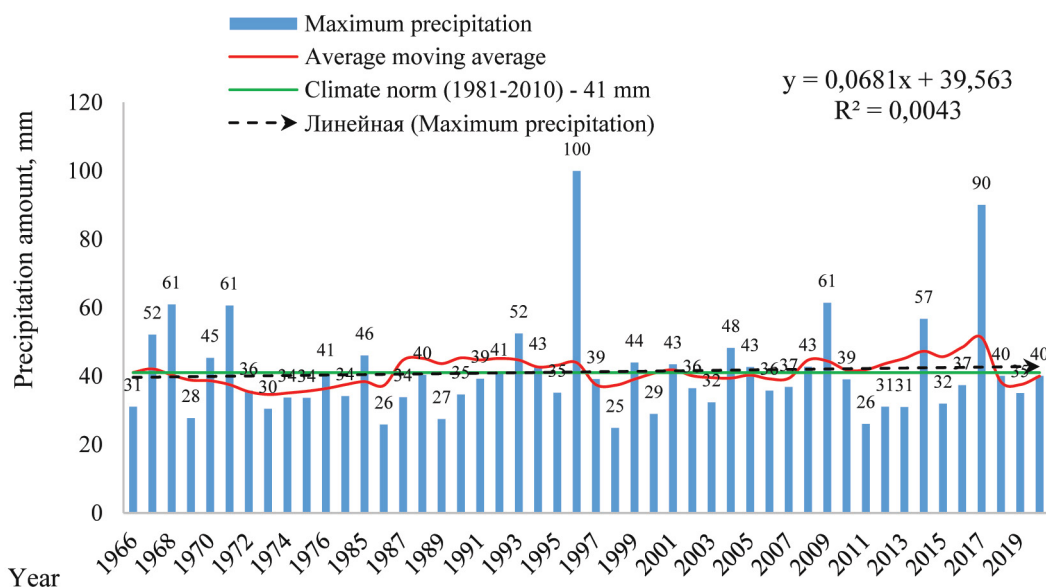


Fig. 5. Annual absolute maximum precipitation in the Northeastern part of the Lesser Caucasus region

Focusing on the dynamics of the moving average, it can be clearly seen that precipitation increased during 1970-1983, 1999, and 2000-2011, and decreased during 1984-1998, 2000, and 2012-2023. In this region, the years 1961, 1995, 1996, 2000, 2017, 2018, 2019, 2020, 2021, and 2022 were among the driest, while 1963, 1972, 1981, 1982, 1988, 2002, 2007, 2009, 2010, and 2011 were among the wettest decades. Analyses also show that all the wettest years occurred before 2011, whereas 90% of the driest years were observed in 1995 and later. The highest average annual precipitation in the region was recorded in 1962 (723 mm), while the lowest was in 2019 (299 mm).

In order to determine the variations of atmospheric precipitation at individual stations in the northeastern part of the Lesser Caucasus region, a differential integral curve has been constructed for each station (Figure 4).

By examining the graph, it becomes evident that the fluctuations of the differential integral curves for the Dashkasan, Shamkir, Aghstafa, Goygol, and Ganja hydrometeorological stations are similar. Specifically, the amount of precipitation increased during the periods 1961-1983 and 2002-2011, while it decreased during 1984-2001 and 2012-2023. The differential integral curve for Gadabay shows some variation. That is, an increase in precipitation was observed during 1961-1994 and 2001-2010, while a decrease occurred during 1994-2000 and 2011-2023. An analysis of the differential integral curves of individual stations in the region shows that all stations exhibit a similar downward trend in precipitation after 2010.

A comparative analysis of the maximum monthly and annual (1961-2020) atmospheric

precipitation values in the northeastern part of the Lesser Caucasus region was conducted, comparing them with the norm. The results of the analysis are presented in the description below (Figure 5). Upon examining the analysis, it can be observed that the highest precipitation values were recorded in 1996 (90 mm) and 2017 (100 mm). The graph shows that the linear trend of maximum precipitation has a weak positive tendency. If we focus on the moving average, we observe that the maximum precipitation values were below the norm during 1967-1986, 1997-2000, 2002-2008, and 2018-2020, while they were above the norm during 1966, 1987-1996, 2001 and 2007-2017. The moving average reached its maximum value in 2017.

The analysis of the maximum annual precipitation values in the northeastern part of the Lesser Caucasus region compared to the climatic norm (1981-2010) was conducted for separate 10-year periods. Specifically, an increase of 6 % was observed in 1961-1970, a decrease of 4 % in 1971-1980, a decrease of 16 % in 1981-1990, an increase of 9 % in 1991-2000, and an increase of 2 % in both 2001-2010 and 2011-2020.

The study also examined precipitation recurrence patterns across the entire region (Figure 6). The most frequently occurring precipitation events (21 %) were low-intensity rains (< 10 mm). The second most recurrent category (17 %) comprised moderate precipitation events (11-20 mm). Significant recurrence rates were also observed for 21-30 mm (16 %), 31-40 mm (14 %), and heavy precipitation events (> 70 mm, 14 %). The least frequent events (4 %) fell within the 61-70 mm range. The predominance of < 10 mm precipitation indicates a high frequency of dry days, particularly in low-mountain areas. However, this pattern

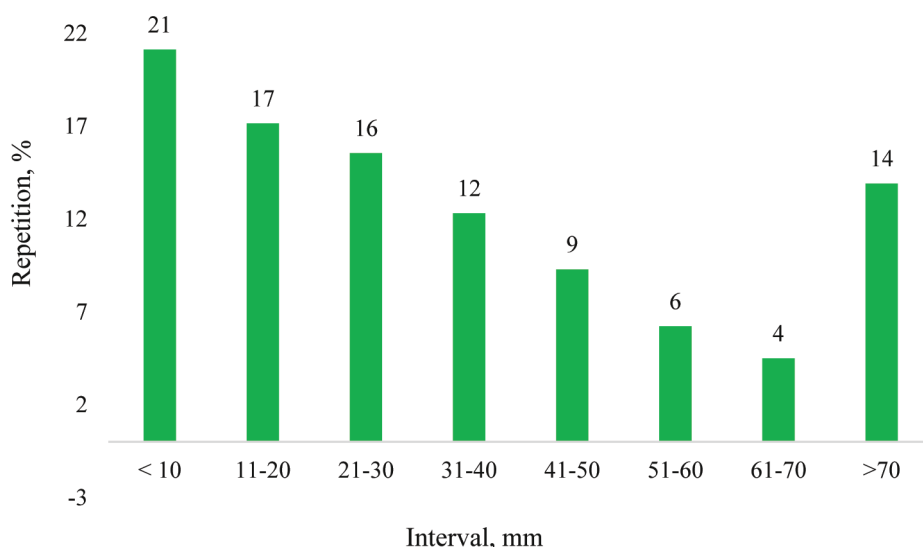


Fig. 6. Recurrence (%) of annual precipitation amounts in the northeastern part of the Lesser Caucasus region

reverses at higher elevations (> mid-mountain zones), where heavy precipitation events (> 70 mm) dominate. Such intense rainfall typically results from convective processes (mainly torrential rains), which frequently trigger flash flood events in the region.

Additionally, in the study, the trend of the precipitation amount in the region from 1961 to 1970 was analyzed, with the tendency of each decadal indicator compared to the previous 10 years (Figure 7).

According to the analysis, compared to the period of 1961-1970, the amount of precipitation increased by 6 % in 1971-1980, by 2 % in 1981-1990, and decreased by 16 % in 1991-2000. Compared to the previous decade, this indicator increased by 27 % in 2001-2010. In the region, precipitation decreased by 19 % in the 2011-2020 decade and by 20 % in 2021-2023.

In the northeastern part of the Lesser Caucasus region, the decade with the highest precipitation over the long-term period was 2001-2010 (535 mm), while the decade with the lowest precipitation was 1991-2000 (422 mm).

Conclusions. Based on observational data for 1961-2023, the study of the spatiotemporal distribution of atmospheric precipitation under climate change in the northeastern part of the Lesser Caucasus region yielded the following results:

1. For the first time, it was determined that 65 % of atmospheric precipitation falls during the warm half of the year and 35 % during the cold half in 1991-2023. In the recent period, the highest monthly precipitation peak was recorded in Gadabay (1100 m).

2. Precipitation in the region increases from 250-300 mm in lowlands to 550–600 mm in high-mountain areas.

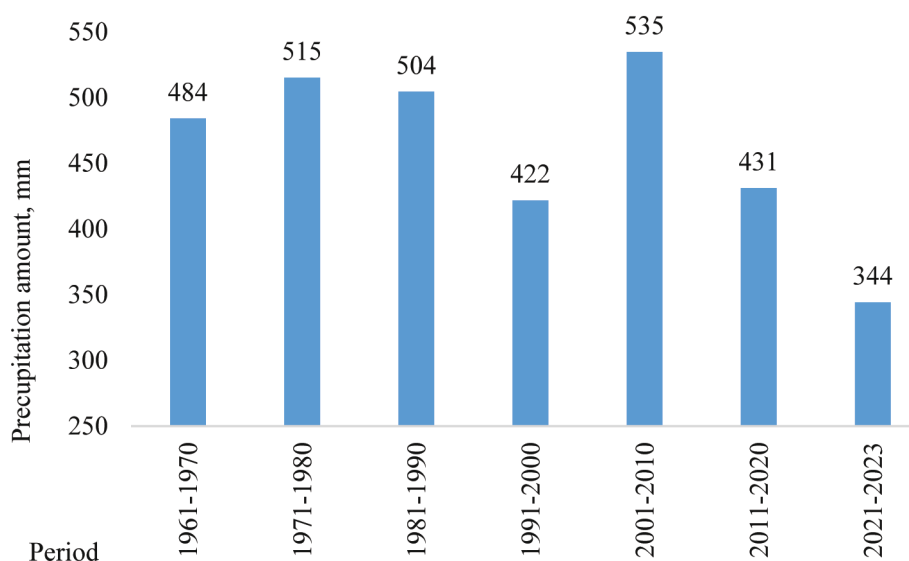


Fig. 7. Dynamics of precipitation amount by decades in the northeastern part of the Lesser Caucasus region

3. In the study area, precipitation during 2011-2023 decreased by 15 % (71 mm) compared to the norm. According to the integral curve, precipitation at all stations in the region has declined since 2015.

4. In the northeastern part of the Lesser Caucasus region, annual maximum precipitation values, compared to the 1981-2010 norm, increased by 6 % in 1961-1970, 9 % in 1991-2000, and 2 % in both 2001-2010 and 2011-2020, while decreases of 4 % and 16 % were recorded in 1971-1980 and 1981-1990, respectively.

The results of the study indicate that atmospheric precipitation in the northeastern part of the Lesser Caucasus region was affected by climate change during 2011–2023. Spatial (from lowlands to high mountains) and temporal (long-term, seasonal, monthly, and quarterly) trends of precipitation suggest that the current

state of atmospheric precipitation should be considered in climate zoning and the assessment of water resources. It should also serve as a key criterion for water resource management in new settlements and energy projects.

The decrease in precipitation in the region may lead to the expansion of drought in lower elevations, reduction of green landscapes, and increased frequency of hazardous hydrometeorological events. In agriculture, drought-resistant crops should be cultivated, and modern irrigation technologies (sprinkler and drip systems) should be applied.

The study's findings should be used for the re-evaluation and mapping of climate resources and types, as well as for planning settlements, industrial and economic sectors, and forecasting water resources. Future research is needed to quantify the impacts of rising air temperatures on precipitation and evaporation indicators.

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Характеристика сучасного просторово-часового розподілу атмосферних опадів у північно-східній частині регіону Малою Кавказу

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АНОТАЦІЯ

Метою дослідження є визначення сучасних просторово-часових характеристик розподілу атмосферних опадів у північно-східній частині регіону Малого Кавказу, а також впливу змін клімату на довгострокові кількості опадів, на основі початкових даних про опади за період 1961-2023 років. В аналізі використовувалися дані про опади (місячні, сезонні, річні та багаторічні) з шести гідрометеорологічних станцій, що працювали в цьому регіоні протягом зазначеного періоду. Дослідження проводилося з використанням математико-статистичних, картографічних та фізичних методів. Для визначення просторової картини розподілу було нанесено на карту зміну річної кількості опадів з висотою за допомогою ГІС-технологій. Результати дослідження показують, що 65% річних опадів випадає в теплий період, тоді як 35% – у холодний період року. У регіоні кількість опадів збільшується від низовин до високих гір. Кількість опадів, яка піднімається до верхньої межі середньогірської зони, має тенденцію до зменшення вище приблизно 2800 м. Період, коли кількість опадів у регіоні найбільше зменшується, відповідає червню-вересні, протягом якого потреба в питній воді досягає свого максимального рівня. У багаторічному періоді 90% 10 років з меншою кількістю опадів припадали на період після 1995 року. Однак протягом цього періоду було зафіксовано збільшення екстремальних кількостей опадів. Це підтверджує, що більша частина річних опадів випадала під час таких подій, тоді як посушливі умови посилювалися в інші фази року. Багаторічна середня кількість атмосферних опадів у північно-східній частині регіону Малого Кавказу (1991-2023) становила 451 мм, що на 15% (71 мм) нижче за норму (1981-2010). Максимальна кількість опадів зареєстрована переважно в Гедабаї (до 1000 мм). Найбільш вологий період у регіоні припав на 2001-2010 роки, а найсухіший – після 2010 року. Різне зменшення кількості опадів влітку суттєво впливає на вирощування сільськогосподарських культур та садівництво в низовинах, а також на сінокосаріння та тваринництво в гірських районах. Рекомендується висаджувати посухостійкі культури та використовувати сучасні технології зрошення (дощувальні та крапельні системи) у сільському господарстві. Визначення сучасного просторово-часового розподілу опадів у цьому регіоні має важливе значення для пом'якшення наслідків зміни клімату, розробки стратегій адаптації та оцінки альтернативних джерел енергії.

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