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Characteristics of the contemporary spatiotemporal distribution of atmospheric precipitation in the southern and southeastern parts of the Greater Caucasus region

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ABSTRACT

Problem definition. Currently, global warming, which is being observed on Earth, continues to show its numerous effects in the South Caucasus, as in all other regions. In the region, along with rising air temperatures, a number of climatic elements are changing their long-term patterns. One of the atmospheric phenomena most affected by climate change is precipitation. The article analyzes the modern spatiotemporal variations of atmospheric precipitation in the southern and southeastern parts of the Greater Caucasus region.

Formulation of the purpose. In previous studies, although the spatiotemporal distribution of atmospheric precipitation was determined, such research did not cover recent periods. This study was conducted to identify the effects of modern climate change on the spatiotemporal distribution of atmospheric precipitation in the southern and southeastern parts of the Greater Caucasus region. For this purpose, the distribution of precipitation indicators across months, seasons, years, and the Earth's surface, as well as their long-term trends, have been determined.

Research methods. The analysis utilized observational data on atmospheric precipitation collected from the hydrometeorological stations of Zaqatala, Oghuz, Shaki, Ismayilli, Shamakhi, Gabala, Gobustan, Saribash, and Alibay over the period from 1961 to 2023. The research was conducted using modern mathematical-statistical, physical, cartographic methods, and GIS technology. In the study, the analysis of extreme atmospheric precipitation events was conducted for the period 1961-2023 due to the probability of their recurrence, while the spatiotemporal distribution characteristics of precipitation (monthly, seasonal, annual, and surface-based) were examined during the modern climate change period, specifically from 1991 to 2023.

The main material. During the analysis, it was determined that the average long-term amount of atmospheric precipitation in the southern and southeastern parts of the Greater Caucasus region is 816 mm. Of the total annual precipitation in the region, 56% occurs during the warm period, while 44% falls during the cold period. In general, across this part of the region, the amount of precipitation decreases from higher elevations to lowlands and from the northwest to the southeast.

Conclusions. In the study area, a decrease in precipitation amounts is observed in all months except January, March, and May. The reduction in precipitation during the spring and summer months is particularly detrimental to the development of agricultural crops, as it coincides with their vegetation period. The precipitation in the region predominantly exhibits a recurrence of 120 mm or higher. The results of the research can be utilized for the establishment of new agricultural fields, the compilation of maps, economic assessments, and the development of mitigation measures against climate change.

Keywords*: climate change, atmospheric precipitations, GIS technology, recurrence limit of precipitation, difference integral, moving average quantity, precipitation anomaly.*

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Problem definition. Precipitation is one of the main climate-forming factors on Earth and is of particular importance in the formation of ecosystems [17]. Precipitation formation culminates with coolling of water particles that have evaporated under high temperature conditions as they rise in the air column, condense into droplets on a small particles at a certain point, growing of the droplets by colliding, and the formation of Liesegang bands and their downward movement [18, 22, 28].

The circulation of water on Earth is carried out by large and small water cycles. Such large cycles consist of the transport of large-volume moist air masses by mesoscale synoptic objects (cyclone, anticyclone, etc.) to longer distances [1, 4]. Small synoptic processes such as the transport of water by local winds to higher mountains evaporated from the surface of the Caspian Sea and the precipitation falling there can be given as an example of small water cycles [7, 9].

Depending on the formation of atmospheric processes, precipitation is distributed unevenly on Earth in different amounts. Thus, in equatorial, temperate climatic zones dominated by descending air masses, the amount of precipitation is higher than in other zones [19, 20].

Climate change on Earth is already an accepted ecological crisis. The rapid expansion of its "warming" characteristics over the past 35 years is already an inevitable fact. Global warming is characterized by its different characteristics in different regions of the Earth [11, 13]. The increase in air temperature, possible evaporation indicators, the recurrence of dangerous atmospheric phenomena, the decrease in the volume of glacier areas, river flows and the amount of atmospheric precipitation are the effects of climate change in the territory of Azerbaijan [12, 13].

Analysis of recent research. The scientific explanation of the time-space distribution of atmospheric precipitation in the country was first reflected in the monograph of A.M. Shikhlinsky and A.A. Madatzade (1968). However, in subsequent periods, the number of such studies increased. In recent times, the study of various characteristics of precipitation in different regions has been reflected in the studies of scientists such as N.Sh. Huseynov, F.A. Imanov, S.H. Safarov, R.N. Mahmudov, A.S. Mammadov, K.S. Rahimov, H.S. Nabiyev, J.S. Huseynov and others. In these studies, the monthly, seasonal, zonal distribution characteristics of precipitation, multi-year dynamics, amount of precipitation at various limits, etc. in the territory of the republic have been investigated [4, 13, 19].

Highlighting previously unsolved parts. Recent global warming has significantly influenced changes in various climatic elements. In this context, a reduction in precipitation amounts has been observed. Previous studies on the impacts of climate change on precipitation patterns across the country concluded by analyzing long-term precipitation dynamics and quantifying monthly variability through percentage deviations. Earlier research provided only generalized comparative analyses for Azerbaijan, contrasting the periods 1961-1990 and 1991-2020. However, comprehensive studies to characterize the contemporary precipitation regime–both for Azerbaijan as a whole and specifically for the Azerbaijani sector of the Greater Caucasus-have been lacking since 1968 [6, 8, 12, 13].

Formulation of the purpose. The aim of the study is to determine the modern characteristics of the temporal and spatial distribution of atmospheric precipitation in the southern and southeastern parts of the Greater Caucasus province.

This study incorporates the latest observational data and employs statistical refinements to elucidate the modern spatiotemporal distribution patterns of precipitation across the southern and southeastern slopes of the Greater Caucasus mountain range within Azerbaijan. The specific mechanisms governing precipitation formation in this region have been analyzed in detail. The impacts of climate change on the precipitation regime were investigated using multiple methodologies [11, 15, 21], thereby enhancing the statistical reliability of the findings.

Research methods. The study was conducted on the basis of observation data on atmospheric precipitation from 9 hydrometeorological stations of the National Hydrometeorological Service operating in the southern and southeastern part of the Greater Caucasus province (Zagatala, Oghuz, Sheki, Ismayilli, Shamakhi, Gabala, Gobustan, Saribash and Alibay) in 1961-2023. Initial data were collected from periodic statistical and scientific publications of state agencies, internet resources and research data of individual scientists [7, 14, 25-28]. The analyses were conducted on monthly, seasonal and annual total precipitation indicators. Taking into account the possibility of recurrence of maximum and minimum monthly indicators of atmospheric precipitation, the study analyzed the period 1961-2023, and the modern spatial-temporal distributions were analyzed for the period 1991-2023.

This period is a time phase in which atmospheric precipitation fluctuates sharply due to the influence of climate change. In order to assess the effects of climate change in recent periods, comparisons were made with the latest climate norm of the World Meteorological Organization (1981-2010) [23, 24]. In addition, in order to accurately determine the changes in the tendency of atmospheric precipitation in the multi-year period, the long-term (1961-2023) period was also considered as 10-year time phases. Based on the results obtained in the analyses, histograms, graphs and tables were processed in the MS Excel program, and maps were processed in the ArcGIS program. Various parameters of hydrometeorological stations are given in Table 1.

In the graphs constructed to monitor the multi-year dynamics of precipitation, unstable jumps in individual years can be seen. To determine the tendency of these indicators in the general period, a trend curve is used.

However, although the trend line shows the tendency in the general period, the dynamics in small time phases can only be determined by the moving average quantity.

The parameter provides smoothing of the graph of random variables with such jumps, which allows the researcher to determine the direction of the trend of the random variable in separate periods [15, 23]. This quantity is calculated as follows:

Table 1

The main characteristics of the hydrometeorological stations

Station	Height, m	Observation periods, year	Climate norm: Precipitation quantity (1981-2010), mm
Alibey	1786	1961-2020	1326
Saribash	1680	2008-2023	-
Gobustan	775	1961-2023	331
Shamakhi	750	1961-2023	576
Gabala	679	1961-2023	941
Ismayilli	653	1983-2023	639
Sheki	639	1961-2023	786
Oghuz	582	1961-2023	889
Zagatala	487	1961-2023	977

$$X_{1i} = \frac{X_1+X_2+X_3...+X_{10}}{10}, X_{2i}...$$

where, X_{1i} - is the moving quantity of the annual precipitation amount of the random quantity. X_1, X_2 etc. are the series limits for the year under consideration and the last 10 years in which it is included. The coefficient of the moving quantity in the cell under consideration is equal to the average of the next 10 years in which it is included in that year. The next limit of the moving quantity is again the average of the precipitation in that year and the next 9-year limit. Thus, the series is completed.

The main material. The time-spatial distribution of precipitation in the southern and southeastern parts of the Greater Caucasus province varies depending on the geographical location and relief features of the area. The region has a mountainous relief. Most of the territory is located at an altitude of 1000 m above sea level. The study area covers the southern and southeastern foothills of the Greater Caucasus Range. The region is bounded by the Ganikh-Ayrichay depression in the northwest and south, and by the Kura depression in the southeast. The Greater Caucasus Range begins with the Gubakh range and changes in altitude above sea level in the southeast, ending with the Garabagh, Langebiz ranges, and the Alat ridge. The main elevations in the area are the peaks of Malkemud (3878 m), Ragdan (4020 m), Tufandagh (4191 m), Bazarduzu (4466 m), etc. [3, 16].

The greatest influence on the distribution of precipitation in the area is exerted by the relief. The main atmospheric precipitation is formed due to air masses coming from the north. The fact that precipitation falls in the warm period of the year creates a great advantage in providing the mountainous region with water resources [1, 2, 10].

According to multi-year (1991-2023) data, the average multi-year amount of precipitation in the southern and southeastern part of the Greater Caucasus province is 816 mm. The amount of precipitation varies between 307-1290 mm at individual stations. The highest average annual precipitation falls in Alibay (1290 mm), the least in Gobustan (307 mm). The amount of precipitation in this part of the Greater Caucasus province decreases from northwest to southeast, from the plain to the high mountains. Thus, the multi-year amount of precipitation is observed at the Zagatala station located in the plain area of 950 mm, at Alibay 1290 mm and in Gobustan in the east 307 mm. Here, the main part of the precipitation falls in spring, summer and autumn, and a smaller part in winter [6, 15]. In general, 56% of the annual precipitation in the region falls during the warm season and 44% during the cold season (Table 2).

Table 2

Temporal distribution of atmospheric precipitation in the south and southeast of the Greater Caucasus province

Station	Year-round, mm					Seasonal, %	
	winter	spring	summer	autumn	year	cold	hot
Alibey	134	397	397	362	1290	38	62
Saribash	133	361	354	259	1108	35	65
Gobustan	62	95	61	88	307	49	51
Shamakhi	111	163	96	169	539	52	48
Gabala	144	297	194	280	915	46	54
Ismayilli	109	199	131	200	639	48	52
Sheki	108	241	202	198	748	41	59
Oghuz	135	278	181	253	847	46	54
Zagatala	117	314	272	247	950	38	62
Region	**117**	**261**	**210**	**228**	**816**	**44**	**56**

The monthly distribution of atmospheric precipitation in the southern and southeastern part of the Greater Caucasus province for 1991-2023 is given in Table 3. As can be seen from the table, the least rainy period in the region falls on the winter months. Thus, the amount of precipitation is 36 mm in December, 38 mm in January, and 43 mm in February. Starting from March, there is an increase in the amount of precipitation. The amount of precipitation reaches 67 mm in spring, that is, in March, and 81 mm in April. The amount of precipitation reaches its annual maximum in May (112 mm). Starting from June, the process of decreasing precipitation begins with an increase in temperature. In June, this amount decreases to 88 mm, in July to 65 mm, and in August to 57 mm. In autumn, the decrease in temperature activates the activity of convective processes in the region [2]. Thus, the amount of precipitation is 89 mm in September, 82 mm in October, and 58 mm in November. Overall, the average annual precipitation in the region is 816 mm.

The distribution of maximum monthly precipitation values in the southern and southeastern parts of the Greater Caucasus province is similar to their average monthly values. The maximum value of multi-year precipitation for the region is 2128 mm. If we focus on individual months, the maximum monthly precipitation is 157 mm in January, 172 mm in February, and 183 mm in March. This indicator increases to 257 mm in April, 344 mm in May, and 501 mm in June. The highest maximum monthly precipitation values are observed in June. From mid-summer, certain decreases occur in the maximum monthly precipitation values. This indicator decreases to 291 mm in July and 367 mm in August. Although the maximum monthly precipitation increases in September (408 mm), it decreases to 333 mm in October and 248 mm in November. The maximum monthly precipitation reaches its lowest value in December and amounts to 146 mm. If we look at the data of individual hydrometeorological stations in this area, the most abundant annual precipitation fell in Sarıbash, amounting to 2128 mm. In the research, the surface distribution of atmospheric precipitation in the south and southeast of the Greater Caucasus province was determined with of GIS technology (Figure 1).

Table 3

Distribution of average monthly (1991-2023) and maximum monthly (1961-2023) precipitation in the south and southeast of the Greater Caucasus province

Station		Months												İl
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average	Alibey	46	49	88	135	174	170	113	114	150	128	83	39	1290
	Saribash	48	44	90	108	164	144	117	93	116	93	51	40	1108
	Gobustan	19	24	31	29	36	26	23	12	32	31	25	20	307
	Shamakhi	34	43	44	51	68	44	28	25	57	63	49	34	539
	Gabala	47	56	79	90	129	84	58	52	99	109	73	42	915
	Ismayilli	32	42	52	56	90	62	40	29	73	72	54	34	639
	Sheki	36	40	64	78	99	86	59	57	76	67	55	32	748
	Oghuz	43	50	78	84	116	72	59	49	93	96	64	42	847
	Zagatala	36	43	76	102	137	109	84	80	103	79	64	38	950
Region		**38**	**43**	**67**	**81**	**112**	**88**	**65**	**57**	**89**	**82**	**58**	**36**	**816**
Maximum	Alibey	126	126	183	237	344	348	291	367	345	329	248	91	1960
	Saribash	120	172	164	170	273	501	286	261	408	167	143	96	2128
	Gobustan	52	75	126	97	171	129	159	53	160	106	93	77	664
	Shamakhi	117	115	131	194	181	135	172	124	229	223	116	91	1099
	Gabala	157	157	178	257	319	242	286	219	265	333	152	111	1514
	Ismayilli	64	91	142	164	233	229	153	137	212	206	145	85	876
	Sheki	101	87	158	195	254	268	145	264	201	212	157	78	1093
	Oghuz	117	103	182	231	318	282	286	219	266	270	129	111	1561
	Zagatala	123	108	171	255	306	264	272	297	268	213	160	146	1409
Region		**157**	**172**	**183**	**257**	**344**	**501**	**291**	**367**	**408**	**333**	**248**	**146**	**2128**

There is a variation in the vertical zonality distribution of precipitation due to the mountainous terrain of the area. If we pay attention to the map, the amount of precipitation over the area falls more in the moderately mountainous area. In the southeast of the region, towards the border of Gobustan-Absheron, the amount of precipitation falls less than 600 mm. Here, less precipitation is observed in the plain, frontal mountainous and low mountainous areas in terms of vertical zonality. This amount varies around 600-1000 mm. However, although the indicator is higher than 1400 mm towards the lower parts of the

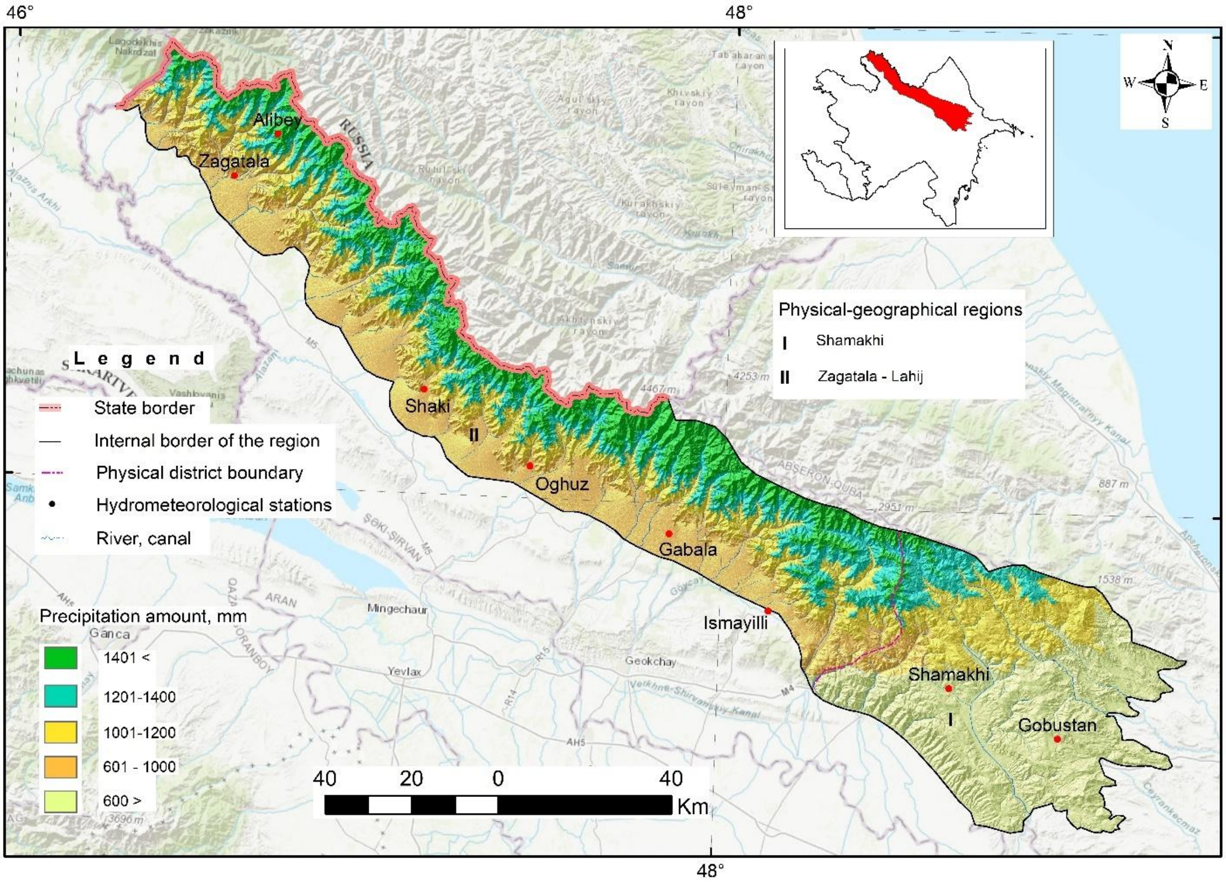

Fig. 1. Average annual precipitation (1991-2023)

high mountainous region, it begins to decrease again at higher altitudes. There are two maxima of precipitation in terms of vertical zonality. However, the lack of visual observation data and the small size of the map do not allow us to express this change. The altitude decreases towards the east of the Greater Caucasus Mountains, and the amount of precipitation continues to decrease as the relief smoothes towards the Absheron Peninsula. The decrease in the average annual amount of precipitation begins from Shamakhi. Because, synoptic processes affecting the Absheron Peninsula have an impact up to this region. Towards the east, the influence of this type of climate conditions increases and the amount of precipitation decreases [3, 16].

The study also paid attention to the changes in the amount of precipitation in the southern slope of the Greater Caucasus Mountains in 2011-2023 compared to 1981-2010. As can be seen from Table 4, the amount of precipitation in the southern and southeastern part of the Greater Caucasus province increased by 3-29% in January at other stations, except for Shamakhi (4%). In February, this indicator increased by 9-16% in Gobustan and Shamakhi, but decreased by 1-28% in other stations. In March, the amount of precipitation decreased by 5-11% in Gobustan and Shamakhi, and increased by 5-19% in other stations. Although there was a slight (1%) positive fluctuation in Zagatala in April, the amount of precipitation at other stations decreased by 2-33% compared to the climate norm. Although this indicator decreased by 3% in Shamakhi in May, it increased by around 3-25% at the remaining stations. Compared to the climate norm, the amount of precipitation at all regional stations in 2011-2023 decreased by 5-35% in June, 4-30% in July, and 5-42% in August. Although these indicators increased by around 1-14% in Gobustan, Ismayilli, Shaki, and Zagatala in September, they decreased by 3-12% at other stations. Although precipitation in October decreased by around 4-17% in Shamakhi, Gabala, Shaki, and Oghuz compared to the climate norm, they increased by 3-18% at other stations. Although precipitation in November decreased by 1-30% in Alibay, Shamakhi, Shaki, Oghuz and Zagatala, it increased by 3-34% in other stations of the region. Compared to the norm, the amount of precipitation in 2011-2023 increased by 34% in Gobustan in December, but decreased by 1-26% in all stations. If we pay attention to the table, precipitation fluctuates chaotically in the autumn months. Thus, although this indicator increases in several stations, it decreases in other stations. Such a process reduces the severity of fluctuations in the total precipitation of the region. This is due to the synoptic situation. Because in autumn, air masses coming from the north to the southeast of the region and

Table 4

Average monthly and average annual precipitation anomalies (mm, **%-bold**)

Station	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Alibey	12	-16	7	-3	8	-9	-39	-58	-16	4	-1	-9	-120
	29	**-28**	**9**	**-2**	**5**	**-5**	**-30**	**-42**	**-11**	**3**	**-1**	**-21**	**-9**
Gobustan	5	4	-4	-9	4	-11	-4	-6	4	6	8	6	4
	25	**16**	**-11**	**-25**	**11**	**-35**	**-15**	**-36**	**14**	**18**	**34**	**34**	**1**
Shamakhi	-1	4	-2	-21	-2	-3	-2	-5	-7	-12	-5	-2	-57
	-4	**9**	**-5**	**-33**	**-3**	**-6**	**-8**	**-18**	**-12**	**-17**	**-9**	**-6**	**-10**
Gabala	2	-3	13	-27	8	-7	-20	-16	-3	-4	2	-0.3	-57
	3	**-5**	**19**	**-27**	**6**	**-9**	**-28**	**-25**	**-3**	**-4**	**3**	**-1**	**-6**
Ismayilli	3	-0.4	6	-22	19	-8	-2	-2	1	3	2	-2	-2
	9	**-1**	**11**	**-32**	**25**	**-13**	**-4**	**-5**	**1**	**4**	**3**	**-5**	**-0.3**
Shaki	7	-7	10	-20	3	-21	-10	-11	8	-12	-14	-2	-69
	23	**-15**	**16**	**-24**	**3**	**-23**	**-16**	**-17**	**13**	**-15**	**-23**	**-6**	**-9**
Oghuz	3	-4	4	-18	8	-21	-12	-7	-7	-8	-5	-1	-69
	7	**-8**	**5**	**-20**	**7**	**-26**	**-17**	**-11**	**-8**	**-7**	**-8**	**-3**	**-8**
Zagatala	8	-10	7	1	6	-20	-10	-19	11	10	-22	-10	-48
	24	**-20**	**9**	**1**	**5**	**-17**	**-12**	**-20**	**12**	**12**	**-30**	**-26**	**-5**
Province	5	-4	5	-15	7	-13	-12	-15	-1	-2	-4	-3	-52
	13	**-9**	**8**	**-18**	**7**	**-15**	**-19**	**-25**	**-1**	**-2**	**-7**	**-7**	**-6**

local air circulation cause a different distribution of precipitation [28].

The average annual precipitation fluctuations in the southern and southeastern parts of the Greater Caucasus province show that although there was a 1% increase in Gobustan, the precipitation of other stations decreased by up to 10% compared to the climatic norm. The maximum decrease in the average annual precipitation compared to the climatic norm occurred in Shamakhi by 10% (57 mm), in Shaki by 9% (69 mm), in Oghuz by 8% (69 mm) and in Alibay by 9% (120 mm). As a result, the average annual precipitation in the study area in 2011-2023 was determined to decrease by 52 mm or 6% compared to the norm (1981-2010). In this region, precipitation levels decreased by 7.7% (67 mm) during the 1991-2023 period (866 mm) compared to the 1961-1990 baseline (799 mm).

The decrease in precipitation in the region leads to a decrease in the freshwater reserves and the water content of the territorial rivers in the area. We know that this mountainous zone plays a major role in providing freshwater to the neighboring plains in the south and the Absheron Peninsula (Oghuz-Gabala-Baku water pipeline). Rapid forest loss is already being observed in the basins of the moderately mountainous parts of the rivers. The decrease in precipitation in the summer months coincides with the vegetation period when plants have the greatest need for water.

A graph of monthly changes in precipitation in 2011-2023 compared to 1981-2010 has been compiled for the southern and southeastern parts of the Greater Caucasus province (Figure 2). As can be seen from the graph, the largest decrease, 15 mm, falls on April (18%) and August (25%). The decrease in precipitation in February is 4 mm (9%), in summer it is 12-15 mm (15-25%), in autumn it is 1-4 mm (1-7%). The recent increase in precipitation was 5 mm (13%) in January, 5 mm (8%) in March, 7 mm (7%) in May. In September, the fluctuation indicators are very weak.

In order to monitor the long-term dynamics of the annual amount of atmospheric precipitation in the southern and southeastern part of the Greater Caucasus province, a graph has been drawn up. On the other hand, the trend line, the moving average value has also been added to the graph.

When examining the moving average, it can be observed that precipitation was higher compared to the climatic norm during the periods 1971-1990 and in the year 2010. However, during the periods 1991-2008 and 2011-2023, the amount of precipitation in this region was lower than the norm (1981-2010). The most significant decreasing trend over the long term occurred during the years 2018-2021 (Figure 3). During the period 1961-2023, the years 1961, 1971, 1985, 1995, 1996, 2001, 2013, 2014, 2017 and 2019 were the 10 years with the least precipitation, and the years 1963, 1972, 1981-1983, 1994, 1997, 2003, 2016 and 2018 were the 10 years with the most precipitation. 70% of the years with abundant precipitation in the study area were observed in the period before 1997. 70% of the years with less precipitation were observed in 1985 and after. These facts ground that precipitation in the region has been rapidly decreasing in recent times. The decrease in precipitation occurs due to increasing in regional temperature.

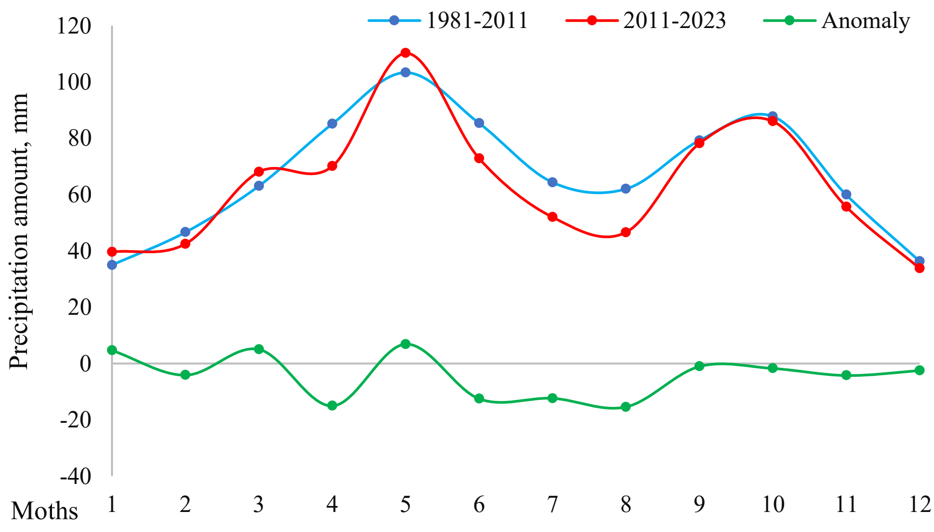

Fig. 2. Fluctuations in monthly precipitation amounts in the southern and southeastern parts of the Greater Caucasus region

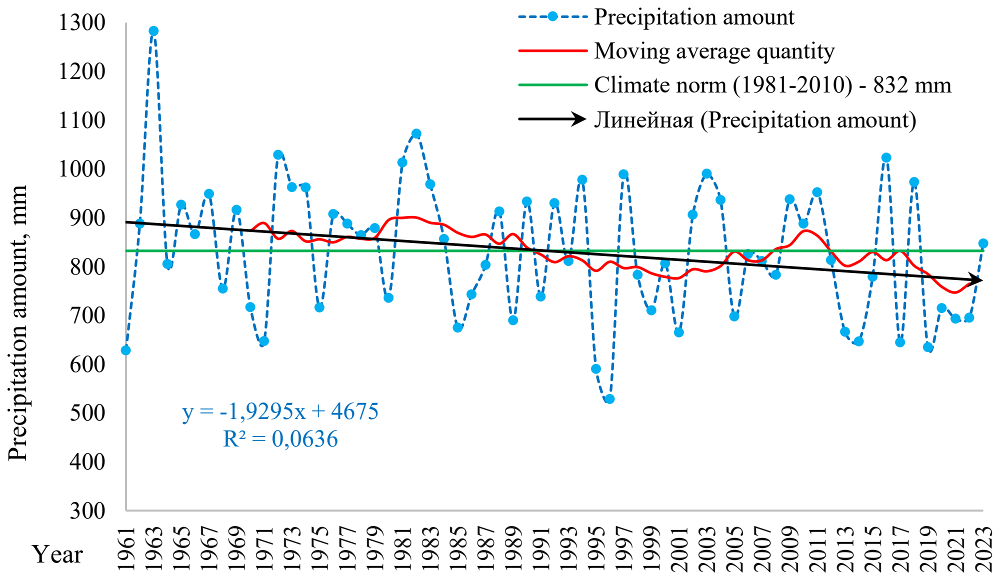

Fig. 3. Multiannual dynamics of precipitation in the southern and southeastern of the Greater Caucasus province

In order to determine the multi-year dynamics of precipitation in the southern and southeastern part of the Greater Caucasus province, a difference integral curve was constructed based on the data of hydrometeorological stations (Figure 4). From figure 4, it is obvious that the tendency for the Oghuz, Zagatala, Gabala, Shaki and Ismailli stations in the period from 1961 to 2023 are approximately the same. Thus, the amount of precipitation increased at the listed 5 stations from 1961 to 1983 (in Sheki from 1984), gradually decreased from 1984 to 1994, and sharply decreased from 1995 to 2023, excluding occasional deviations. The dynamics of the difference integral of atmospheric precipitation at the Alibay station is similar to the multi-year changes of other stations. Only, although there was a significant increase in the amount of precipitation here in 2001-2012, the decrease from 2013 continues until the end of the period. At the Gobustan and Shamakhi stations, which differ from other stations, there was an increase in the amount of precipitation from 1961 to 1990. Although there was no noticeable change at these stations for several years, from 1994, precipitation at the Gobustan station decreased towards 2023. However, the decrease in the amount of precipitation in Shamakhi continued until 2008, there was a short-term increase between 2009-2013, and then decreased until the end of the period. The existence of such differences at the Gobustan and Shamakhi stations can be explained by the different physical and geographical position of these areas compared to other stations, and variable synoptic and albedo conditions.

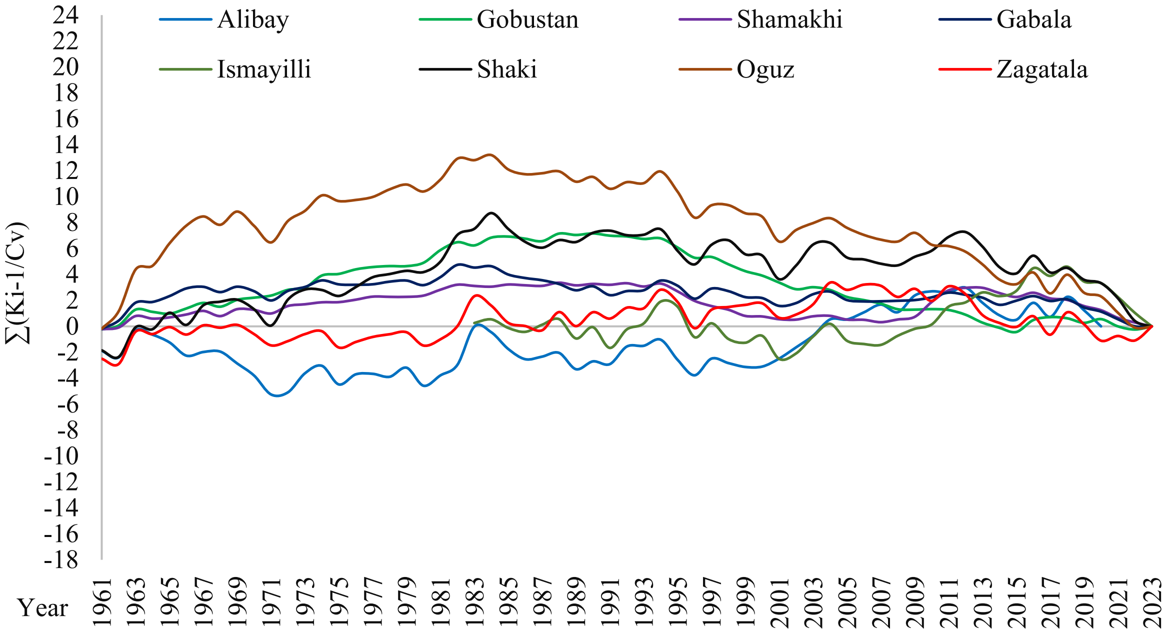

Fig. 4. Difference integral curve of precipitation in 1961-2023

Various climate models predict an increase in maximum precipitation expected towards the end of this century due to climate change. Currently, determining the impact of climate change on the maximum precipitation that occurs annually in individual regions is of particular importance for the early prediction of hazardous natural phenomena [5, 19].

The absolute maximum values of precipitation in the southern and southeastern parts of the Greater Caucasus province for the period 1961-2020 have been determined (Figure 5). From figure it is obvious that the multi-year maximum precipitation in the region fell by 107 mm in 1997. There are sharp fluctuations in precipitation at certain time phases in the long-term period. Thus, it is noteworthy that maximum precipitation occurs more frequently in 1962-1967, 1992-1997, 2004-2007, 2013-2015, 2019 and 2020. The trend line shows that the maximum annual precipitation in this area has increased. Given that the maximum amount falls more often in torrential rains, it follows that there has also been an increase in the frequency of this type of precipitation in recent times. The moving average graph shows a decrease in precipitation in 1961-1968 and 1992-1999.

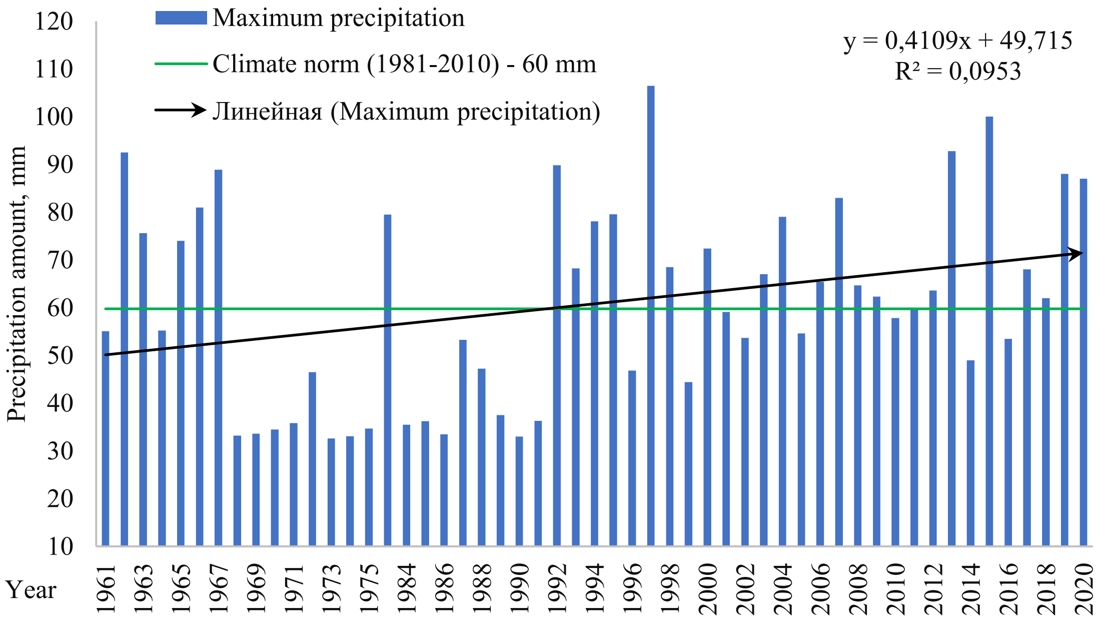

Fig. 5. Annual absolute maximum precipitation in the southern and southeastern of the Greater Caucasus province

However, it has a positive indicators in 1969-1992 and 2000-2020. If we pay attention to the graph, although the maximum precipitation was subject to sharp changes until 1992, there are more chaotic changes in 1993-2020. This is also due to a similar feature of modern warming.

The average 10-year indicators of the amount of multi-year maximum precipitation were compared with the climate norm (1981-2010). Compared with the norm, the absolute maximum precipitation amount fell more than the norm in 1961-1970 (4%), 1991-2000 (9%), 2001-2010 (8%) and 2011-2020 (21%). Maximum precipitation fell less than the climate norm in 1971-1980 (27%) and 1981-1990 (34%). In 1971-1990, annual maximum precipitation was less recurrenced than in other periods. This is one of the dangerous effects of climate change. Thus, in addition to the decrease in the amount of precipitation in the considered area, its annual distribution period is shortened.

The overall annual recurrence of precipitation amounts is shown in the histogram below (Figure 6). We can also see from the histogram that the lowest recurrence limits of precipitation are 6% for the region and are observed in the ranges of 61-70 mm, 71-80 mm and 101-120 mm.

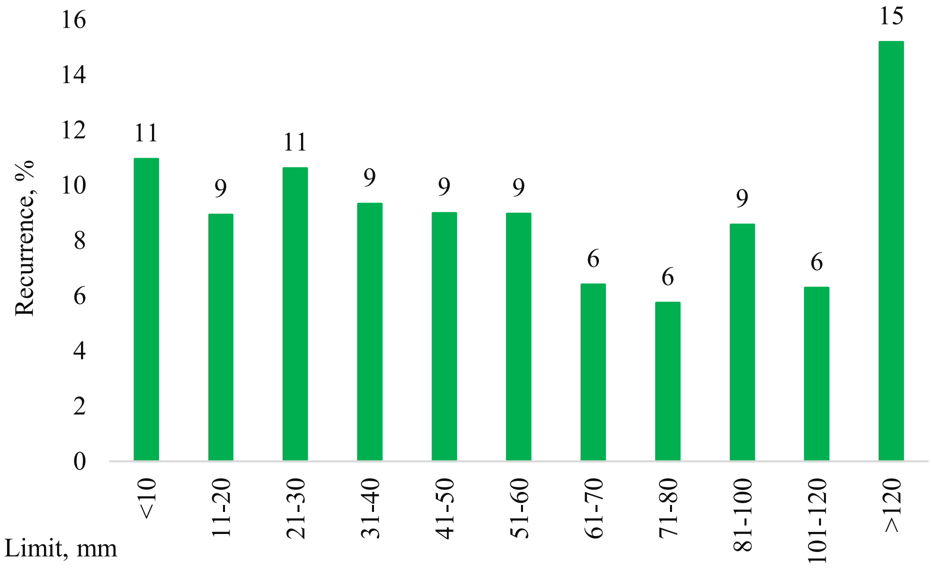

Fig. 6. Recurrence of various annual precipitation limits in the southern and southeastern of the Greater Caucasus province (%)

The average decade precipitation indicators for continuous stations in the southern and southeastern part of the Greater Caucasus province (Alibey, Gobustan, Shamakhi, Gabala, Sheki, Oghuz, Zagatala) were compared with the corresponding indicators of the previous decade (Figure 7). Thus, although the amount of precipitation in the region was 873 mm in 1961-1970, it decreased by 1.6% in 1971-1980 compared to the previous decade, increased by 0.9% in 1981-1990, and decreased by 9.3% in 1991-2000. The amount of precipitation in the region in 2001-2010 was 7.3% more than the previous 10 years. However, the amount of precipitation here in 2011-2020 decreased by 7.0%.

Conclusions. The following results were obtained from the analysis conducted on the basis of preliminary data on atmospheric precipitation in the southern and southeastern of the Greater Caucasus province for 1961-2023:

1. The average annual value of atmospheric precipitation in the southern and southeastern of the Greater Caucasus province for 1991-2023 was 816 mm. 56% of the annual precipitation in the region fell in the warm season, and 44% in the cold season.

2. In this part of the region, the mean annual precipitation decreased by 6% (52 mm) during the 2011-2023 period compared to the 1981-2010 reference interval. The greatest decrease by months occurred in April and August, amounting to 15 mm.

3. While the region’s maximum precipitation exhibited sharp interannual fluctuations up to 1992, the period from 1993 to 2020 was characterized by increased chaotic variability. This trend aligns with the analogous features observed in contemporary warming patterns.

4. The region is dominated by the recurrence of heavy precipitation, exceeding 120 mm, with an annual recurrence rate of about 15%. The most frequent occurrences of II and III in the region are less than 10 mm and 21-30 mm, which accounts for 11% of the region's occurrence.

The southern and southeastern parts of the Greater Caucasus province are the areas where the country's main river systems are formed. These rivers meet the agricultural and drinking water needs of not only this area, but also neighboring regions. The de-

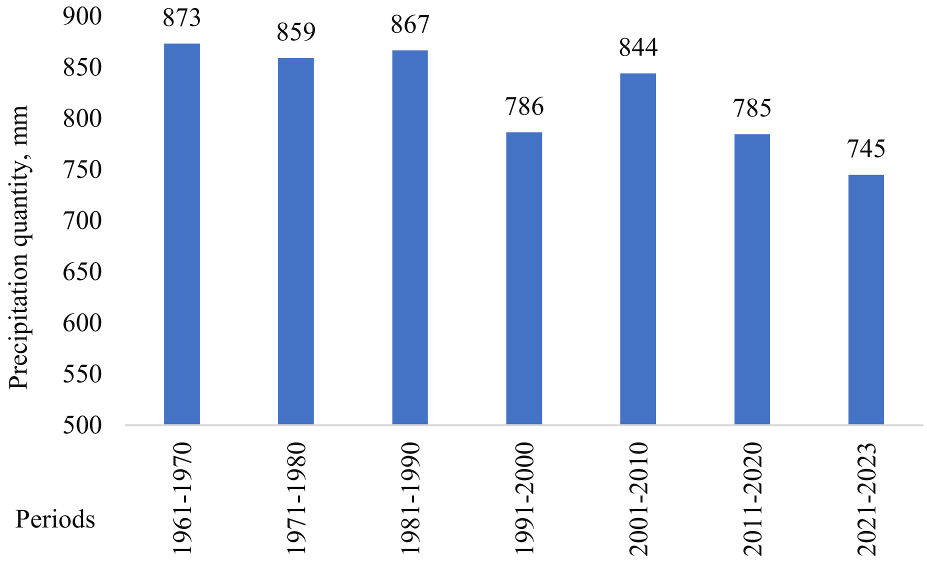

Fig. 7. Dynamics of precipitation over decades in the southern and southeastern of the Greater Caucasus province

crease in precipitation due to climate change leads to a decrease in the water content of rivers. If this process continues, serious difficulties may arise. It is true that this area receives sufficient precipitation throughout the year (with the exception of Gobustan and Shamakhi), but the decrease in precipitation in the summer months, especially when plants enter the vegetation period, reduces productivity. Therefore, it is important to carry out proper irrigation measures. It is necessary to build reservoirs to meet the water needs of the economy and people (especially neighboring areas). In addition, in order to prevent water loss, the channels and surfaces of the canals should be closed with a special cover. In agriculture, it is important to plant drought-resistant plants and also to conduct irrigation using new modern intensive methods (drip, spraying) rather than traditional ones.

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Характеристика сучасного просторово-часового розподілу атмосферних опадів у південній та південно-східній частинах регіону Великого Кавказу

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Наразі глобальне потепління, що спостерігається на Землі, проявляє свої наслідки на Південному Кавказі, як і в усіх інших регіонах. Зі зростанням температури повітря низка кліматичних елементів змінює свої довгострокові закономірності. Проаналізовано сучасні просторово-часові зміни атмосферних опадів у південній та південно-східній частинах регіону Великого Кавказу. Дослідження проводилося з метою визначення впливу зміни клімату на просторово-часовий розподіл атмосферних опадів у південній та південно-східній частинах регіону Великого Кавказу. В аналізі використовувалися дані спостережень за атмосферними опадами, зібрані з гідрометеорологічних станцій Закатала, Огуз, Шеки, Ісмаїлли, Шамахи, Габала, Гобустан, Сарібаш та Алібай за період з 1961 по 2023 рік. Дослідження проводилося з використанням сучасних математико-статистичних, фізичних, картографічних методів та ГІС-технологій. У дослідженні розглянуто екстремальні випадки атмосферних опадів з 1961 по 2023 рік, а також сучасні просторово-часові характеристики розподілу (місячні, сезонні, річні та поверхневі) за період з 1991 по 2023 рік. Під час аналізу було визначено, що середня багаторічна кількість атмосферних опадів у південній та південно-східній час тинах регіону Великого Кавказу становить 816 мм. Із загальної річної кількості опадів у регіоні 56% припадає на теплий період, а 44% – на холодний. Загалом у цій частині регіону кількість опадів зменшується від більших висот до низин та з північного заходу на південний схід. У досліджуваній зоні зменшення кількості опадів спостерігається в усі місяці, крім січня, березня та травня. Зменшення кількості опадів у весняні та літні місяці особливо негативно впливає на розвиток сільськогосподарських культур, оскільки збігається з їх вегетаційним періодом. Опади в регіоні переважно мають повторюваність 120 мм і вище. Результати дослідження можуть бути використані для створення нових сільськогосподарських угідь, складання карт, економічних оцінок та розробки заходів щодо пом'якшення наслідків зміни клімату.

Ключові слова: *зміна клімату, атмосферні опади, ГІС-технологія, межа повторюваності опадів, різницевий інтеграл, ковзна середня величина, аномалія опадів.*

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