https://doi.org/10.26565/2410-7360-2024-61-23
UDC 551.509.324
Received 14 October 2024
Accepted 21 November 2024

Current situation of glacier and snow glades in the southern mountain area of Lesser Caucasus province

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ABSTRACT

Problem definition. The rise in air temperature due to the impact of global warming causes the melting of glaciers in mountainous regions and accelerates freshwater scarcity in lowland areas. This process gradually reduces the annual duration of ice and snow cover in the Lesser Caucasus Mountains. The reduction in the area of ice and snowfields, along with the decline in precipitation, leads to an expansion of desertification and deforestation in lowland and foothill regions.

Formulation of the purpose. The research was conducted to determine the current state of perennial snowfields and glacier reserves located on the Karabakh volcanic plateau, Mixtoken, and Saribulag ridges, considered part of the southern mountainous region of the Lesser Caucasus.

Research methods. For this purpose, satellite imagery interpretation was conducted, utilizing the data archives of satellites such as Azersky, Landsat, Sentinel-1, and others. Analyses were carried out on the raster files obtained after decoding the satellite images, employing various measurement and processing methods. The study also addressed the region's physical geographical position and climatic conditions, examining the long-term variations in air temperature and precipitation levels. The analyses were conducted using observational data (air temperature and atmospheric precipitation) covering the years 1961–2023. Mathematical-statistical and cartographic methods were employed in the study. The interpretation of satellite images, their analysis based on various indices, and the mapping of data were carried out using GIS technology.

The main material. In comparison with the period 1981–2010, the average monthly temperature in this part of the Lesser Caucasus region increased by 0.9-1.4°C in January (0.9°C), May (1.4°C), and June (0.9°C) during 2011-2022, while it decreased by 0.5°C in February and 0.7°C in November. Between 2011–2015, the average annual precipitation in the region decreased by 1%, or approximately 7 mm, compared to the overall period. The results indicate that, depending on air temperature, the extent of snowfields in this region does not exceed 6.0 km². Firn ice in the region is distributed at elevations of approximately 3100–3300 meters. These glaciers are located on the eastern slope of the Gizilbogaz Heights, accumulating on rocky surfaces exposed on sloping terrain. The total area of firn ice, which is situated in small clusters, is 0.148 km², comprising five glacier clusters of varying sizes. Two of these are large, covering an area of 0.14 km², while the remaining three smaller glaciers have a combined area of approximately 0.005 km² (8.67 hectares).

Conclusions. The area of snowfields decreases during warm years as air temperature rises. In this mountainous region, the long-term average increase in air temperature has been 0.2°C. In other months, temperature fluctuations remained within climatic norms. The reduction in the period during which precipitation falls in solid form due to the effects of climate change prevents the formation of new glaciers and snowfields. In periods with higher average annual temperature, the process of glacier melting accelerates.

Keywords*: Mikhtokan Mountain range, climate change, climate norm, glacier, firn, snow glades, GIS technology, amount of precipitation, temperature anomaly, tendency.*

In cites: Huseynov Jamal, Tagiyev Allahverdi. (2024). Current situation of glacier and snow glades in the southern mountain area of Lesser Caucasus province. Visnyk of V. N. Karazin Kharkiv National University, series "Geology. Geography. Ecology", (61), 288-302. https://doi.org/10.26565/2410-7360-2024-61-23

Problem definition. The ice masses in the world's most remote and harsh regions are formed not only by the remains of ancient ice ages but also by ongoing active processes in nature [1, 2, 18]. As the glaciers expand, they begin to slide with increasing mass, slowly moving down valleys and into plains, as a result, the rocks are subjected to exaration processes, forming a cirque and glaciated valley. That is, after the ice mass reaches a critical thickness, it begins to move under the influence of gravity. As glaciers move, they erode the underlying rocks, transporting them over long distances and accumulating them [15, 18].

The initial stage of glacier formation begins with the accumulation of snow. This process occurs when annual snow exceeds seasonal ablation (melting and sublimation). Glaciation is usually concentrated in accumulation zones, areas of glaciers where snowfall exceeds melting losses [1, 22]. As snow accumulates, the pressure of the load from successive layers of snow causes compaction. This process reduces the porosity inside the snow [20, 23]. Compaction causes the air trapped inside the snow to be expelled. Compacting snow becomes a granular and more densely packed "firn", representing an intermediate stage between snow and ice. Firn usually has a density varying between 400-830 kg/m³, depending on the period of formation and local conditions. Accumulation of snow, melt, avalanche and other materials on the firn results in its continuous burial and strong compaction [15, 21]. When the density exceeds about 830 kg/m³, the firn becomes glacial ice. At this stage, recrystallisation processes dominate, and small ice crystals grow at the expense of smaller crystals. The transition from firn to ice is also accelerated by the melting and refreezing of ice in the pore spaces. Thus, the melting of ice reduces the volume of air spaces and increases its density. As a result of this, the emerging glacier is characterized by an ice crystal structure. Glacier refers to the annual layers formed by the accumulation of layers of snow over time, the firn stage and the dense ice sheets formed at the end. These layers can be identified by changes in crystal size, impurity (dust, debris, etc.) content and isotopic composition. The stratigraphy of a glacier provides valuable information about past climatic conditions and the dynamics of the glacier over time [15, 19].

Analysis of recent research. About 69 % of the world's freshwater is frozen in glaciers. In many regions, glaciers provide a steady supply of meltwater to both human communities and the rivers and lakes that feed the settlements. However, glaciers are also sensitive indicators of climate change. As global temperatures rise, many glaciers around the world are retreating at an alarming rate, leading to concerns about rising sea levels and loss of freshwater supplies [6, 13, 20].

By studying the glaciers that existed in the Greater Caucasus mountains in different periods, researchers such as G.V. Abikh, K.I. Bogdanovich, P.J. Bolarovich, A.V. Pastukhov, L.N. Leontyev, B.A. Budagov, R.A. Ismayilov, V.F. Yahyayev and others made various calculations [1].

Highlighting previously unsolved parts. However, the global warming observed in recent times is expanding its influence, causing rapid melting of glaciers and shrinking of water resources. Therefore, the discovery of the current state of glaciers and snowdrifts in other regions of the country is considered one of the most urgent issues for the scientific community today.

Formulation of the purpose. Studying the current state of the ice and snow glades located in the southern mountainous part of the Lesser Caucasus province is the primary goal of the research. Based on observational data from 1961-2022, against the background of changes in air temperature and atmospheric precipitation, it has been tried to determine the modern condition and distribution characteristics of perennial ice and snow glade in the area where the Karabakh volcanic plateau, Saribulagh and Mikhtokan ridges meet and where the highest peaks of the region are located.

Research methods. The research is based on the observation of air temperature and atmospheric precipitation in the Istisu, Shusha, Lachin, Khankendi, Asgaran and Aghdara hydrometeorological stations of the National Hydrometeorological Service located in the southern part of the Lesser Caucasus province from 1961-1990, and expanded data with statistical methods from 1991-2015. The annual time series could only be extended by AI until 2022. The analysis of glaciers is based on expedition data, interpretation of satellite images and application of GIS technology to them.

Primary data were collected from the National Hydrometeorological Service, State Statistics Committee, satellite-reanalysis resources, and periodical scientific and statistical publications [25, 26, 27]. To determine the effects of climate change on the temperature and precipitation of this region in recent years, a comparative analysis of the relevant indicators of the years 1981-2010 and the relevant indicators of the years 2011-2015 recommended by the World Meteorological Organization (WMO) as the latest climate norm was conducted [24].

In hydrometeorology, the evaluation of the dynamics of time series in the long term was performed by various methods. The multi-year trend of annual precipitation and the graphical representation of the trend curve attached to it make it difficult to determine the multi-year tendency of this random quantity due to the high coefficient of variation in individual years.

For a more reliable determination of the multi-year trend of air temperature and atmospheric precipitation, the concept of moving average quantity is applied. Sharp deviations of random quantities consisting of long series in a small time phase (individual years) distort the trend plotted for the overall series and the accuracy becomes lower. A moving average quantity is used to smooth out those deviations and determine the tendency of the series in small time phases (3, 5, 10 years, etc.). This permits to determine the dynamics of the considered random quantity (precipitation amount) in any period with data [9]. In this study, the average moving quantity is calculated by the following formula (1) for ten years:

$$X_{1i} = \frac{X_1+X_2+X_3...+X_{10}}{10},\ X_{2i} = \frac{X_2+X_3+X_4...+X_{11}}{10},\ ... \quad (1)$$

there, X_{1i}, X_2... etc., is the decadal moving average of the time series. X_1, X_2, etc. and the annual precipitation series is the considered year and the series limits of the next 9 years (10 years in total) including that year. In other words, the further limit of the moving quantity consists of the amount of precipitation in that year and the mathematical average of the next 9 years. Thus, the rows are completed with this rule until the end. The last limit of the series is equal to the amount of precipitation for that year only. Calculating decadal average indicators for each year avoids sharp deviations on the graph and expresses the tendency of the general dynamics.

The main material. The southern mountainous part of the Lesser Caucasus province consists of the Karabakh volcanic plateau, Mikhtokan and Saribulagh ridges. In the central part of the mountainous region of Kalbajar-Lachin, Saribulaghdagh (3005 m, Saribulaghdagh), Chil-Gaya extends in the meridian direction, and Mikhtokan range (3616 m, Dalidagh) continues from west to east [11, 16]. Volcanic cones such as Boyuk Ishigli, Dalidagh, Alagollar, Garadagh, Gorus volcanic plateau and intrusive massifs, which are considered the highest relief forms of the volcanic plateau with an absolute height of 2500-3500 m, occupy a large area [11, 21]. Exaration, accumulative relief forms, cirque, trog valley, moraine ridge and closed depressions are widely developed in the highlands and plateau area. Here, the accumulative relief forms have decreased up to 2600 metres [1, 22]. This mountainous region is located in seismic dislocation, landslide, flood, avalanche, surface and erosion zones.

With the increase in altitude in the mountainous part of the area, atmospheric pressure decreases, solar radiation and effective radiation increase, and air temperature and its daily amplitude become usually small [7, 10]. In this area, the share of water vapour decreases, and the strength and direction of the wind undergoes a complex change. In the mountains, the amount of cloudiness and precipitation also changes with height. Precipitation in this area increases up to a certain height and then commences to decrease. The change of meteorological elements in the mountainous area causes the overall change of climatic conditions depending on the altitude. Therefore, from the plain areas towards the highest areas, mountain steppes are replaced by mountain forests. Summer pastures alternate with alpine and subalpine meadows in the cold climate with dry winters in most of the territory of Kalbajar and Lachin districts. In the higher parts, nival and subnival landscapes are common in the mountain-tundra climate with frosty winter and cold summer [10, 16].

The annual amount of sunshine hours is 2000-2200 hours in the parts above 3000 m with the increase in altitude. A decrease in cloudiness in high mountain areas leads to an increase in sunny hours. Sunless days decrease to a minimum in the Mikhtokan range, especially around the peak of Dalidagh, and due to the reduction of cloudiness, there is always sunshine. The total solar radiation reaches 150-152 kcal/cm^2 in the area of the volcanic plateau and the Mikhtokan ridge. The largest amounts of albedo fluctuate between 40-60% in the highlands. In the winter season, the formation of snow cover in medium and high mountain areas allows the indicators of reflected radiation to be close to 50-70%. In the summer months, albedo is characterized by low values (18-22%). On the volcanic plateau and in the territory of the Mikhtokan range, the effective radiation on the peak of Dalidagh is characterized by indicators of 46-48 kcal and less. In the annual course of the effective radiation of the surface cover in the study area, maximum amounts are recorded in summer, and minimum amounts are recorded in winter months. The annual amount of the radiation balance of the area is 22-30 kcal and lower in the parts of the volcanic plateau above 3000 m. The radiation balance is always positive in the warm season and negative in the cold season [11, 16].

The large rivers of the region, Tartar (200 km), Khachin (119 km), Hakari (113 km), etc., flow from this mountainous terrain. and their length is higher than 100 km. Among these rivers, Tartar (2650 km^2) and Hakari (2570 km^2) have the largest catchment area. The density of the river network in the Tartar River basin is 0.82 km/km^2, and 0.80 km/km^2 in Khachin. Almost all of the rivers starting from this zone belong to the group of spring-summer torrential rivers formed by melting snow. In the area of 1500-2000 m, which is considered the zone where the stream originates, the first snow falls in October-November. The maximum level of spring-summer luxuriance lasts from the end of May to the middle of June. During this period, the occurrence of snow melt, underground water and frequent incessant precipitations create the conditions to reach the maximum level of drought in the mountainous region. The mountainous terrain, high watershed ridges, high water level and high volume of flow affect it [11, 14].

Analyses indicate that January is the coldest month with an average temperature of 0.4^{0}C in the central part of the Lesser Caucasus Mountains, where Kalbajar and Lachin districts are located. In this month, the average monthly air temperature decreases from +3^{0}C to -5^{0}C from the plains (≈300-400 m) to the upper parts of the middle highlands (≈2300 m). This indicator was around 1.3^{0}C (+4 – (-4^{0}C)) in February and 5^{0}C (+9 – (-1^{0}C)) in March [8]. In the central mountainous region of the southern part of the Lesser Caucasus province, the average monthly temperature indicators commence to increase from April (9.8^{0}C), and rise to 14.5^{0}C in May and 19.2^{0}C in June. July and August are the hottest months in these regions of the province and the average monthly temperature for both months is around 22^{0}C across the province. In July and August, this indicator varies in the range of 14-27^{0}C, depending on the stations. The average monthly temperature decreases in September and October and is close to 6^{0}C in the region in November. Although the average monthly temperature in December is around 2^{0}C, this indicator drops to -3^{0}C in the upper parts of the middle highlands. The multiannual average temperature varies from 5.0 to 14.6^{0}C, depending on the stations, from the plains to 2300 m of the mid-mountain range, and is 11.1^{0}C for the region. In this area, the snow line passes through approximately 2900-3100 m. In January, February, March, April, May, October, November and December, the average monthly air temperature in the highlands is below 0^{0}C.

A trend graph of the average annual temperature in the mountainous region of Kalbajar and Lachin from 1961-2022 was developed (Figure 1). As can be seen from the graph, although the temperature indicators in the multi-year period have different fluctuations in individual years, an increase in air temperature can be seen in all stations in the general multi-year period.

There is an increase in the trend curve on the graph. In the 62-year time period of average annual total temperature indicators for these parts of the province, 1966, 1995, 1998, 1999, 2001, 2004, 2010, 2018, 2019 and 2021 are the warmest years of the series, 1964, 1967, 1969, 1972, 1973, 1974, 1976, 1982, 1984, and 2011 are 10 relatively cold years. The analysis indicates that 90% of the coldest years in the region occurred before 1984, and 90% of the warmest years occurred after 1995. This ratifies that the warming in this region has intensified since 1995.

Determining the effects of climate change,

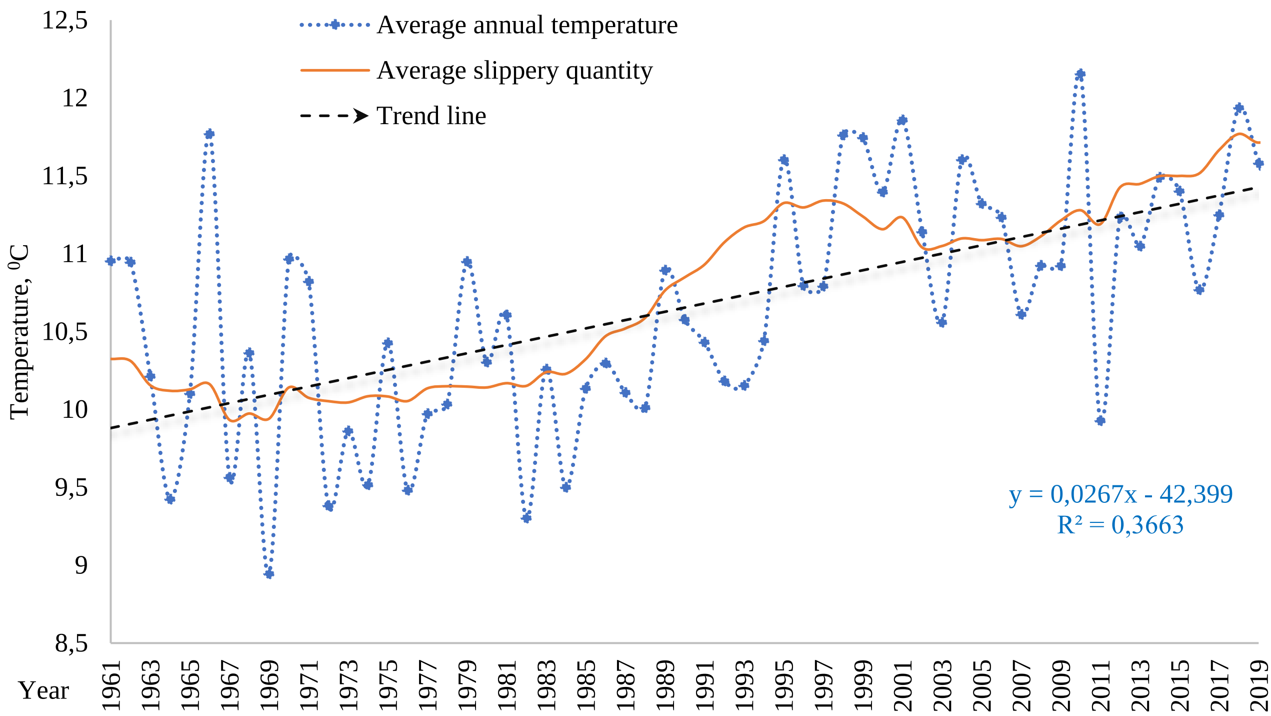

Fig. 1. Dynamics of average annual air temperature at hydrometeorological stations

which are currently showing their effects in all regions [6], on the air temperature regime in the southern mountainous part of the Lesser Caucasus province is one of the most important issues today. Analysis of statistical data unveils that from 2011-2022, the average monthly temperature indicators in these parts of the Lesser Caucasus province were 0.9-1.4^{0}C in January (0.9^{0}C), May (1.4^{0}C), June (0.9^{0}C), April (0.5^{0}C) and it increased by 0.5^{0}C in September (0.5^{0}C), decreased in February (0.5^{0}C) and November (0.7^{0}C), and fluctuated within the climatic norm in other months. The multi-year average increase in air temperature in this mountainous region was 0.2^{0}C. The increase in air temperature is at its highest in January, May and June. In February and November, compared to the norm, lower fluctuations were recorded (Figure 2). At the stations in the region, a higher increase in monthly average temperatures was recorded in Aghdara (1.9^{0}C, May), and a greater decrease was recorded in Lachin (-1.2^{0}C, November).

The analysis indicates that the reliability of the extended statistical series data for this region is somewhat low. For this reason, the satellite data of the air temperature of the region was consulted. Satellite data was based on the air temperature data (T2M) covering the years from 1981-2021 recorded by the Merra-2 satellite at a height of 2 m above the

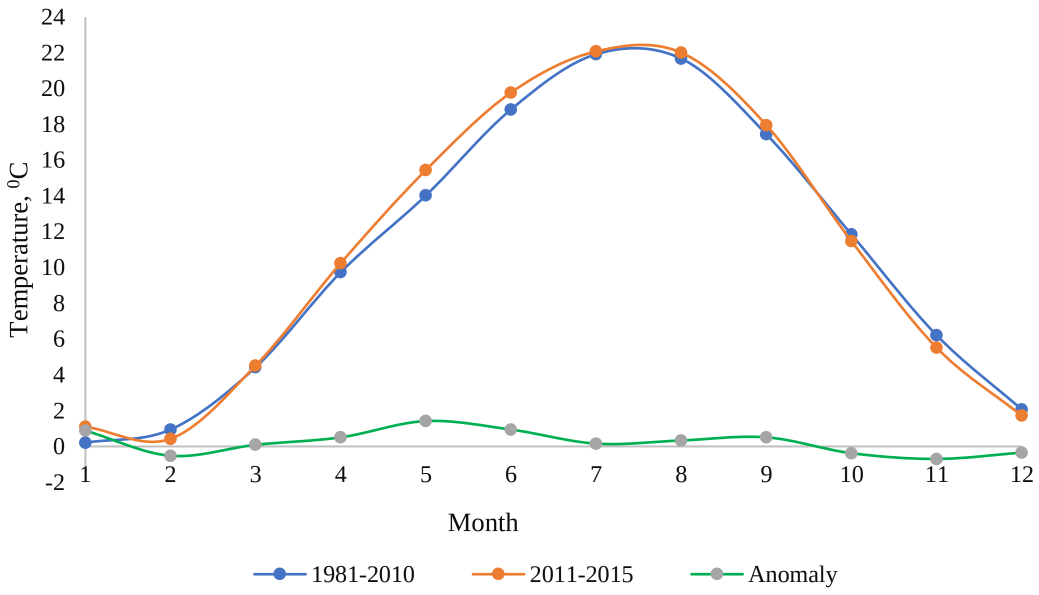

Fig. 2. Fluctuations of air temperature from 2011-2015 compared to 1981-2010 according to ground observation data

earth's surface [25, 26, 27]. According to the analysis of satellite data, compared to 1981-2010, from 2011-2022, an increase in air temperature was observed in the region in all months except October (-0.2^{0}C) and November (-0.4^{0}C). Temperature increase was higher in May (1.6^{0}C) and June (1.2^{0}C). In other months, this indicator is around 0.2-0.9^{0}C. The average perennial temperature increase in the region is 0.5^{0}C. Analysis of observation and satellite data reveals that the air temperature in this region increased in May and June, and decreased in November.

The average annual rainfall for the region is around 520 mm (403-608 mm). Although the amount of annual precipitation in the region increases from the plains to the 1000-1500 m area of the middle highlands (Shusha, 608 mm), it slightly decreases in the upper parts of the middle highlands (Istisu, 508 mm). It increases again in the lower parts of the highlands and starts to decrease above 3000 m. In this area, 66% of the annual precipitation falls in the hot season and 34 % in the cold season. The highest precipitation falling in the south-central mountainous part of the Lesser Caucasus province is observed in spring (205 mm). Summer (139 mm) has more precipitation than autumn (110 mm).

In the low mountains and plains, the amount of precipitation is greater in summer (80-140 mm) than in autumn (100-110 mm). Less precipitation falls here in winter and is 65 mm (51-73 mm). Stations located in the middle highlands, such as Shusha and Lachin, have higher annual precipitation than other stations. Less precipitation is recorded in the east in the Karabakh plain (Aghdara) (403 mm). In the 2200-2400 m area of the middle highlands (Istisu) the precipitation with 11-20 mm (17 %), 21-30 mm (16 %), 31-40 mm (17 %) and 41-50 mm (17 %) amount is more widespread.

A multi-year analysis of precipitation in the region by month shows that less precipitation is recorded in January and December (18 mm) in winter. May (96 mm) is the month with the maximum rainfall in the region. Starting in June, the increase in air temperature reduces the temperature contrast between altitudes and increases evaporation. In this month, until the end of July, strong convective processes take place and quite rainy weather conditions are observed. Although the amount of precipitation is 73 mm in June, it is reduced by half in July (38 mm). Such precipitation decrease continues in August (28 mm). A slight decrease in air temperature from September (38 mm) leads to an increase in temperature differences associated with orography, resulting in a gradual acceleration of the cloud formation process. In October, the amount of precipitation increases to 40 mm, and the autumn maximum of precipitation is observed. Starting from November (32 mm), precipitation decreases again and reaches 18 mm in December.

Compared to the climate norm, from 2011-2015, the average perennial precipitation in the southern mountainous part of the Lesser Caucasus province was observed to be low at Asgaran (1%) and Aghdara (1%) stations, and decreased by 1-5% at other stations of the region. Provided paying attention to the graph showing the fluctuations compared to the climate norm with average indicators, compared to the years 1981-2010, the average annual precipitation in the region from 2011-2015 decreased by 1% or 7 mm for the entire period (Figure 3). The amount of atmospheric precipitation in the

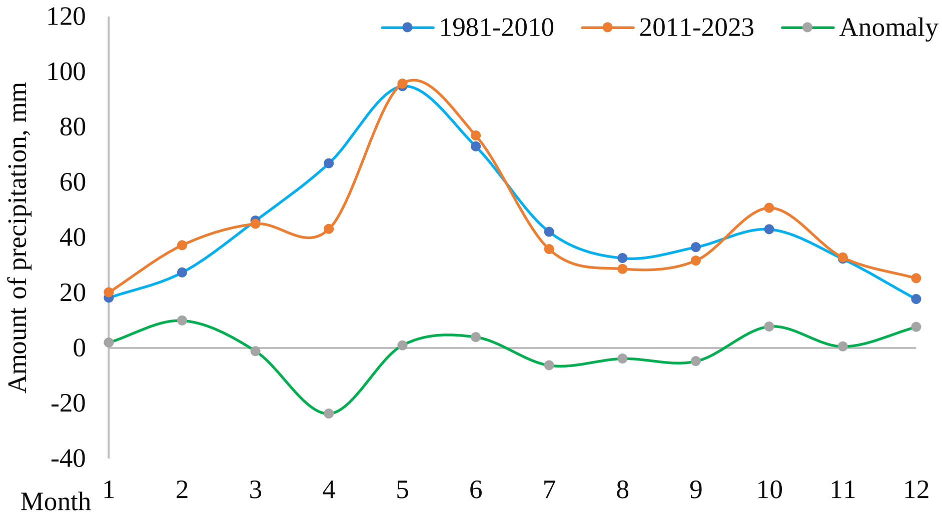

Fig. 3. Fluctuations of average monthly precipitation of ground stations in the southern mountainous part of the Lesser Caucasus province

region increased by no more than 10 mm in January, February, July, October and December.

This indicator remained stable in March, June and November, decreased 24 mm in April, 6 mm in July, 4 mm in August and 5 mm in September compared to the climatic norm. The total precipitation of the region remained almost unchanged in March, May and November. Small indicators of precipitation fluctuations in the whole region are related to the increase of its amount in some stations and decrease in some stations. A greater decrease in the amount of precipitation in the region occurred in April.

The analysis unveils that in the southern mountainous part of the Lesser Caucasus province, although precipitation has increased slightly from mid-autumn to mid-winter in recent times, there is a chaotic decrease in early spring and mid-summer to early autumn. Such fluctuations in precipitation indicate an increase in drought in spring and summer in the plains relief of the middle highlands and a decrease in the volume of water in permanent streams. Shrinking of forests in the region, the evolution of green landscape types towards bush and dry-desert types is inevitable. Additionally, the decrease in precipitation during the vegetation period has a negative effect on their development and damages the productivity of the rural economy [6, 7]. The reduction in rainfall in the late spring and summer months leads to the evolution of plant varieties. That is, fluctuations in temperature and precipitation in the same landscape zone lead to a better spread of other plant varieties [3, 12]. Figure 4 indicates a clear example of how dry massifs will be replaced by thickets over time.

A graph depicting the long-term dynamics of the annual amount of atmospheric precipitation in the Kalbajar and Lachin districts has been drawn up. As can be seen here, the multi-year indicator of the annual precipitation has varied in the range of approximately 350-850 mm. The trend of precipitation in the general period tends to decrease. If we pay attention to the dynamics of the average moving amount over the entire period, the precipitation in the region compared to the climate norm (1981-2010) showed small fluctuations from 1961-1970, higher from 1971-1982, 2002, 2009 and 2015-2022, 1983 - had lower indicators in 2001, from 2003-2008. Compared to the climate norm, 52% of the annual rainfall totals in the long term for the entire region are lower than the climate norm, and 48% are higher (Figure 5). The multi-year precipitation trend indicates that 1961, 1970, 1971, 1989, 1995, 1996, 1999, 2000, 2005 and 2006 are the least, 1963, 1972, 1974, 1981, 1982, 1988, 1994, 2006 2, 2003 and 2018 is 10 consecutive years with the most precipitation. Analysis of multi-year rainfall in this region exhibits that 70% of the 10 years with the lowest rainfall occurred after 1989. During this period, 70% of the 10 years with the highest precipitation occurred before 2002. Here, the highest average values of precipitation in the long term were found in 1963 (854 mm) and 1981 (761 mm).

In recent times, regional climate change has made the winter milder with the increase in air temperature, while the summer is hotter and stuffiness. Convective processes have shifted until mid-summer [3,12, 22]. Such a warming process reduced the period of solid precipitation in the central highlands and extended the phase of foggy weather conditions. Due to the increase in the rate and volume of melting in the high mountain zone, the amount of glaciers and snow glades that carry over to the next year has decreased sharply [5, 17]. In some years, the glaciers, which have completely melted and run out, cause the water in the river basins to decrease [8, 13, 20].

Fig. 4. Drying of forest massifs in the area of 900-1100 m altitude in the Lachin district (August 2024)

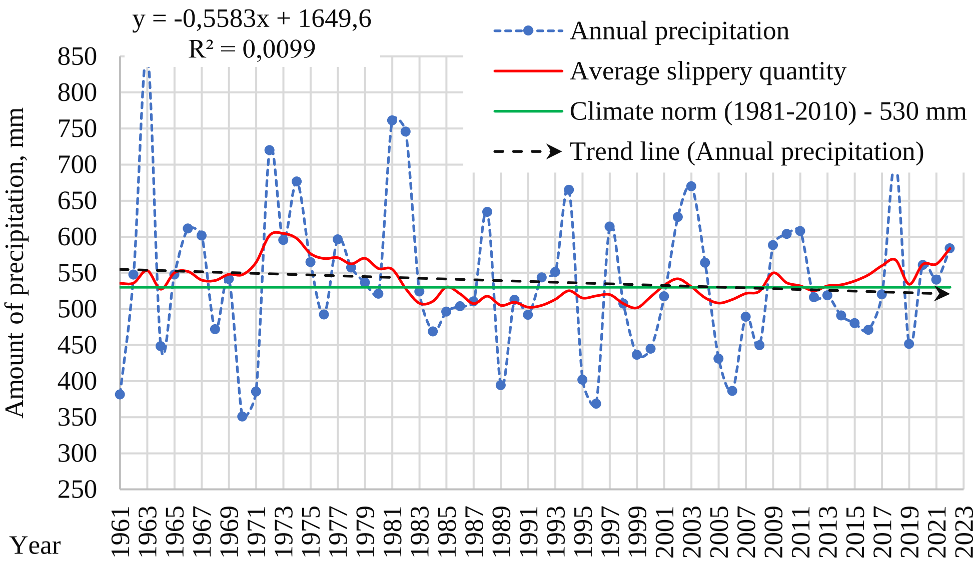

Fig. 5. Perennial dynamics of average annual precipitation in the Kalbajar and Lachin districts

In the Lesser Caucasus Mountains, no extensive studies have been conducted about glaciers, snowfields, etc. In recent times, known processes have led to a slowdown in research in this field. With this research, for the first time, the snow reserves available in August in the area above 3000 m above the junction of the Mikhtokan and Karabakh ridges in the southern part of the Lesser Caucasus mountains were evaluated.

The territory of the watershed, where Mikhtokan, Saribulagdagh and Karabakh volcanic plateaus are connected, studied with satellite photos, is located in an area 2800-3600 m above sea level. This zone is between the summits of Sarchali (3433 m), Gizilboghaz (3581 m) of the Karabakh volcanic plateau and Dalidag (3616 m) of the Mikhtokan range. Since the higher peaks are on the edges, the central part where the ridges meet has a relatively flat topography. The high mountain slopes located here are distinguished from other mountain slopes by their gentle slope and smooth surface (Figure 6).

The relief consists of large peaks and plateaus between which large volcanic sediments come to the surface. If we pay attention to the relief in August, when the ice and snow cover of the year has a minimal area, it is clearly observed that the nival and subnival landscape develops in the area. In the places where the volcanic lava rises to the surface, the gravel, oval rocky relief occupies a large area. Since there are gaps in the deeper parts of such rocks, melting snow and ice flows over the rocks and fills those depressions, resulting in the formation of cirque lakes. Outcrops of rock and grey soil patterns look a lot like ice and snow because they appear pale white in satellite images.

However, if we pay attention to all the images, the borders of the snow glades are completely cut and stand out sharply from the surroundings. Additionally, the sun's glare is clearly felt in all parts covered with snow. The presence of such a shine distinguishes snow cover from ordinary soil samples. Sunlight is a sharp, bright white colour that results from the presence of small amounts of sediment or dust particles (Figure 7).

If we take into account that the sediments were covered by the snow cover by wind and avalanches, it can be concluded that these covers fell a short time ago. There is no doubt that such snow glades are the product of the last one or several years. Both the analysis of images (2017-2023) and physical characteristics permit us to clarify the result.

In this area, snow glades are available in August as well. Glades can usually be found parallel to the direction of flow in valleys in depressions or at

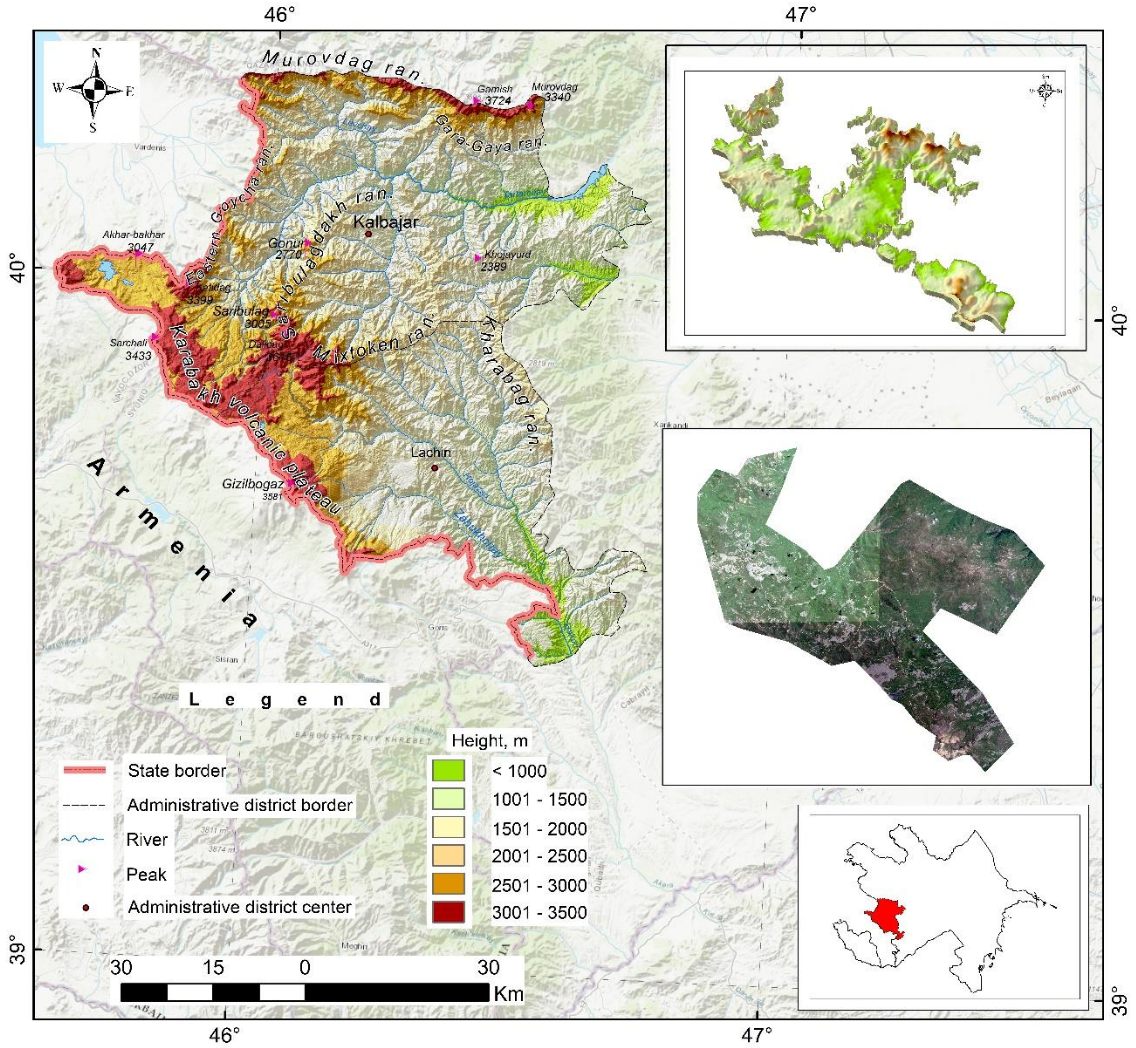

Fig. 6. 3D, satellite and physical-geographic image of the research object

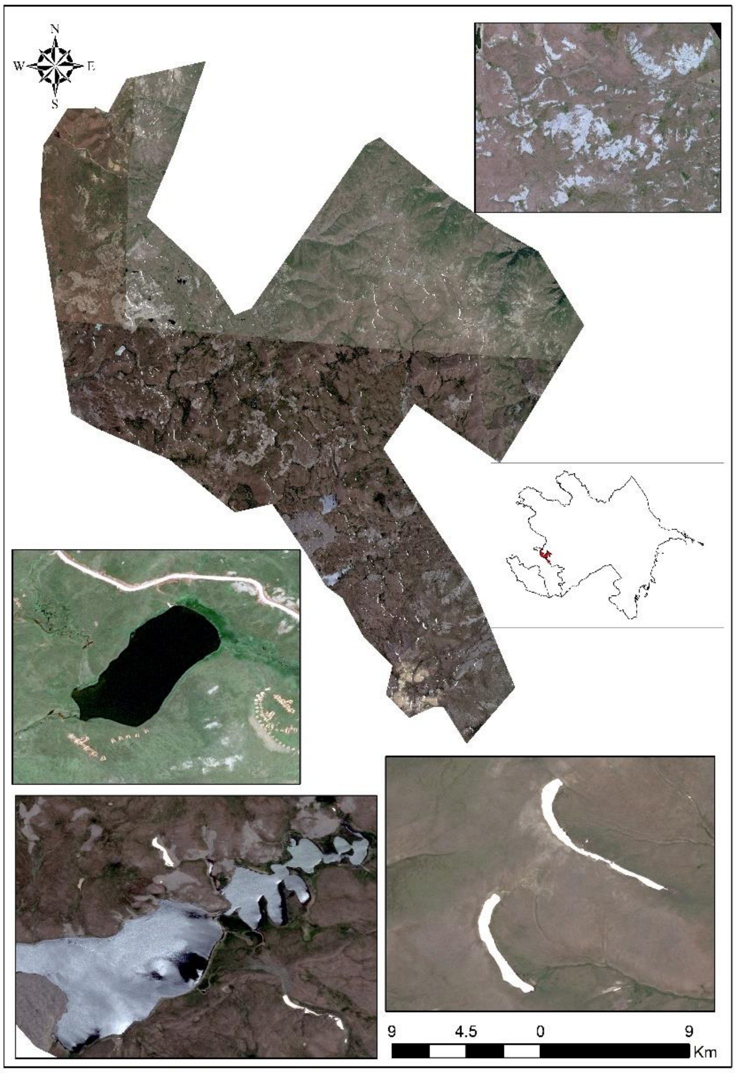

Fig. 7. View of the primary elements of the terrain from satellite images

the watersheds of ridges and hills. Areas with snow glades can be called areal **snowfields**, where the snow glades of the area become a general massif (Figure 8). The location of those snowfields on the banks of the flow zones of the valleys moving vertically or horizontally causes late melting of those residues that flow from the surrounding areas during melting and turn into ice during the cold season. Such snowfields can usually remain for the next year, and in the cold period, snow falls on them again several times.

Studies prevail that, depending on the air temperature of the region in individual years, the total area of snowfields does not exceed 6.0 km^2. The territory of such glades can retreat with the rise of air temperature in the hot season. According to satellite data, the snowfields were more in 2017, 2019, 2021, 2023 and 2024, where the most snowfields were 5.72 km^2 in 2017. This shows itself with lower indicators in the following years. According to the analysis of 2021, the number of snow glades in the region is 1250-1300 units. Even if the snow glades left here in the following year melt, there will be snow in this area again the following year.

With the application of GIS technology, the boundaries and areas of the mentioned snow glades were determined. Changes in the area of snow glades in the perennial period indicate that more snow reserves were recorded in the region in 2021. This is due to more rainfall that year. Therefore, those areas are areas of potential snow glades. Snow glades, which had maximum indicators in 2021, gradually decreased in the following years (Figure 9). The total area of snow glades in this area was minimal in 2017. From 2021, it increased to the maximum level in the region, and until 2023, a decrease was recorded. In 2024, the expansion of snow glades was again experienced.

Some of the fields located in cirques are covered with debris cones that are constantly moving from the highlands. Debris layers covering the top of the snow protect it from permanent and strong melting. The primary reason for the maintenance of snow fields here is the climate, and another reason is

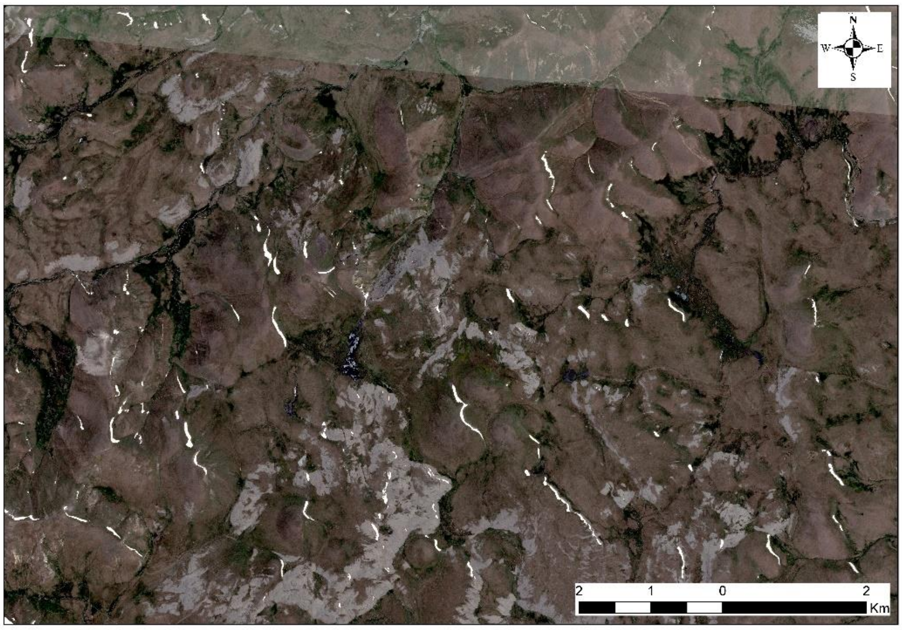

Fig. 8. Snow glades and general snowfield in the area

their location on the northern slopes of the mountains, in the sunless zone. Thus, the sun's rays fall on these slopes at a sharp angle, and the temperature on that surface is lower.

Since the climate of the Lesser Caucasus Mountains is dry, hot and continental, modern glaciers have rarely developed in this area. Modern glaciers develop as small ridges only on high peaks where there is a great elevation and the climatic conditions are favourable for the formation and maintenance of the glacier. The lack of favourable cold climatic conditions does not permit the spread of glacier reserves in this part of the Lesser Caucasus. However, in a small part of the research area, it can be possible to find remnants of snow that have turned into several-year-old furnaces.

In this region, the glaciers (firn) are scattered in a small area and isolated at an altitude of about 3100-3300 m. Those glaciers were collected on the rocks in the sloping plain zone on the eastern slope of the Gizilboghaz elevation (Figure 10). The moraine deposits on the snow block the brightness of the glacier. Generally, glaciers reflect most of the sunlight falling on an open surface, and it causes loü level of albedo. However, covering the surface of the glacier with sediments increases the absorption of solar rays and causes the glacier to melt faster. The total area of firn ice located here in the form of small balls is 0.148 km^2 (148 ha). This glacial firn is still in the firn stage. Analysis indicates that the ice remnant was formed in the last few years. That area of the glacier melts in some years, turning it into a bedrock lake.

In this area, the number of big and small glacier balls is 5. Two of them cover a relatively large area of 0.14 km^2 (139.3 ha). The area of 3 other smaller ices is about 0.005 km^2 (8.67 ha).

The lakes are poorly developed when the ice exists or the cirque is almost empty. When there is no ice, these lakes are filled with water, and in satellite images, such lakes resemble relatively round black spheres with a black colour (Figure 11a, b). There are more than 100 large and small lakes, ponds and small water holes in the area. The total area of the lakes is about 2.36 km^2. Nourishment of such small lakes collecting water feed with snow, ice and rainwater. 20 of these lakes are large compared to others. One of the big lakes here is Zalkhagol (Figure 11b).

During the cold season of Zalkhagol, its surface is covered with ice. This lake is considered the source of Bazarchay. The water seeping from the lakes is the primary source of nutrition for the beginning of the Tartar River and the left tributary of the Hakari River. Since these lakes are located in a rocky terrain, there is a constant supply of water, as water percolates and evaporates at a slow rate. Starting from the end of September, the process of freezing these lakes and covering the area with snow begins. From the beginning of autumn, precipitation begins to fall heavily on these mountains.

The analysis reveals that the air temperature has constantly increased with higher indicators from 2017-2023.

Despite these growth indicators, the snow and ice reserves in the region were sufficient in 2021. There is a relationship between the increase in temperature and the dynamics of the snow reserve. However, because the increase in temperature in the low highlands increases possible evaporation, the

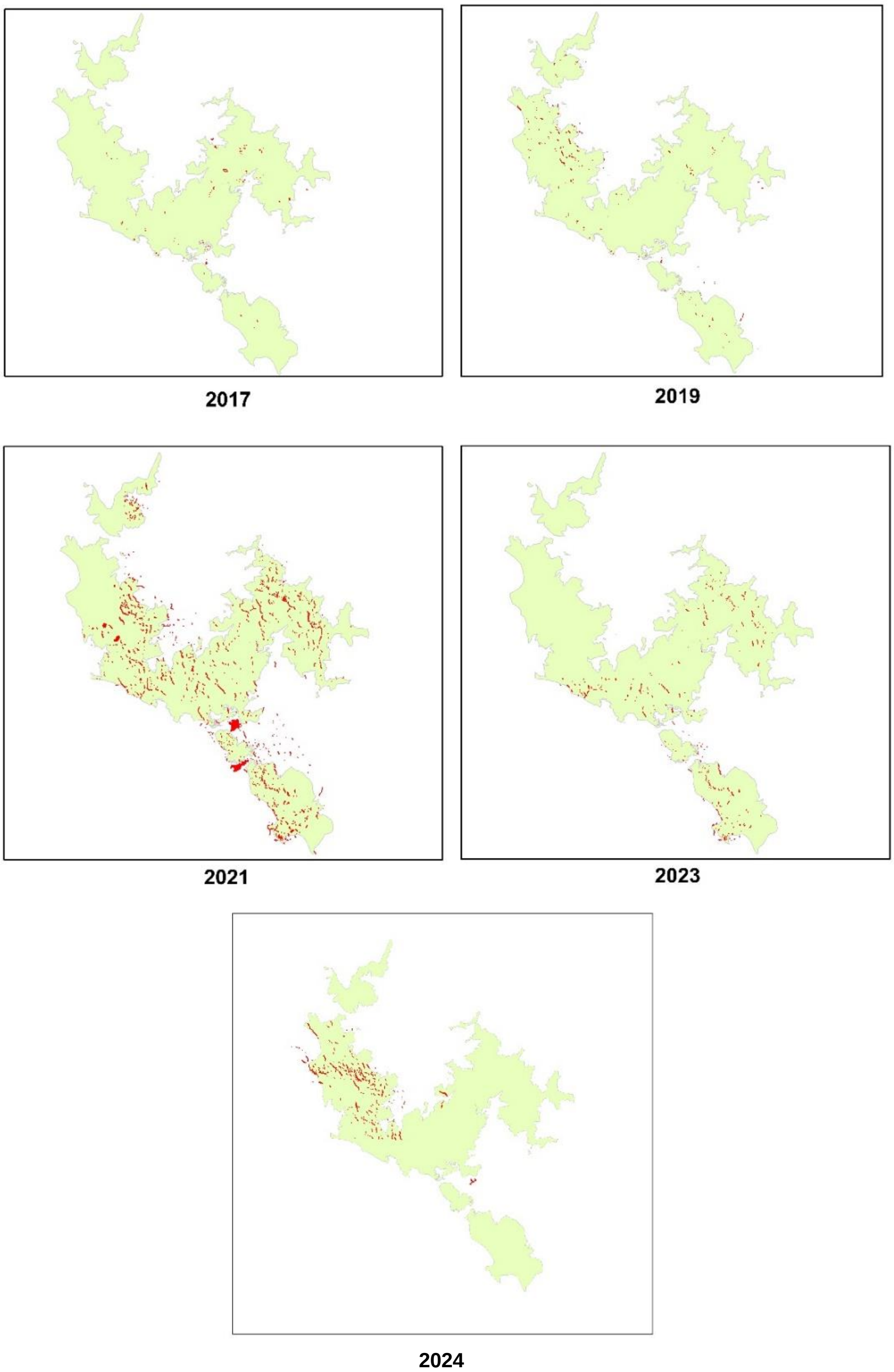

Fig. 9. Perennial dynamics of snow glades (red polygons) in the area

precipitation in the middle and high highlands increases compared to other years as well. The formation of precipitation means an increase in the number of cloudy days. This prevents the sun's rays from directly falling on the snow and ice cover in the high mountains and causes an increase in its existence period. At the same time, solid or mixed precipitation prolongs the duration of the snow supply in this area.

Conclusions. The following conclusions were obtained in the research conducted based on hydrometeorological data and satellite images in the southern mountainous part of the Lesser Caucasus physical-geographical province (Mikhtokan, Saribulagh ranges and Karabakh volcanic plateau):

1. From 2011-2022, the average monthly temperature indicators in these parts of the Lesser Caucasus province increased by 0.9-1.4^0C in January (0.9^0C), May (1.4^0C), June (0.9^0C); by 0.5^0C in April (0.5^0C) and September (0.5^0C), whereas it decreased in February (0.50C) and November (0.70C), and fluctuated within the climatic norm in other months.

2. Compared to 1981-2010, the average annual

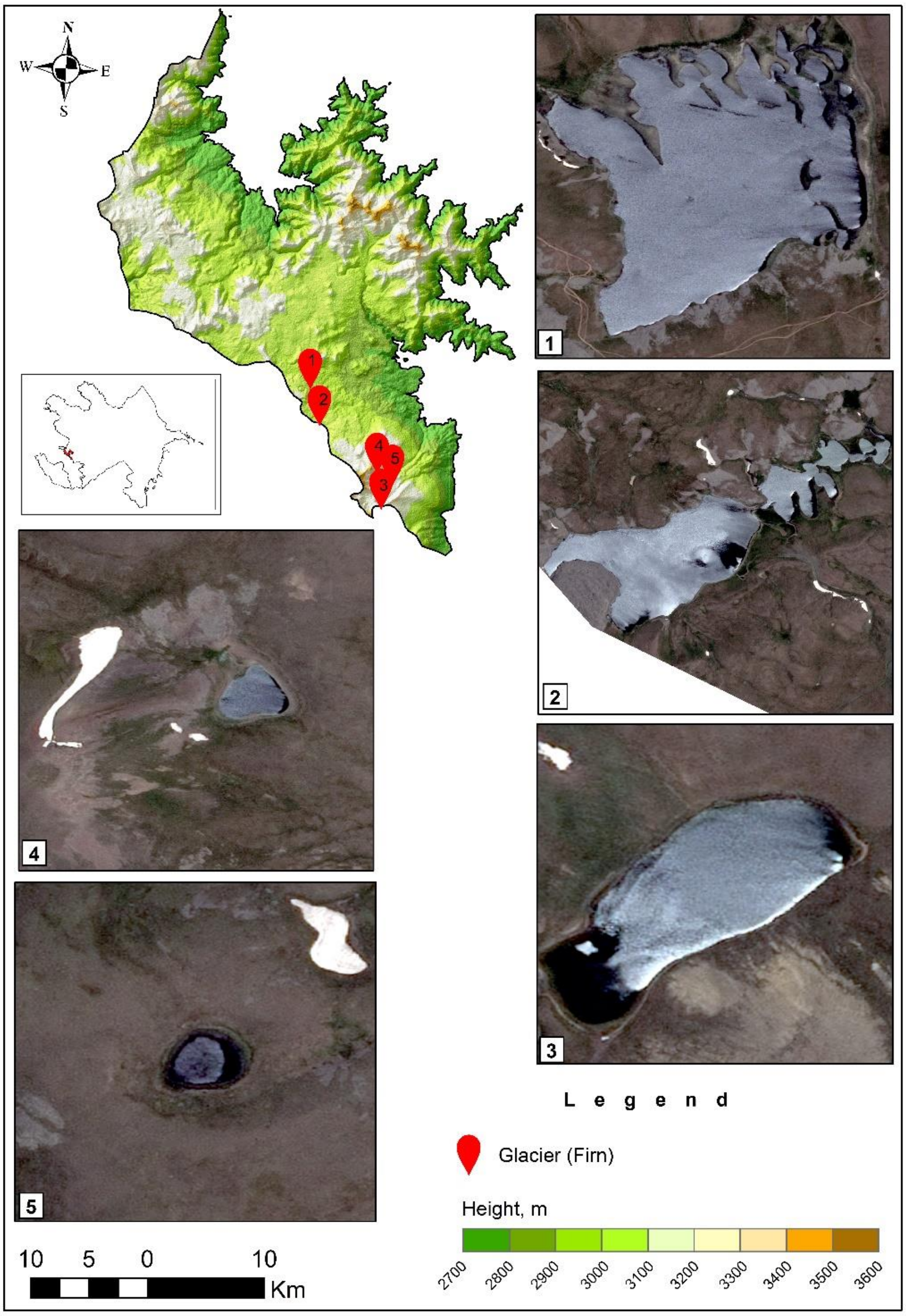

Fig. 10. Firn ice of Gizilboghaz peak

a) b)

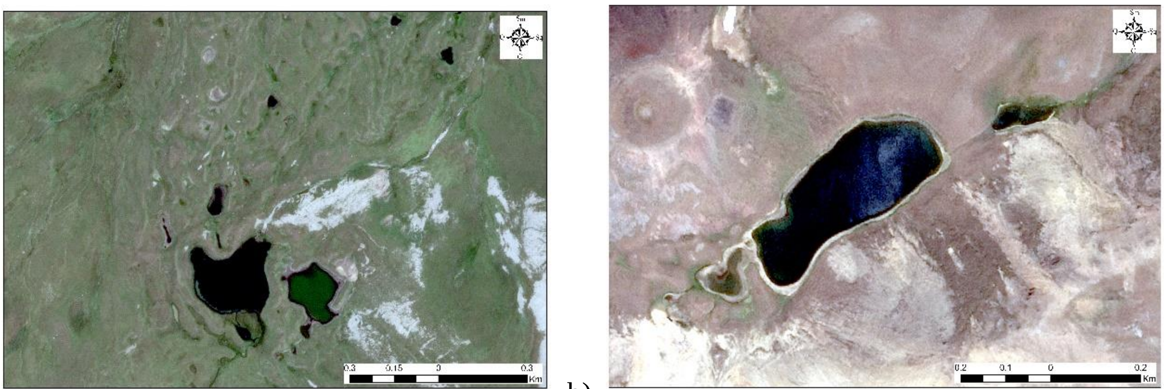

Fig. 11. Glacier-fed lakes of the Karabakh volcanic plateau

precipitation in the region from 2011-2015 decreased by 1% or 7 mm over the entire period.

3. Depending on the air temperature, the amount of snow cover in this region does not exceed 6.0 km^2. According to satellite data, the snowfields were more in 2017, 2019, 2021, 2023 and 2024, where the most snowfields were 5.72 km^2 in 2017. According to the analysis of 2021, the number of snow glades in this zone is 1250-1300 pieces.

4. Glaciers (firn) are spread in the region at an altitude of approximately 3100-3300 m. Those glaciers were collected on the rocks in the sloping plain zone on the eastern slope of the Gizilboghaz elevation. The total area of firn ice located here in the form of small balls is 0.148 km^2 (148 ha). Here, the number of big and small glacier balls is 5. Two of them are large, covering an area of 0.14 km^2 (139.3 ha).

As a result of the field expedition and satellite research carried out for the first time in the highland region of Mikhtokan, Saribulagh ridges and Karabakh volcanic plateau, modern information about snow glades and glaciers was obtained for the first time. The results of the research can be used in mitigation and adaptation measures against climate change. At the same time, the water resources of the rivers originating from that region can be evaluated and can be of special importance in the preparation of future forecasts. Considering that the research area (Kalbajar-Lachin) is a brand-new settlement area, it can be used during the placement of residential and social infrastructure, agricultural and industrial areas in this zone. The results of the research should be taken into account when developing warning systems to protect against destructive natural events in this zone.

This work was supported by the Azerbaijan Science Foundation – Grant № AEF-MQM-QA-2-2023-3(45)-05/02/1-M-02.

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Authors Contribution: All authors have contributed equally to this work
Conflict of Interest: The authors declare no conflict of interest

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Сучасний стан льодовиків і снігових галявин у південному гірському районі провінції Малий Кавказ

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У роботі досліджено сучасний стан багаторічних снігових галявин і льодовикових запасів, розташованих на Карабахському вулканічному плато, хребтах Міхтокан і Сарібулаг, що вважається південною гірською частиною провінції Малий Кавказ. Для цього були інтерпретовані супутникові усереднені фотографії, а також використані супутникові бази даних Azersky, Landsat, Sentinel-1 та ін. Розрахунки та аналізи проводилися з використанням різних методів вимірювання та обробки отриманих растрових файлів після декодування супутникових зображень. Крім цього, в дослідженні вказувалося фізико-географічне положення місцевості, кліматичні умови, зверталася увага на багаторічні зміни температури повітря та кількості опадів. У дослідженні розглядався вплив зміни клімату на запаси льодовиків. Порівняно з 1981-2010 рр., з 2011-2022 рр. середньомісячні показники температури в цій частині провінції Малий Кавказ підвищилися на 0,9-1,4°C у січні (0,9°C), травні (1,4°C), червні (0,9°C); зросла на 0,5°C у квітні (0,5°C) та вересні (0,5°C); при цьому в лютому (0,5°C) і листопаді (0,7°C) цей показник знижувався, а в інші місяці коливався в межах кліматичної норми. Середньорічна кількість опадів по області за 2011-2015 роки за весь період зменшилася на 1%, або на 7 мм. Залежно від температури повітря площа снігових галявин у цьому регіоні не перевищує 6,0 км^2. Територія таких галявин може танути з підвищенням температури повітря в теплу пору року. У регіоні фірновий лід поширений приблизно на висоті 3100-3300 метрів. Ці льодовики були зібрані на східному схилі гори Гізилбогаз, на скелях, які знаходяться близько до поверхні на похилому схилі. Загальна площа фірнового льоду, розташованого на цій ділянці у вигляді малих куль, становить 0,148 км^2, а кількість великих і малих льодовикових куль – 5. Дві з них великі і займають площу 0,14 км^2. Площа 3 інших менших льодів становить близько 0,005 км^2 (8,67 га).

Ключові слова: *хребет Міхтокан, зміна клімату, кліматична норма, льодовик, фірн, снігові галявини, ГІС-технологія, кількість опадів, температурна аномалія, тенденція.*

Внесок авторів: всі автори зробили рівний внесок у цю роботу
Конфлікт інтересів: автори повідомляють про відсутність конфлікту інтересів

Надійшла 14 жовтня 2024 р.
Прийнята 21 листопада 2024 р.