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Observed changes in monthly maximum and minimum temperatures in the Nakhchivan Autonomic Republic (Azerbaijan) between 1961 and 2023

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ABSTRACT

Problem Statement. This study analyzes long-term spatiotemporal trends in monthly maximum and minimum air temperatures in the Nakhchivan Autonomous Republic for the period 1961–2023, using data from five meteorological stations to assess regional climate change.

Purpose. The study aims to develop and refine research methods for detecting climate-induced changes, with a particular focus on maximum and minimum air temperatures. Specifically, it seeks to establish robust statistical and spectral techniques that can identify temporal trends, diurnal variations, and extreme temperature events. By integrating observed temperature records with optimized analytical tools, the study intends to enhance the accuracy and reliability of regional climate assessments.

Methods. The study employed a combination of linear trend analysis, Pearson correlation, and anomaly-based methods to assess long-term variations in maximum and minimum air temperatures. Temperature anomalies were referenced to the 1961–1990 WMO climatological normal, and warming/cooling rates (°C/decade) quantified temporal trends. The use of non-parametric methods, moving time windows, and recurrence frequency analysis across temperature gradations enabled robust detection of long-term changes, recent shifts, and asymmetries in temperature distributions.

Results. For the period 1961–2023, a steady and widespread increase in maximum temperature has been established across all months and at all stations. The most intense warming is observed in winter, particularly in February (up to 1.180C/decade), in spring – March (up to 0.780C/decade), in summer – June to August (up to 1.50–2.090C/decade), and in autumn – September to October. The most statistically significant Tmax trends are characteristic of spring (up to 93% of cases) and summer (up to 87%), indicating the greatest stability of warming during the warm season. An analysis of different climatic periods reveals an intensification of warming rates in maximum temperature over time, especially after the 1980s and most prominently during 1991–2023. Minimum temperature demonstrates a more complex and heterogeneous behavior, including steady warming in winter, mixed trends in spring, localized cooling in summer (July), and pronounced spatial contrasts in autumn. Frequency analysis of temperatures indicates an expansion of the Tmax range from −90C to 420C, an increase in the recurrence of high temperatures (30–360C), and a rare but persistent occurrence of extremely high values (up to 420C). The comparison of Tmax and Tmin confirms that contemporary warming is asymmetric, with a dominant increase in daytime temperatures. Spatial differences are determined by topography. Overall, it has been established that the region's climate is characterized by increasing temperature extremity, a rising frequency of high-temperature classes, and enhanced interseasonal and inter-station contrasts.

Conclusions. Seasonal variations in temperature changes are particularly important in this region, where agriculture and the transportation sector hold substantial economic significance. Rapid increases in maximum temperatures during spring and summer could adversely affect various economic sectors in the coming decades. Such studies are essential for understanding climate change and play a crucial role in monitoring and analyzing climate trends to support policymakers in mitigation and adaptation strategies.

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Introduction

In the context of ongoing global climate warming, changes in extreme air temperature indicators – particularly maximum and minimum values – are recognized as key signals of transformations within regional climate systems. Contemporary research indicates that not only

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shifts in mean temperature but also changes in the tails of the distribution (i.e., extremes) exert disproportionately strong impacts on natural and socio-economic systems.

Extreme temperature events – such as heatwaves, cold spells, and nocturnal frosts – have been shown to adversely affect agricultural productivity, income stability, and plant reproductive processes. At the same time, adaptive measures, including targeted irrigation, improved soil management, and regulation of diurnal temperature range (Tmax–Tmin), can partially mitigate these negative effects and enhance ecosystem resilience [24; 25; 34; 35].

Moreover, temperature extremes contribute to reductions in economic productivity and household welfare, while also posing significant risks to human health, including increased mortality, higher rates of hospital admissions, impaired child nutrition, and disruptions in biological processes [1; 4; 8; 33; 36]. Even relatively small increases (on the order of 1–2 °C) in maximum and minimum air temperatures may exceed species-specific tolerance thresholds, leading to substantial impacts on ecosystems, agriculture, and socio-economic systems, and thus playing a critical role in climate vulnerability assessments and the development of effective adaptation strategies [13; 18].

In this regard, the statistical analysis of long-term variability and trend components of monthly maximum and minimum temperature series is of fundamental importance for detecting regional climate change patterns. In the Nakhchivan Autonomous Republic (AR) of Azerbaijan, characterized by a continental and semi-arid climate, changes in the thermal regime directly affect water resource formation, agricultural productivity, energy demand, and ecosystem stability. Therefore, investigating the temporal behavior of temperature extremes in this region represents a scientifically and practically significant task.

Global studies show spatiotemporal variability of maximum and minimum temperatures, with 1951–1990 observations revealing asymmetric warming – minima rising ~0.84 °C, roughly three times maxima (~0.28 °C) across hemispheres – and 1946–2000 trends indicating widespread increases, particularly in winter and spring, with accelerated warming in the 1980s–1990s [15].

The regional results of maximum and minimum temperature changes and the results of other studies related to air temperature changes can be briefly summarized as follows.

Observed trends in North America, Europe, China, Russia, and Australia indicate increases in both maximum and minimum temperatures, with more pronounced warming in minimum temperatures, particularly during winter and spring. Daily analyses reveal hotter days and milder nights, reflecting significant nocturnal warming and intensified temperature extremes, which exhibit notable seasonal and regional variability [15; 19].

Between 1950 and 2018, Europe experienced widespread warming, with maximum temperatures showing smooth spatial patterns and notable increases in extreme heat events [2]. In northeastern Spain (1960–2006), minimum temperatures rose markedly in winter and spring, while maximum temperature changes were minor or spatially heterogeneous [7].

Long-term air temperature changes in central Ukraine using continuous meteorological records were analyzed in [11]. Winter and spring temperatures exhibit significant warming trends, with record-high annual averages in recent years (2020–2021). These results reflect a clear regional manifestation of climate warming, with implications for local climate variability, ecosystem responses, and adaptation in agriculture and water resource management.

The study of analyzing of spatiotemporal air temperature changes across Ukraine (1970–2014) using hydrometeorological data given in [16]. Significant warming trends were observed, with annual increases of 3.1–3.5 °C and pronounced summer variability. Regional differences show stronger warming in eastern than western Ukraine. The study demonstrates the value of hierarchical statistical methods for assessing seasonal and multi-decadal temperature dynamics and their ecological and socioeconomic impacts.

The study [22] examines heat wave characteristics and trends in selected Ukrainian cities under regional climate change. Using historical meteorological data and RCP scenarios (2.6, 4.5, 8.5) through 2050, results show that while annual heat wave frequency is lowest in southern Ukraine, duration and intensity vary regionally. Projections indicate an increase in heat wave days, especially during the cold season (October–April), highlighting temperature extremes' complex impacts on public health, agriculture, and infrastructure resilience.

Long-term temperature trends in Turkey indicate general increases in maximum temperatures (1929–1999), with exceptions in Central Anatolia, the Black Sea, and parts of Eastern Anatolia, and slight autumn declines [27]. Minimum temperatures rose significantly at many stations, especially in spring and summer, while winter and autumn trends were regionally mixed. From 1970–2014, both annual maximum and minimum temperatures increased notably in the Middle Fırat region [6], whereas in Mediterranean coastal zones (1970–2010), maxima rose significantly but minima showed a non-significant decline [12].

This study [23] integrates statistical, spatial, and thermodynamic analyses to examine temperature dynamics in the Lake Sevan basin. Long-term observations reveal a century-scale

warming trend with distinct warming periods, highlighting that a physical understanding of temperature enhances the interpretation of regional climate variability and supports broader climate change assessments.

A study conducted in Central Asia indicates that in recent decades, both maximum and minimum temperatures have exhibited increasing trends, contributing to a higher frequency of heatwaves [17].

In Lahore (Pakistan), minimum temperatures have steadily increased annually and seasonally, while maximum temperatures generally declined. Sub-period analysis (1988–2003 vs. 2004–2019) shows no significant changes in minima and rising maxima in the first period, whereas both minima and maxima increased in the second period [31].

As evidenced by the above analyses, the study of regional manifestations of climate change has become one of the key priorities of the international scientific agenda in recent years.

However, in the strategically important Nakhchivan AR of Azerbaijan, the long-term variability of temperature extremes has not yet been investigated in a sufficiently systematic and comprehensive manner.

The **main objective of this study** is to identify and evaluate long-term trends, variability, and statistical characteristics of monthly maximum and minimum air temperature series in the Nakhchivan AR over the period 1961–2023.

The **object** of the research is the observational series of monthly maximum and minimum air temperatures recorded at meteorological stations within the Nakhchivan AR.

The **subject** of the research is the temporal variability, trend structure, and statistical properties of monthly maximum and minimum temperature series, including their interpretation as indicators of regional climate change.

The Nakhchivan AR (5,363 km²) in southwestern Azerbaijan, spanning the Lesser Caucasus and Middle Aras Depression and bordering Armenia, Iran, and Turkey, is predominantly mountainous with Daralayaz and Zangazur ranges covering two-thirds of the territory and lowlands along the Aras River; elevations range from ~600 m to 3,906 m (mean ~1,400 m), with pronounced hypsometric and geomorphological heterogeneity influencing regional climate and local meteorological conditions [3]. Complex topography, continental climate, variable hydrology, vegetation, and anthropogenic influences have shaped three main soil types; climatic and edaphic constraints limit vegetation to xerophytic communities, while agricultural land use remains uneven due to rugged relief, climatic limits, and chronic irrigation constraints.

The Nakhchivan AR, Azerbaijan's most continental region (continentality index 60–80%), shaped by inland location, complex relief, and high solar radiation, exhibits active temperature sums of 2,000–4,500 °C and a frost-free period of ~210–230 days; seasonal evolution features subzero winter minima, rapid spring–midsummer warming, and autumnal declines in all temperature indicators with rising precipitation and humidity, while precipitation increases with elevation and is slightly higher in the east than the west [21].

The meteorological station network provides representative coverage of Nakhchivan AR's diverse physiography, with coordinates and elevations summarized in Table 1 and spatial distribution relative to major landscape units shown in Figure 1, enabling robust assessment of climate variability in relation to topography and landscape heterogeneity and ensuring reliable regional climatic analysis.

Data Sources. Daily maximum and minimum temperatures, reflecting daytime and nighttime thermal conditions, were averaged monthly from 1961–2023 observations obtained from the National Meteorological Data Bank of Azerbaijan [20] and used to characterize diurnal cycle periods and long-term climatic trends.

Air maximum and minimum temperatures for 1961–2023, along with several related indices, were calculated using a FORTRAN algorithm within the Norton Commander interface, with statistical analysis and graphical visualization performed in MS Excel to comprehensively assess temporal trends and spatial variations in temperature extremes across the study area.

Methods

Linear Tendency Estimation Method and Pearson correlation coefficient. A linear trend method was applied to assess long-term variations in maximum

Table 1

Main indicators of the Hydrometeorological stations

Stations	Altitude, m	Geographic latitude, north latitude	Geographic longitude, east longitude
Ordubad	861	38.9	46.0
Julfa	736	39.0	45.6
Nakhchivan	885	39.2	45.4
Shahbuz	1205	39.4	45.6
Sharur	812	39.6	45.0

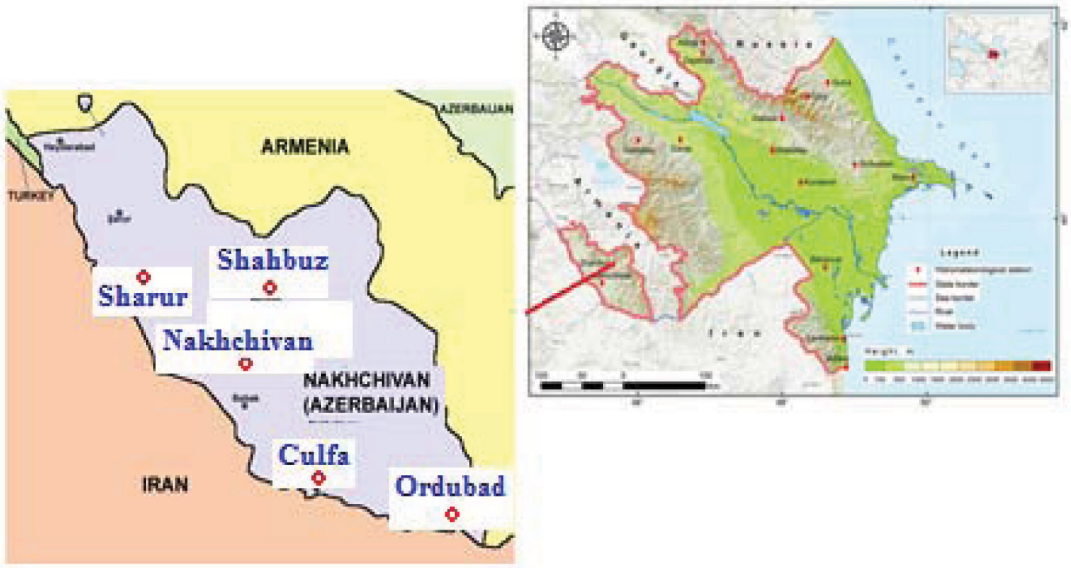


Fig. 1. Location of the study area and spatial distribution of the meteorological stations

and minimum temperatures across Nakhchivan AR, with Pearson correlation [28] used to quantify the strength and direction of monthly temperature–time relationships, serving as the primary criterion for evaluating the significance and intensity of temporal trends across the study area.

Methodology to Analyse Anomalies, Trends and Gradations. Temperature anomalies for Tmax and Tmin (1961–2023) were calculated from monthly averages of daily values at all stations, referenced to the 1961–1990 WMO standard climatological normal to ensure consistency and comparability with previous studies [30].

To ensure a more comprehensive assessment of maximum and minimum temperature anomalies, their normal values for the period 1961–1990, calculated and evaluated by the author, are presented in Tables 2 and 3, respectively.

In December, depending on altitude and topography, the maximum air temperature varies within 5.0–7.2 °C, while the minimum ranges from −0.6 to 3.2 °C. In January, although maximum temperatures in the Nakhchivan AR remain above zero, minimum temperatures are negative throughout the entire region. In February, maximum temperatures are positive across the area, whereas minimum temperatures remain below zero.

From March to July, maximum air temperature increases from 10.4–14.1 °C to 31.8–34.7 °C, while minimum temperature rises from −0.2–2.5 °C to 18.4–23.5 °C. During the autumn months,

Table 2

Monthly and annual values of maximum air temperature norms in Nakhchivan AR, °C (for 1961-1990)

Station	The number of months												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Ordubad	3.4	6.3	13.3	20.0	25.2	29.5	31.8	31.4	28.3	21.5	14.1	7.1	19.3
Julfa	3.2	6.3	14.1	20.9	26.7	31.7	34.7	34.1	30.6	22.8	14.3	7.2	20.5
Nakhchıvan	1.5	4.4	12.7	19.6	25.1	30.5	34.5	34.0	29.7	21.8	13.7	6.0	19.4
Shahbuz	1.4	3.8	10.4	16.9	22.4	27.7	31.9	31.7	27.6	19.7	11.8	5.0	17.5
Sharur	1.0	3.9	12.4	19.1	24.4	29.6	33.9	33.3	29.0	20.0	12.7	5.6	18.8

Table 3

Monthly and annual values of minimum air temperature norms in Nakhchivan AR, °C (for 1961-1990)

Station	The number of months												Year
	01	02	03	04	05	06	07	08	09	10	11	12	
Ordubad	-4.5	-2.6	2.5	8.1	12.6	16.9	20.7	20.0	15.8	9.7	4.1	-0.6	8.5
Julfa	-5.4	-3.0	2.2	8.3	13.5	18.7	23.5	22.6	17.2	9.6	3.3	-1.3	9.1
Nakhchıvan	-7.0	-4.6	1.1	7.2	11.7	15.8	19.7	19.1	14.4	8.4	2.6	-2.2	7.2
Shahbuz	-7.2	-5.5	-0.2	5.8	10.1	14.4	19.1	18.5	13.5	7.2	1.9	-3.2	6.2
Sharur	-7.8	-5.6	0.3	6.5	10.7	14.6	18.4	17.6	12.8	6.5	1.5	-3.2	6.0

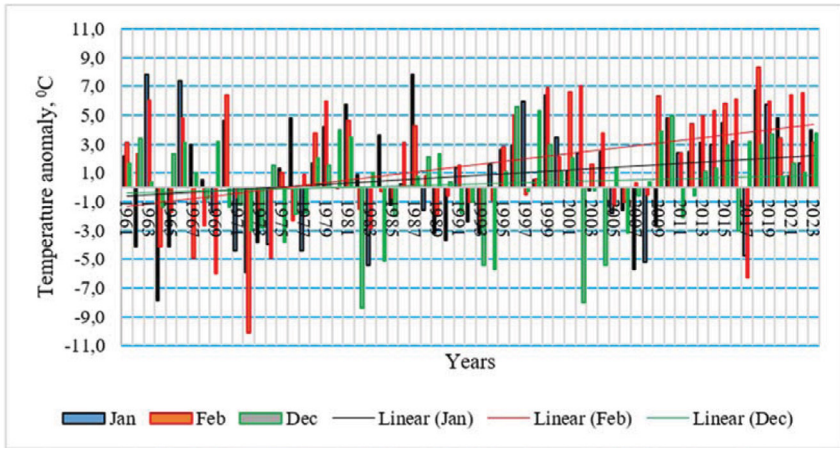


Fig. 2. Time variation trend in the mean monthly maximum temperature anomalies in winter season on the Nakhchivan AR

all temperature indicators show a decline. The long-term mean annual maximum temperature ranges from 17.5 to 20.5 °C, while the minimum temperature varies between −6.0 and 9.2 °C.

Temperature anomalies were calculated relative to the 1961–1990 baseline period:

$$T_{Ai}=T_i-T_{1961-1990}, \qquad (1)$$

where T_{Ai} – is the anomaly, T_i– is the observed temperature, and $T_{1961-1990}$ is the long-term mean for the corresponding month.

The rate of warming or cooling (°C/decade) was used to quantify long-term temperature changes, providing a standard WMO- and IPCC-endorsed metric that facilitates comparison across studies and spatial scales, reflects trend intensity, supports analysis of climate extremes and model projections, and enhances reliability by reducing interannual variability under non-stationary conditions [9; 10; 14; 30].

Combining non-parametric methods with decreasing and moving time series provides robust assessment of temperature trends across multiple temporal scales, with successively shorter periods (1961–2023 to 1991–2023) capturing long-term and recent changes, and 30-year moving windows, consistent with WMO standards, enabling comparable trend analysis and detection of temporal anomalies [5].

Analyzing recurrence frequencies of maximum and minimum temperatures across predefined gradations provides a robust assessment of extreme event intensity, persistence, and spatial characteristics, enabling evaluation of long-term warming or cooling, asymmetries toward higher values, and increases in heat extremes at annual and seasonal scales, while supporting statistical analyses using histograms, empirical distribution functions, percentile-based metrics, and extreme indices, and facilitating climate risk assessment, model validation, regional anomaly detection, and updating of climate norms [15; 26; 29; 32].

Results and Discussion

Long-term Dynamics of Monthly Mean Maximum and Minimum Temperature Anomalies (1961–2023). In this stady anomalies of maximum anda minimum temperatures are calculated in relation to the 1961–1990 reference period.

Long-term winter anomalies of monthly mean maximum and minimum temperatures in Nakhchivan AR (relative to 1961–1990) show a general warming trend from 1961 to 2023, with seasonal variation. Maximum temperature increases are strongest in February (0.92 °C/decade), weakest in December (0.21 °C/decade), and intermediate in January (0.46 °C/decade), with February trends statistically significant. Interannual variability and seasonal differences are summarized in Figure 2 and in Table 4.

Figure 2 shows that, overall, positive winter maximum temperature anomalies in Nakhchivan

Table 4

Some statistical characteristics of the long-term trends of area-averaged monthly maximum and minimum temperature anomalies across the Nakhchivan AR for the period 1961–2023

		Number of month											
		01	02	03	04	05	06	07	08	09	10	11	12
ΔTmax	°C/decade	0.46	0.92	0.59	0.43	0.30	0.55	0.46	0.55	0.36	0.37	0.12	0.21
	r	0.21	**0.43**	**0.39**	**0.36**	**0.31**	**0.51**	**0.50**	**0.55**	**0.37**	**0.38**	0.10	0.12
ΔTmin	°C/decade	0.17	0.49	0.34	0.06	-0.03	0.16	-0.05	0.17	0.27	0.15	-0.02	-0.02
	r	0.08	**0.28**	**0.30**	0.08	-0.02	0.23	-0.08	**0.29**	**0.44**	0.19	-0.02	-0.01

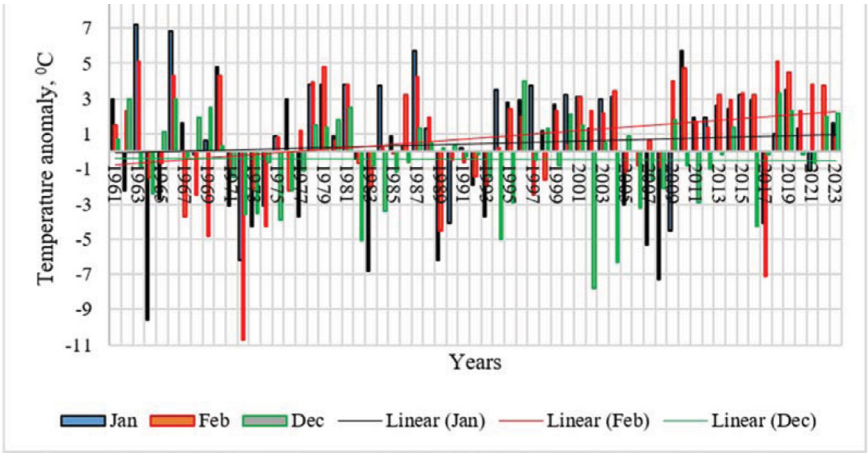


Fig. 3. Time variation trend in the mean monthly minimum temperature anomalies in winter season on the Nakhchivan AR

AR occurred in 57% of December, 69% of January, and 57% of February, with negative anomalies at 41%, 36%, and 41%, respectively. Between 1961 and 1992, negative anomalies were more frequent (December 54%, January 65%, February 69%), reflecting a pronounced winter warming trend of varying intensity. Positive anomalies were mostly concentrated in 1993–2023, and negative anomalies in 1961–1992.

Monthly mean minimum temperature anomalies in Nakhchivan AR show increasing trends only in January (0.17 °C/decade) and February (0.49 °C/decade), with the February trend statistically significant (Figure 3, Table 4).

Figure 3 shows that positive winter minimum temperature anomalies in Nakhchivan AR occurred in 38% of December, 64% of January, and 63% of February, while negative anomalies occurred in 60%, 33%, and 38%, respectively. Between 1961 and 1992, negative anomalies were more frequent (December 45%, January and February 67%), reflecting a variable increase in January and February minima. Most large positive anomalies were recorded during 1993–2023.

Comparative analysis indicates that January maximum temperature anomalies increased 2.7 times, and February 1.9 times, more than minimum anomalies, suggesting that winter warming is primarily driven by faster daytime temperature rises.

Spring monthly mean maximum and minimum temperature anomalies in Nakhchivan AR (relative to 1961–1990) show significant warming in all spring months, with the fastest increase in March (0.59 °C/decade) and the slowest in May (0.30 °C/decade) (Figures 4–5, Table 4).

Positive spring maximum temperature anomalies in Nakhchivan AR occurred in 63% of March, 60% of April, and 57% of May, with negative anomalies at 37%, 40%, and 40%, respectively. Between 1961 and 1992, negative anomalies were more frequent (March 74%, April 64%, May 69%), indicating a variable increase in spring maxima. Positive anomalies were concentrated in 1993–2023,

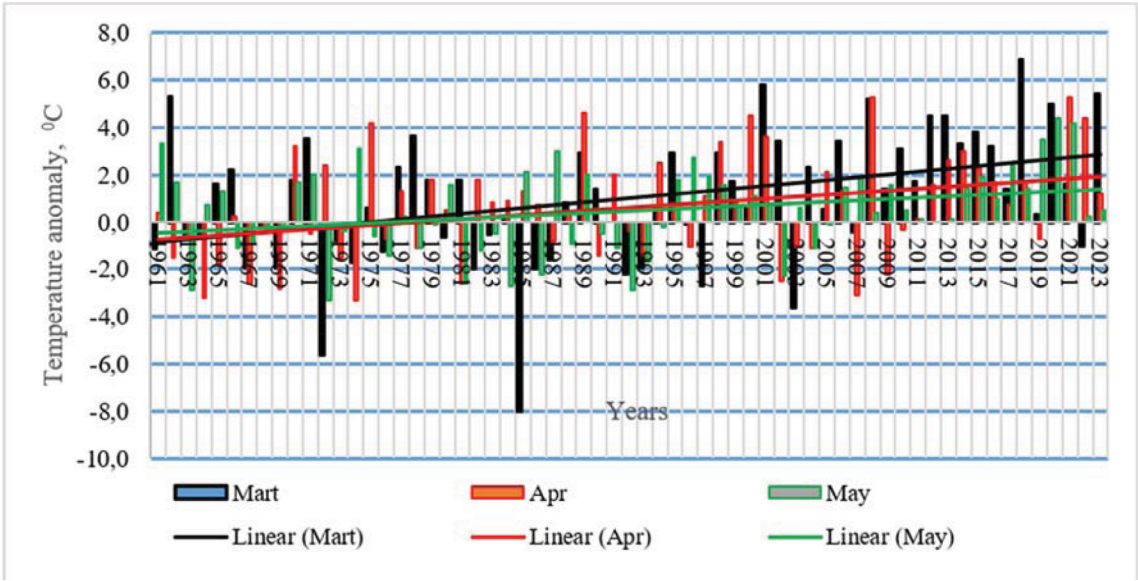


Fig. 4. Time variation trend in the mean monthly maximum temperature anomalies in spring season on the Nakhchivan AR

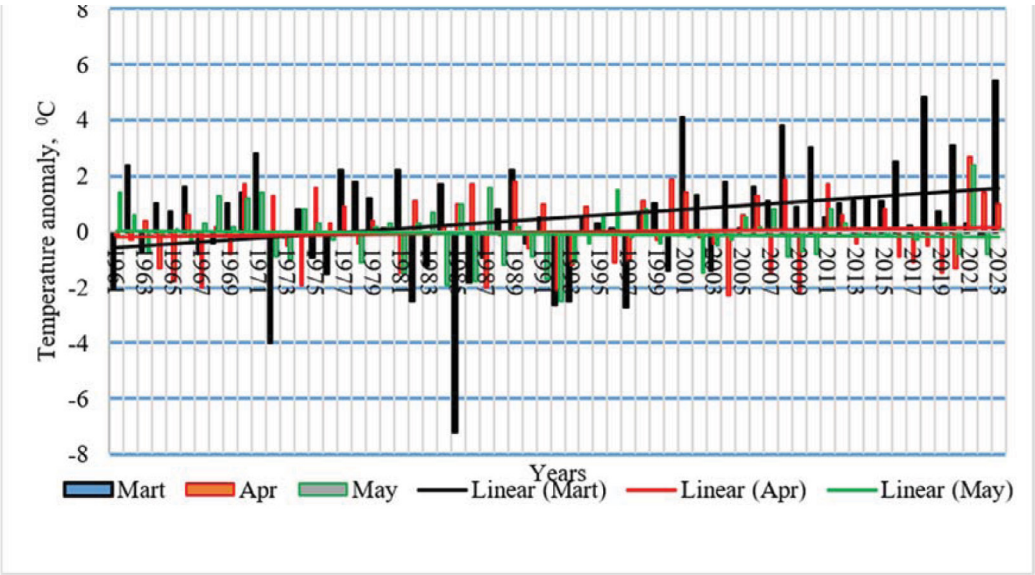


Fig. 5. Time variation trend in the meanmonthly minimum temperature anomalies in spring season on the Nakhchivan AR

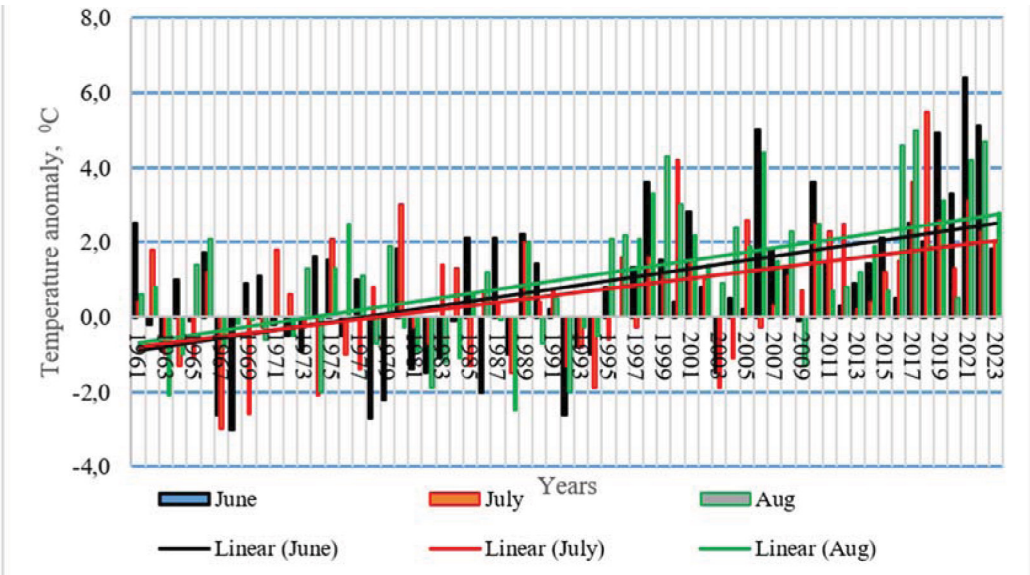


Fig. 6. Time variation trend in the meanmonthly maximum temperature anomalies in summer season on the Nakhchivan AR

while negative anomalies dominated 1961–1992 (Figure 4).

Spring monthly mean minimum temperature anomalies in Nakhchivan AR showed a significant upward trend in March (0.34 °C/decade), a weaker increase in April (0.06 °C/decade), and a non-significant decrease in May (−0.03 °C/decade) (Table 4). Positive anomalies occurred in 68% of March, 44% of April, and 46% of May, while negative anomalies dominated 32%, 51%, and 49% of years, respectively. Between 1961 and 1992, negative anomalies were more frequent, indicating the strongest minimum temperature increase in March. Positive anomalies were concentrated in 1993–2023 (Figure 5).

Comparative analysis indicates that March maximum temperature anomalies increased 1.7 times, and April anomalies 7.1 times, more than minimum anomalies, suggesting that spring warming is mainly driven by faster daytime temperature rises.

Summer monthly mean maximum and minimum temperature anomalies in Nakhchivan AR show significant warming in all months, with the fastest increase in June and August (0.55 °C/decade) and the slowest in July (0.46 °C/decade) (Figures 6–7, Table 4).

Positive summer maximum temperature anomalies in Nakhchivan AR occurred in 65% of June, 62% of July, and 67% of August, with negative anomalies at 40%, 35%, and 35%, respectively. Between 1961 and 1992, negative anomalies were more frequent (June 82%, July 68%, August 86%), indicating a variable increase in summer maxima. Positive anomalies were mainly recorded in 1993–2023, and negative anomalies in 1961–1992 (Figure 6).

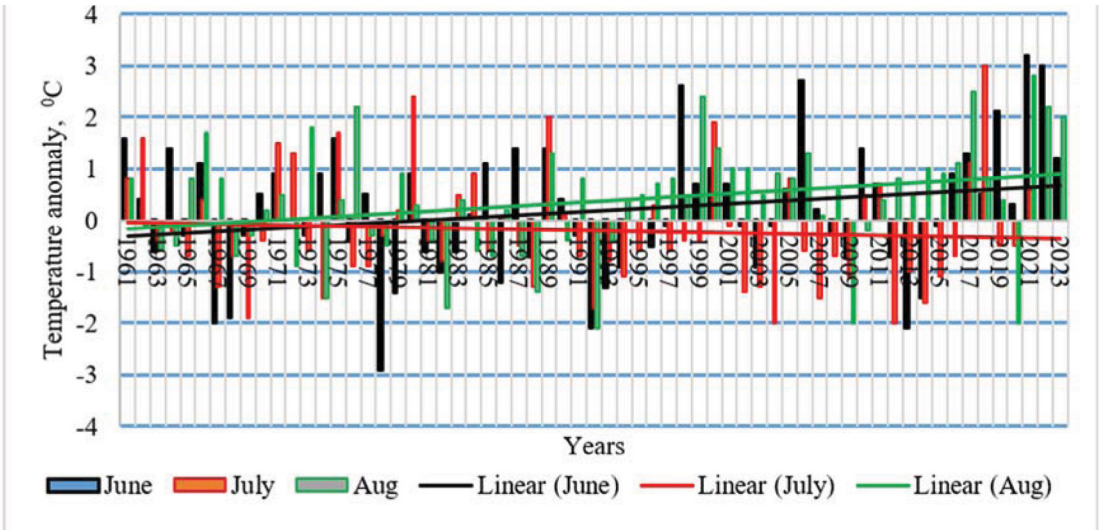


Fig. 7. Time variation trend in the mean monthly minimum temperature anomalies in summer season on the Nakhchivan AR

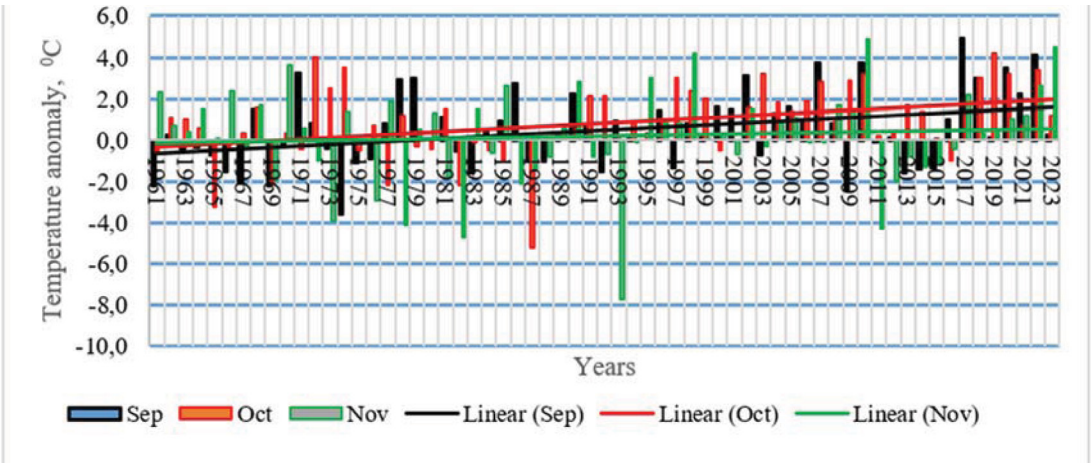


Fig. 8. Time variation trend in the meanmonthly maximum temperature anomalies in autumn season on the Nakhchivan AR

Summer monthly mean minimum temperature anomalies in Nakhchivan AR increased significantly only in August (0.17 °C/decade), rose slightly in June (0.16 °C/decade), and declined non-significantly in July (−0.05 °C/decade) (Table 2). Positive anomalies occurred in 51% of June, 33% of July, and 67% of August, while negative anomalies dominated 46%, 64%, and 33% of years. Between 1961 and 1992, negative anomalies were more frequent, indicating the strongest increase in August minima. Positive anomalies were concentrated in 1993–2023, while roughly half of the negative anomalies occurred in 1961–1992 (Figure 7).

Comparative analysis indicates that June and August maximum temperature anomalies increased 3.3 times more than minima, suggesting that summer warming, like winter and spring, is primarily driven by faster daytime temperature rises.

Autumn monthly mean maximum and minimum temperature anomalies in Nakhchivan AR show increasing trends in all months, with the fastest and statistically significant rises in September (0.36 °C/decade) and October (0.37 °C/decade), and a slower, non-significant increase in November (0.12 °C/decade) (Figure 8, Table 4).

In Nakhchivan AR, positive autumn maximum temperature anomalies occurred in 60% of September, 75% of October, and 57% of November, while negative anomalies occurred in 38%, 25%, and 43% of years. Between 1961 and 1992, negative anomalies were more frequent (September 71%, October 88%, November 56%), indicating variable warming intensity. Positive anomalies were mainly observed in 1993–2023, and negative anomalies in 1961–1992 (Figure 8).

Autumn monthly mean minimum temperature anomalies in Nakhchivan AR increased significantly in September (0.27 °C/decade), rose non-significantly in October (0.15 °C/decade), and slightly declined in November (−0.02 °C/decade) (Table 4). Positive anomalies occurred in 65% of September, 54% of October, and 44% of November, while negative anomalies dominated 29%, 41%, and 33% of years. Between 1961 and 1992, negative anomalies were more frequent, indicating the strongest increase in September minima. Positive anomalies were concentrated in 1993–2023, while

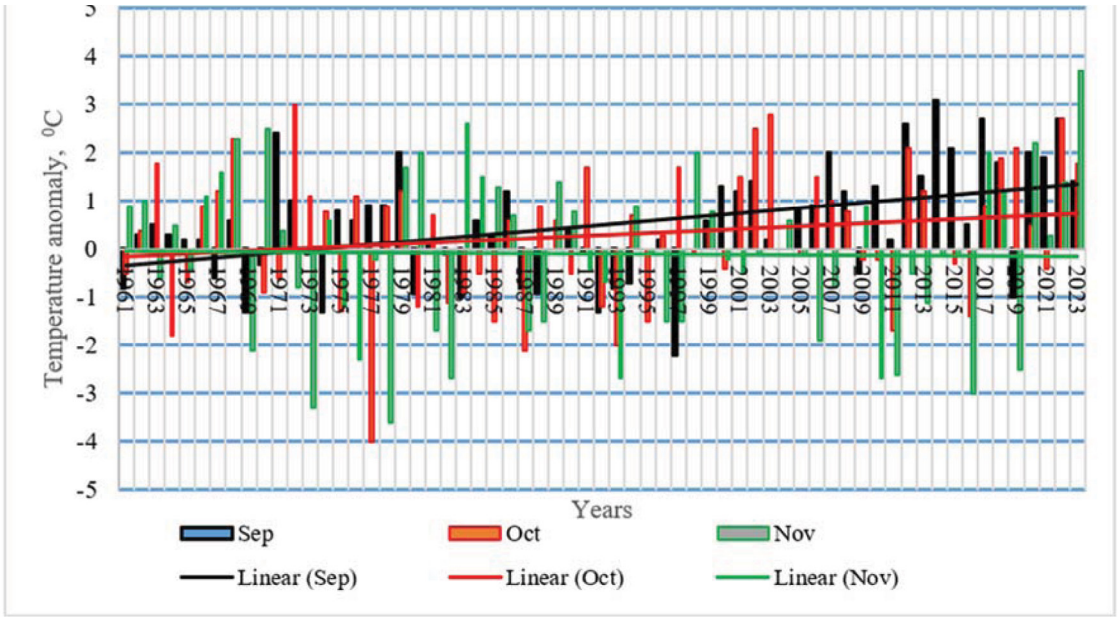


Fig. 9. Time variation trend in the meanmonthly minimum temperature anomalies in autumn season on the Nakhchivan AR

negative anomalies mostly occurred in 1961–1992 (Figure 9).

Comparative analysis shows that September maximum temperature anomalies increased 1.3 times, and October anomalies 2.5 times, more than minima, indicating that autumn warming, like in other seasons, is mainly driven by faster daytime temperature rises.

Temporal Variability of Maximum Temperature Anomaly Trends

Table 5 summarizes the monthly rates of change in maximum temperature anomalies (ΔTmax) across 30-year intervals and selected periods, while Table 6 presents the corresponding Pearson correlation coefficients, indicating the consistency and variability of temporal trends.

During 1961–2023, the strongest winter warming occurred in February at all stations, with statistically significant rates ranging from 0.58 to 1.18 °C/decade ($r > 0.24$). In January, significant warming was detected only at Ordubad and Sharur (0.61–0.64 °C decade/), while December trends were not significant (Tables 5–6).

During the **spring months**, statistically significant warming in maximum temperature was observed at all stations, except for May in Nakhchivan. The warming rates ranged from 0.38 to 0.78 °C/decade in March, 0.34 to 0.54 °C/decade in April, and 0.01 to 0.40 °C/decade in May.

During **autumn,** maximum temperature increased at all stations, with rates of 0.13–0.68 °C/decade in September, 0.14–0.52 °C/decade in October, and 0.02–0.31 °C/decade in November;

Table 5

The rates of change in monthly mean maximum temperature anomalies (°C/decades) for the meteorological stations across different climatic periods.

Station	Periods	Number of month											
		01	02	03	04	05	06	07	08	09	10	11	12
Ordubad	1961-2023	0.61	0.89	0.55	0.44	0.36	0.80	1.12	1.10	0.68	0.52	0.24	0.27
	1971-2023	0.83	1.11	0.76	0.22	0.45	0.93	1.10	1.18	0.49	0.37	0.46	0.59
	1981-2023	0.66	1.06	1.13	0.23	0.61	1.15	1.50	1.56	0.58	0.75	0.61	0.73
	1991-2023	0.87	1.18	1.19	0.51	0.68	1.59	2.09	1.63	0.82	0.40	0.79	0.98
Julfa	1961-2023	0.37	1.07	0.78	0.54	0.51	0.39	0.40	0.73	0.48	0.45	0.31	0.40
	1971-2023	0.73	1.46	1.15	0.46	0.79	0.57	0.45	0.98	0.44	0.48	0.69	0.90
	1981-2023	0.71	1.53	1.74	0.65	1.26	0.81	0.73	1.36	0.67	0.86	0.93	1.31
	1991-2023	1.00	1.52	1.84	0.86	1.71	1.02	0.98	1.16	0.98	0.55	1.04	1.78
Nakhchivan	1961-2023	0.30	0.89	0.63	0.35	0.10	0.42	0.18	0.29	0.21	0.14	0.07	0.01
	1971-2023	0.67	1.34	0.99	0.29	0.32	0.68	0.22	0.45	0.15	0.17	0.26	0.34
	1981-2023	0.46	1.22	1.47	0.43	0.67	1.02	0.44	0.81	0.43	0.51	0.35	0.77
	1991-2023	0.50	1.41	1.50	0.49	0.71	1.23	0.65	0.51	0.39	0.01	0.55	1.00

Продовження Таблиці 5 / Continuation Table 5

Şahbuz	1961-2023	0.39	0.58	0.38	0.34	0.29	0.66	0.43	0.27	0.13	0.39	0.02	0.17
	1971-2023	0.60	0.82	0.55	0.19	0.42	0.84	0.41	0.26	-.03	0.38	0.17	0.48
	1981-2023	0.21	0.75	0.69	-.06	0.42	0.90	0.47	0.35	0.02	0.58	0.03	0.69
	1991-2023	0.03	0.77	0.49	-.12	0.41	1.09	0.65	-.06	-.09	-.00	-.06	0.60
Şharur	1961-2023	0.64	1.18	0.60	0.47	0.25	0.46	0.17	0.38	0.34	0.33	0.13	0.22
	1971-2023	0.92	1.58	0.88	0.45	0.45	0.66	0.21	0.46	0.34	0.48	0.51	0.65
	1981-2023	0.74	1.43	1.11	0.42	0.55	0.87	0.28	0.59	0.41	0.69	0.44	0.79
	1991-2023	1.01	1.73	1.02	0.46	0.60	1.23	0.50	0.22	0.57	0.24	0.50	1.15

Table 6

The Pearson correlation coefficients for the trends of monthly mean maximum temperature anomalies in the Nakhchivan AR over different climatic periods (10-year intervals). Significance expressed as (bold font) $p < 0.05$

Station	Periods	Number of month											
		01	02	03	04	05	06	07	08	09	10	11	12
Ordubad	1961-2023	**0.28**	**0.44**	**0.38**	**0.34**	**0.33**	**0.64**	**0.76**	**0.72**	**0.52**	**0.43**	0.20	0.16
	1971-2023	**0.34**	**0.48**	**0.42**	0.15	**0.35**	**0.63**	**0.69**	**0.68**	**0.35**	**0.27**	**0.28**	**0.27**
	1981-2023	0.23	**0.40**	**0.51**	0.12	**0.38**	**0.64**	**0.75**	**0.70**	**0.34**	**0.45**	**0.39**	0.26
	1991-2023	0.24	0.33	**0.45**	0.20	**0.35**	**0.66**	**0.80**	**0.60**	**0.35**	0.21	0.28	0.27
Julfa	1961-2023	0.16	**0.45**	**0.43**	**0.42**	**0.37**	**0.33**	**0.38**	**0.60**	**0.43**	**0.37**	0.23	0.20
	1971-2023	**0.28**	**0.54**	**0.52**	**0.31**	**0.46**	**0.38**	**0.36**	**0.64**	**0.33**	**0.33**	**0.42**	**0.37**
	1981-2023	0.23	**0.50**	**0.61**	**0.35**	**0.56**	**0.42**	**0.45**	**0.70**	**0.41**	**0.47**	**0.46**	**0.40**
	1991-2023	0.26	**0.38**	**0.54**	**0.34**	**0.57**	**0.39**	**0.44**	**0.52**	**0.43**	0.26	**0.40**	**0.42**
Nakhchivan	1961-2023	0.13	**0.36**	**0.35**	**0.30**	0.10	**0.37**	0.21	**0.32**	0.20	0.15	0.01	0.00
	1971-2023	0.26	**0.48**	**0.43**	0.21	0.26	**0.50**	0.21	**0.40**	0.12	0.15	0.17	0.15
	1981-2023	0.15	**0.40**	**0.51**	0.25	**0.46**	**0.60**	**0.35**	**0.55**	0.28	**0.37**	0.18	0.26
	1991-2023	0.14	**0.35**	**0.42**	0.22	**0.39**	**0.56**	**0.38**	0.30	0.20	-0.02	0.23	0.26
Şahbuz	1961-2023	0.20	**0.33**	**0.26**	**0.28**	**0.30**	**0.56**	**0.46**	**0.26**	0.12	**0.35**	0.02	0.10
	1971-2023	**0.28**	**0.42**	**0.30**	0.13	**0.36**	**0.60**	**0.39**	0.22	-0.02	**0.29**	0.11	0.23
	1981-2023	0.09	**0.36**	**0.30**	-0.03	**0.31**	**0.54**	**0.36**	0.21	0.01	**0.35**	0.02	0.26
	1991-2023	0.00	0.28	0.17	-0.05	0.25	0.51	**0.39**	-0.02	-0.04	0.00	-.02	0.18
Şharur	1961-2023	**0.26**	**0.47**	**0.38**	**0.37**	**0.25**	**0.40**	0.18	**0.39**	**0.36**	**0.35**	0.09	0.12
	1971-2023	**0.32**	**0.54**	**0.45**	**0.30**	**0.38**	**0.47**	0.18	**0.39**	**0.30**	**0.41**	**0.30**	**0.29**
	1981-2023	0.21	**0.45**	**0.47**	0.23	**0.37**	**0.49**	0.19	**0.39**	**0.30**	**0.50**	0.22	0.27
	1991-2023	0.22	**0.41**	**0.38**	0.19	0.33	**0.51**	0.24	0.11	0.30	0.17	0.18	0.30

however, statistically significant trends were limited to Ordubad (September–October), Julfa and Sharur (September), Shahbuz (October).

The results summarized in Table 7 show a consistent increase in maximum temperatures across all months, seasons, and annually during 1961–2023. Statistically significant warming was observed in 47% of winter cases, 93% in spring, 87% in summer, 47% in autumn, and 68% annually, indicating that the strongest significant increases occurred in spring and summer.

For the subsequent climatic periods (1971–2023, 1981–2023, 1991–2023), generalized trends in maximum temperature anomalies (Tmax) were as follows.

1) **1971–2023:** Warming signals strengthened and persisted in winter and autumn, whereas spring and summer exhibited relatively weaker warming.

2) **1981–2023:** Weaker warming was observed in winter, spring, and autumn, as well as annually, while summer showed a relatively stronger warming trend.

3) **1991–2023:** Winter warming occurred in all months, with significance in 27% of cases. Spring and summer warming affected 93% of months, with 53% and 73% statistically significant, respectively. Autumn warming occurred in 80% of months (20% cooling), but only 20% was significant. Annually, warming prevailed in 92% of years (8% cooling), with 43% reaching statistical significance.

4) Across all periods, winter warming was persistent, with statistically significant cases increasing from 47% to 73% before declining to 27%

Table 7

Generalized table of positive and negative values of the rates of maximum temperature anomalies and the recurrence of cases of their observation (in %) in the territory of Nakhchivan AR for different climatic periods, seasons and years. Recurrence of months showing warming or cooling in the numerator, recurrence of months with statistically significant warming or cooling in the denominator

Periods	Winter		Spring		Summer		Autumn		Year	
	war-ming	coo-ling	war-ming	cool-ing	war-ming	cool-ing	war-ming	coo-ling	warm-ing	cool-ing
1961-2023	100/47	0/0	100/93	0/0	100/87	0/0	100/47	0/0	100/68	0/0
1971-2023	100/73	0/0	100/73	0/0	100/80	0/0	93/80	0/0	98/77	0/0
1981-2023	100/47	0/0	93/60	7/0	100/87	0/0	100/67	0/0	98/65	2/0
1991-2023	100/27	0/0	93/53	7/0	93/73	7/0	80/20	20/0	92/43	8/0

in 1991–2023. Spring warming occurred in nearly all months (93–100%), although significance decreased from 93% to 53%. Summer warming was widespread (93–100%) and consistently highly significant (73–87%). Autumn warming was more variable, with peak significance (80%) in 1971–2023. Annually, warming affected 92–100% of years, with statistical significance ranging from 43% to 77%.

These results demonstrate that warming trends are seasonally and temporally variable, with spring and summer exhibiting the most consistently significant increases.

Temporal Variability of Minimum Temperature Anomaly Trends

Table 8 summarizes monthly trends in minimum temperature (ΔTmin) anomalies, with corresponding Pearson correlation coefficients shown in Table 9. During 1961–2023, **winter** warming was strongest in February at all stations (0.42–0.97 °C/decade), with statistically significant increases at Ordubad, Julfa, and Sharur. January trends were positive but not significant (0.34–0.66 °C/decade), while December exhibited non-significant cooling or weak warming depending on the station.

Table 8

The rates of change in monthly mean minimum temperature anomalies (°C/decades) for the meteorological stations across different climatic periods

Station	Periods	Number of month											
		01	02	03	04	05	06	07	08	09	10	11	12
Ordubad	1961-2023	0.34	0.42	0.44	0.23	0.24	0.56	0.38	0.58	0.68	0.23	0.16	-.02
	1971-2023	0.60	0.69	0.68	0.18	0.37	0.58	0.22	0.53	0.66	0.26	0.44	0.33
	1981-2023	0.51	0.65	1.09	0.34	0.65	0.90	0.47	0.83	1.06	0.54	0.56	0.37
	1991-2023	0.40	0.92	1.22	0.49	0.87	1.28	0.74	0.80	1.42	0.41	0.86	0.57
Julfa	1961-2023	0.35	0.69	0.40	0.21	0.05	0.23	0.01	0.34	0.63	0.50	0.32	0.15
	1971-2023	0.45	0.94	0.65	0.18	0.11	0.25	-.04	0.45	0.73	0.65	0.49	0.38
	1981-2023	0.34	0.90	1.03	0.23	0.17	0.24	0.00	0.59	0.97	0.75	0.45	0.33
	1991-2023	0.12	1.13	1.20	0.40	0.27	0.41	0.16	0.50	1.41	0.90	0.91	0.51
Nakhchivan	1961-2023	-.07	0.40	0.22	-.20	-.28	-.05	-.37	-.13	-.10	-.11	-.22	-.20
	1971-2023	0.14	0.72	0.46	-.22	-.17	0.13	-.28	0.09	0.00	0.02	-.07	0.05
	1981-2023	0.05	0.69	1.05	0.05	0.20	0.57	0.13	0.62	0.65	0.46	0.09	0.31
	1991-2023	-.43	1.14	1.24	0.16	0.30	0.91	0.45	0.50	0.68	0.38	0.17	0.62
Şahbuz	1961-2023	-.12	0.23	0.19	-.18	-.25	-.03	-.27	-.10	-.16	-.23	-.27	-.03
	1971-2023	0.12	0.51	0.35	-.30	-.19	0.04	-.30	-.04	-.18	-.20	-.09	0.39
	1981-2023	-.30	0.34	0.57	-.43	-.19	0.08	-.23	0.13	0.00	-.16	-.24	0.38
	1991-2023	-.64	0.62	0.54	-.45	-.13	0.28	0.13	0.10	0.23	-.28	0.03	0.73
Şharur	1961-2023	0.66	0.97	0.60	0.18	0.19	0.17	-.04	0.22	0.32	0.46	0.07	0.40
	1971-2023	0.66	0.97	0.60	0.18	0.19	0.17	-.04	0.22	0.32	0.46	0.07	0.40
	1981-2023	0.25	0.58	0.74	0.00	0.06	0.02	-.23	-.07	0.26	0.35	-.23	0.20
	1991-2023	0.19	1.16	0.91	0.17	0.08	0.04	-.10	-.36	0.46	0.21	0.02	0.63

Table 9

The Pearson correlation coefficients for the trends of monthly mean minimum temperature anomalies in the Nakhchivan AR over different climatic periods (10-year intervals). Significance expressed as (bold font) p < 0.05

Station	Periods	Number of month											
		01	02	03	04	05	06	07	08	09	10	11	12
Ordubad	1961-2023	0.18	**0.26**	**0.37**	**0.26**	**0.28**	**0.56**	**0.42**	**0.62**	**0.65**	0.23	0.18	-0.01
	1971-2023	**0.30**	**0.37**	**0.45**	0.16	**0.35**	**0.50**	0.21	**0.50**	**0.54**	0.21	**0.41**	0.21
	1981-2023	0.21	**0.31**	**0.57**	0.23	**0.48**	**0.65**	**0.37**	**0.60**	**0.70**	**0.38**	**0.44**	0.18
	1991-2023	0.14	0.33	**0.53**	0.25	**0.50**	**0.69**	**0.41**	**0.46**	**0.69**	0.22	**0.54**	0.21
Julfa	1961-2023	0.17	**0.41**	**0.34**	0.23	0.06	0.23	0.02	**0.45**	**0.58**	**0.35**	**0.27**	0.11
	1971-2023	0.21	**0.49**	**0.44**	0.17	0.12	0.20	-0.04	**0.49**	**0.56**	**0.37**	**0.35**	0.23
	1981-2023	0.13	**0.44**	**0.55**	0.16	0.15	0.15	0.00	**0.50**	**0.58**	**0.33**	0.26	0.16
	1991-2023	0.03	**0.42**	**0.56**	0.21	0.17	0.19	0.12	0.33	**0.60**	0.28	**0.38**	0.18
Nakhchivan	1961-2023	-0.03	0.21	0.16	**0.28**	**-0.40**	-0.06	**-0.43**	-0.15	-0.13	-0.12	-0.22	-0.13
	1971-2023	0.05	**0.32**	**0.27**	-0.25	-0.21	0.13	**-0.29**	0.08	0.00	0.02	-0.06	0.03
	1981-2023	0.01	0.29	**0.48**	0.05	0.22	**0.50**	0.12	**0.50**	**0.69**	**0.38**	0.06	0.14
	1991-2023	-0.10	**0.38**	**0.50**	0.12	0.26	**0.56**	0.33	0.33	**0.59**	0.24	0.09	0.20
Şahbuz	1961-2023	-0.05	0.13	0.17	-0.23	**-0.39**	-0.04	**-0.32**	-0.15	-0.23	**-0.28**	-0.23	-0.02
	1971-2023	0.05	0.24	0.26	**-0.30**	-0.26	0.05	**-0.29**	-0.05	-0.21	-0.21	-0.06	-0.20
	1981-2023	-0.09	0.15	**0.33**	**-0.33**	-0.20	0.07	-0.18	0.13	0.00	-0.15	-0.14	0.15
	1991-2023	-0.15	0.20	0.29	-0.27	-0.11	0.20	0.08	0.07	0.17	0.19	0.01	0.22
Şharur	1961-2023	0.17	**0.34**	**0.36**	**0.32**	0.18	0.19	-0.02	**0.30**	**0.53**	**0.38**	-0.04	0.02
	1971-2023	0.24	**0.39**	**0.40**	0.21	0.30	0.20	-0.04	**0.28**	**0.49**	**0.43**	0.05	0.22
	1981-2023	0.08	0.23	**0.40**	0.00	0.07	0.01	-0.19	-0.08	**0.34**	**0.30**	-0.15	0.09
	1991-2023	0.05	**0.35**	**0.44**	0.12	0.08	0.03	-0.06	-0.30	**0.45**	0.14	0.01	0.20

In spring, Tmin exhibited statistically significant warming at Ordubad in all months (0.23–0.44°C/decade), at Julfa in March (0.40°C/decade), at Sharur in March (0.60°C/decade) and April (0.18°C/decade). By contrast, March warming was non-significant in Nakhchivan and Sharur, while April–May cooling occurred, with significant decreases in Nakhchivan (April: −0.20°C/decade) and Shahbuz (May: −0.25°C/decade).

During **summer**, Tmin increased significantly in Ordubad (0.38–0.58 °C/decade), with similar trends in Julfa and Sharur in August. In contrast, Nakhchivan (−0.37 °C/decade) and Shahbuz (−0.27 °C/decade) showed decreasing Tmin trends, with the July declines being statistically significant.

In **autumn**, Tmin showed positive trends in Ordubad, Julfa, and Sharur, and negative trends in Nakhchivan and Shahbuz. Statistically significant warming occurred in Ordubad (September: 0.68 °C/decade), Julfa (all months: 0.32–0.63 °C/decade), and Sharur (September: 0.32 °C/decade; October: 0.46 °C/decade), while significant cooling was observed only in Shahbuz in October (−0.23 °C/decade).

Similar to the Tmax anomalies, for subsequent climatic periods, a series of generalized results were obtained regarding the trend changes in Tmin time series (noting that these trend variations are described by the values presented in Tables 8 and 9) (see Table 10).

1)For 1971–2023, Tmin anomalies indicate continuous winter warming (100%), with 33% statistically significant. Spring warming occurred in 73% of months, though significant cases declined from 47% to 33%, with 27% non-significant cooling. Summer warming rose from 53% to 67%, while significance dropped from 33% to 20%; autumn followed a similar pattern. Annually, warming increased, but significant events nearly halved, and cooling decreased from 37% to 23% without significance, indicating that shorter analysis periods amplify apparent warming trends.

2)For 1981–2023, Tmin trends showed seasonal modulation: winter warming weakened (20% significant, 20% cooling), spring warming increased (40% significant, 7% cooling), and summer–autumn warming rose (60% significant). Annually, warming frequency was stable, with significant warming increasing from 23% to 53% and significant cooling from 0% to 13%.

3) For 1991–2023, Tmin trends showed winter warming in 87% of cases (20% significant) and 13% cooling. Spring warming also affected 87% of months, with fewer significant events. Annually, warming dominated (88%) versus 15% cooling, with 30% of warming and 2% of cooling statistically significant.

Table 10

Generalized table of positive and negative values of the rates of minimum temperature anomalies and the recurrence of cases of their observation (in %) in the territory of Nakhchivan AR for different climatic periods, seasons and years. Recurrence of months showing warming or cooling in the numerator, recurrence of months with statistically significant warming or cooling in the denominator

Periods	Winter		Spring		Summer		Autumn		Year	
	war-ming	coo-ling	war-ming	cool-ing	war-ming	cool-ing	war-ming	coo-ling	warm-ing	cool-ing
1961-2023	67/20	33/0	73/47	27/13	53/33	47/13	60/40	40/7	63/42	37/8
1971-2023	100/33	0/0	73/33	27/0	67/20	33/7	67/53	33/0	77/23	23/0
1981-2023	80/20	20/0	87/40	13/7	80/60	20/0	80/67	20/0	77/53	18/13
1991-2023	87/20	13/0	87/33	13/0	87/27	13/0	93/40	7/0	88/30	15/2

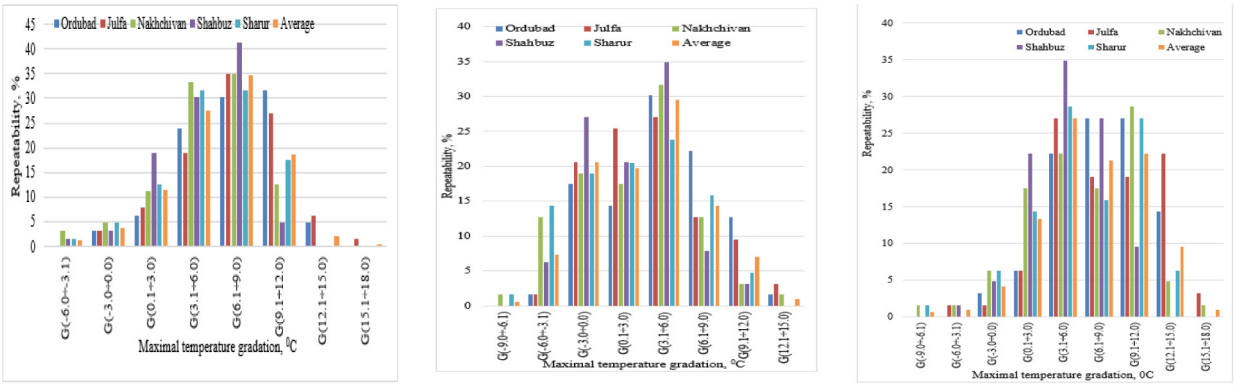
Assessment of the Frequency of Occurrence of Maximum Air Temperature Across Different Gradations

Monthly maximum temperatures in Nakhchivan AR (1961–2023) were analyzed using 3 °C intervals from −9.0 °C to 42.0 °C. For each of the five stations, the number and percentage of observations within each gradation were calculated, averaged across stations, and then compiled for the entire region. The results are presented graphically.

The frequency of occurrence of different maximum temperature gradations during the **winter months** in the Nakhchivan AR is illustrated in Figure 10.

Monthly maximum temperature distributions in Nakhchivan AR exhibited clear spatial patterns. In December, −6.0 to −3.1 °C occurred at Nakhchivan, Shahbuz, and Sharur (1.6–3.2%), 12.1–15.0 °C at Ordubad, Julfa, and Sharur (2.2–6.3%), and 15.1–18.0 °C only at Julfa (1.6%), with 6.1–9.0 °C most frequent; temperatures spanned eight intervals (Figure 10). In January, the coldest maxima (−9.0 to −6.1 °C) appeared at Nakhchivan and Sharur (1.6%), the warmest (12.1–15.0 °C) at Ordubad, Julfa, and Nakhchivan (1.6–3.2%), and 3.1–6.0 °C was most frequent (23.8–34.9%), across eight intervals. In February, −9.0 to −6.1 °C occurred only at Nakhchivan (1.6%), −6.0 to −3.1 °C at Julfa, Nakhchivan, and Shahbuz (1.6% each), and 15.1–18.0 °C at Julfa and Nakhchivan (1.6–3.2%), with 3.1–6.0 °C most frequent (22.2–34.9%); temperatures spanned nine intervals.

In March, negative maxima were absent, 21.1–24.0 °C occurred at Julfa and Nakhchivan (4.8%), Shahbuz did not exceed 18.1–21.0 °C, and 12.1–15.0 °C was most frequent (30.2–41.7%), spanning seven intervals (Figure 11). In April, rapid warming was evident, with most stations showing maximum temperatures of 15.1–18.0 °C and peak values reaching 24.1–27.0 °C. At Shahbuz, 15.1–21.0 °C was most frequent (39.7%), while other stations were dominated by 18.1–24.0 °C (28.6–49.2%); temperatures spanned six intervals. In May, Shahbuz maxima were mostly 18.1–27.0 °C (13–55.6%), Julfa reached 33.1–39.0 °C (1.6%), and other stations were dominated by 24.1–27.0 °C (36.5–58.7%), with seven intervals overall reflecting rapid warming.



December January February

Fig. 10. Repetition of average monthly maximum air temperatures in Nakhchivan AR during winter months in different gradations

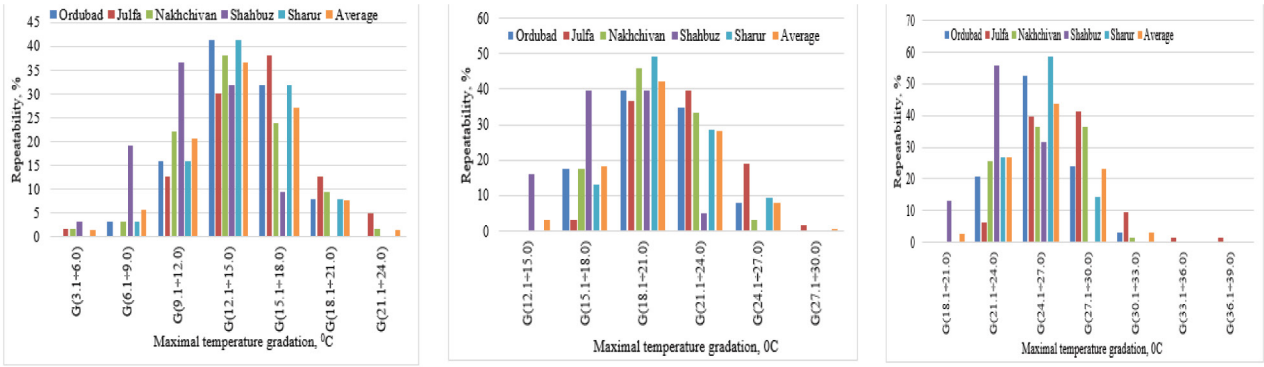


Fig. 11. Repetition of average monthly maximum air temperatures in Nakhchivan AR during spring months in different gradations

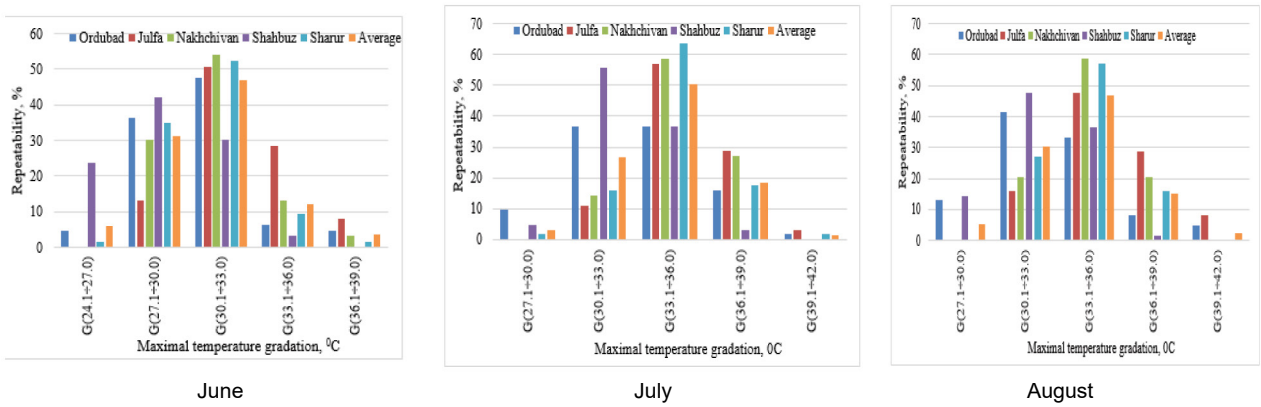


Fig. 12. Repetition of average monthly maximum air temperatures in Nakhchivan AR during summer months in different gradations

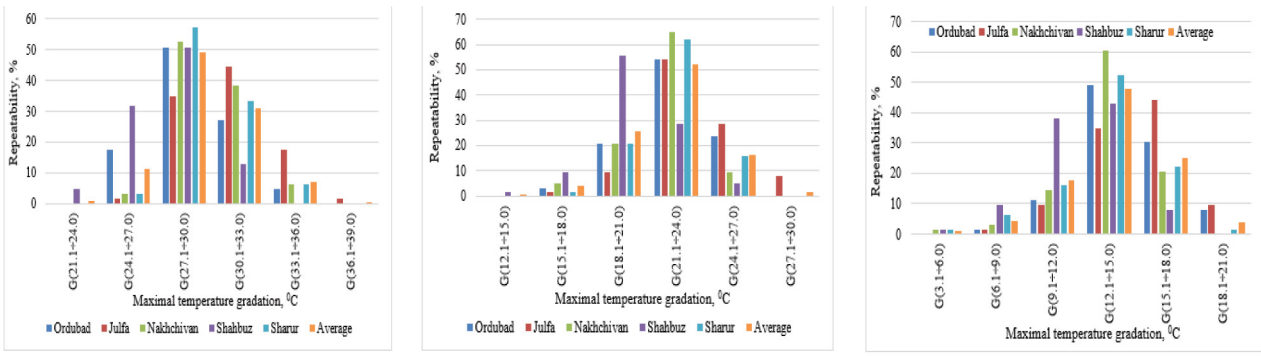


Fig. 13. Repetition of average monthly maximum air temperatures in Nakhchivan AR during autumn months in different gradations

In July, maximum temperatures ranged from 27.1–30.0 °C at Ordubad, Shahbuz, and Sharur, and 30.1–33.0 °C at Julfa and Nakhchivan, with extreme values of 39.1–42.0 °C at Ordubad, Julfa, and Sharur. Shahbuz most frequently recorded 30.1–33.0 °C (55.6%), while other stations favored 33.1–36.0 °C (36.5–63.5%); five gradation intervals were observed (Figure 12). In August, maxima were 27.1–30.0 °C at Ordubad and Shahbuz, 30.1–33.0 °C at other stations, and 39.1–42.0 °C at Ordubad and Julfa. Most frequent gradations were 30.1–33.0 °C at Ordubad and Shahbuz, and 33.1–36.0 °C at Julfa, Nakhchivan, and Sharur; less frequent 36.1–39.0 °C occurred at Julfa and Nakhchivan. Overall, August maxima spanned five intervals (Figure 12).

In September, minimum maxima were 21.1–24.0 °C at Shahbuz and 24.1–27.0 °C at other stations, with highest values at Julfa (36.1–39.0 °C) and 33.1–36.0 °C elsewhere. The most frequent gradation, excluding Shahbuz, was 27.1–30.0 °C (44.4–57.1%); six intervals were observed (Figure 13). In October, minimum maxima were 12.1–15.0 °C at Shahbuz and 15.1–18.0 °C elsewhere, with peaks at Julfa (27.1–30.0 °C) and 24.1–27.0 °C at other stations. Most frequent gradations were 21.1–24.0 °C at Ordubad, Julfa, Nakhchivan, and Sharur, and 18.1–21.0 °C at Shahbuz; six intervals overall.

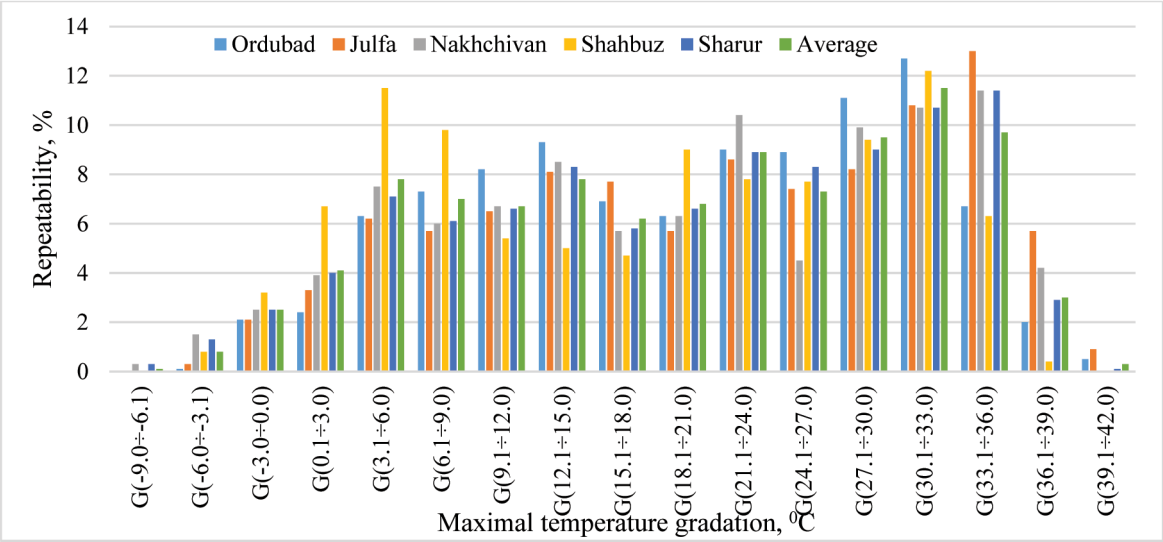


Fig. 14. Repetition of average monthly maximum air temperatures in the Nakhchivan AR in 1961-2023 years period in different gradations

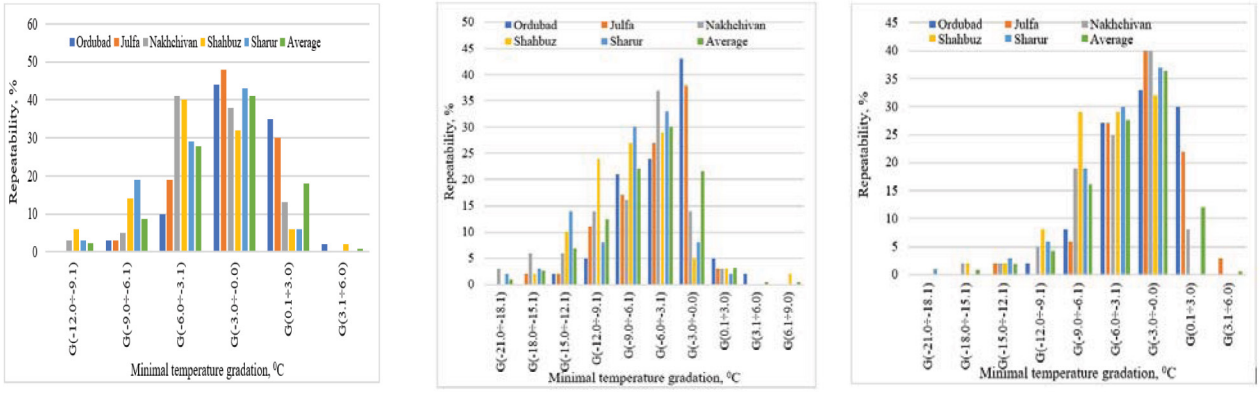
In November, minimum maxima were 3.1–6.0 °C at Nakhchivan, Shahbuz, and Sharur, 6.1–9.0 °C at Ordubad and Julfa, with highest values 18.1–21.0 °C at Ordubad and Julfa and 15.1–18.0 °C at other stations. Most frequent gradations were 12.1–15.0 °C at four stations and 15.1–18.0 °C at Julfa; six intervals overall.

Across all months and stations, maximum temperatures ranged from −9.0–6.1 °C to 39.1–42.0 °C, spanning 17 gradation intervals (Figure 14). At Shahbuz (~400 m higher), lower gradations (−3.0–0.0 °C to 18.1–21.0 °C) recurred 3.2–9.8%, while 30.1–33.0 °C reached 12.2%. At other stations, 30.1–33.0 °C was most frequent (10.7–12.7%).

Frequency Distribution of Minimum Air Temperatures in the Nakhchivan AR

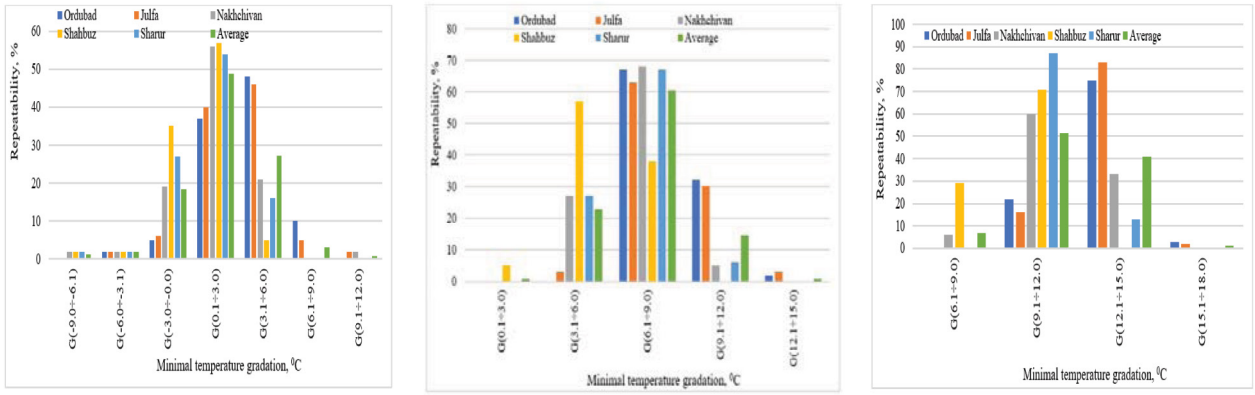
Monthly minimum temperatures in Nakhchivan AR (1961–2023) were analyzed using 3.0 °C intervals (−21.0 to 27.0 °C). Frequencies at five stations were normalized as relative recurrence (%), spatially averaged to represent regional conditions, and integrated across all classes. Results are presented graphically, with winter distributions shown in Figure 15.

In December, minimum temperatures in Nakhchivan AR ranged from −11.8 to 5.0 °C. The −12.0 to −9.1 °C class was infrequent at Nakhchivan, Shahbuz, and Sharur (3–4%), while 3.1–6.0 °C occurred only at Ordubad and Shahbuz (2%). The most frequent classes were −6.0 to −3.1 °C at Nakhchivan (41%) and Shahbuz (40%), and −3.0 to 0.0 °C at Ordubad, Julfa, and Sharur (43–48%); 0.1–3.0 °C was second most frequent at Ordubad and Julfa (30–35%), spanning six intervals. In January, −21.0 to −18.1 °C occurred at Nakhchivan (3%) and Sharur (26%), and 6.1–9.0 °C only at Shahbuz (2%). Most minima were −15.0 to −12.1 °C and 0.1–3.0 °C, with ten intervals overall. In February, −21.0 to −18.1 °C appeared only at Sharur (2%), 3.1–6.0 °C only at Julfa (3%), and −15.0 to 0.0 °C showed increasing recurrence, peaking at −3.0 to 0.0 °C (32–40%), across nine intervals (Figure 15).



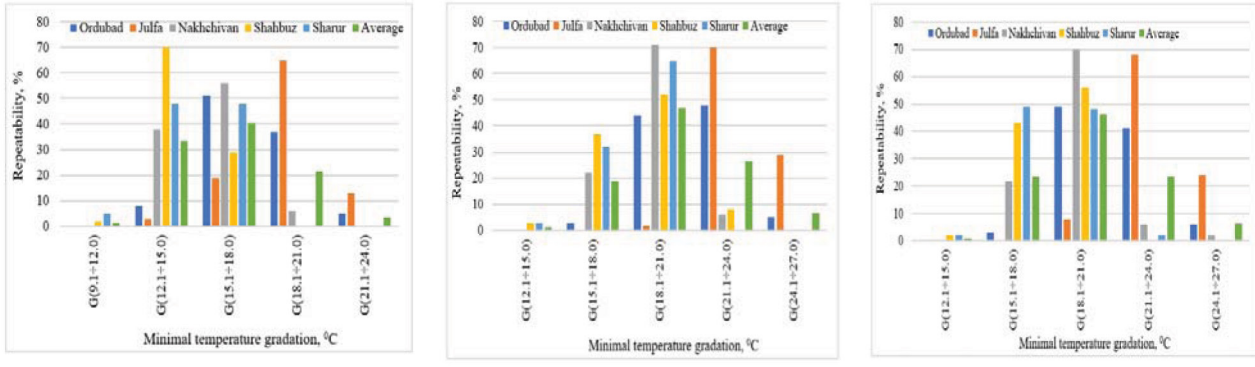
December **January** **February**

Fig. 15. Repetition of average monthly minimum air temperatures in Nakhchivan AR during winter months in different gradations



March April May

Fig. 16. Repetition of average monthly minimum air temperatures in Nakhchivan AR during spring months in different gradations



June July August

Fig. 17. Repetition of average monthly minimum air temperatures in Nakhchivan AR during summer months in different gradations

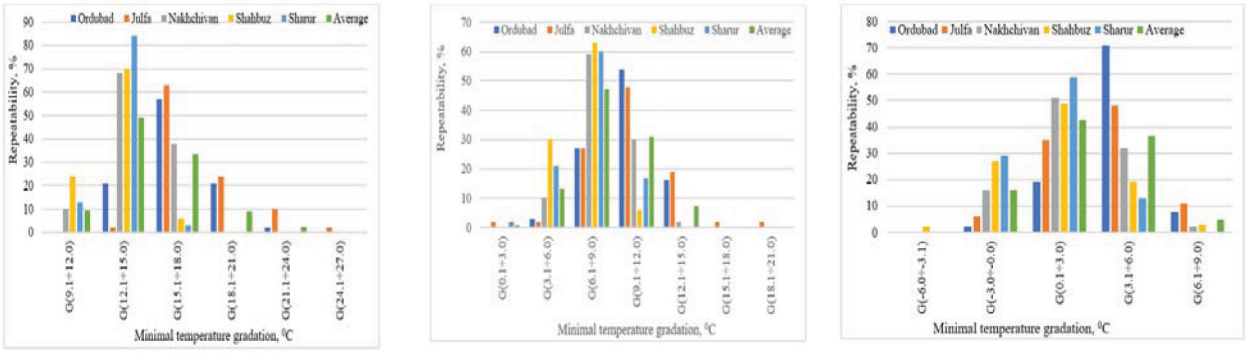
In March, negative minima (−9.0 to −3.1 °C) were rare (≤2%), with highest positive minima (9.1–12.0 °C) recorded infrequently at Nakhchivan, Julfa, and Ordubad. Dominant classes were 0.1–3.0 °C at Nakhchivan, Shahbuz, and Sharur (54–57%) and 3.1–6.0 °C at Ordubad and Julfa (46–48%), while Shahbuz showed higher recurrence in −3.0 to 0.0 °C; seven intervals were observed. In April, minima were 6.1–9.0 °C at most stations (63–68%), with Shahbuz dominated by 3.1–6.0 °C (57%), and higher minima (12.1–15.0 °C) were least frequent at Ordubad and Julfa (2–3%); five intervals overall. In May, minima were most frequent in 12.1–15.0 °C at Ordubad (75%) and Julfa (83%), and 9.1–12.0 °C at Nakhchivan (60%), Shahbuz (71%), and Sharur (87%), spanning two to three intervals depending on station (Figure 16).

In June, minimum temperatures spanned five gradation intervals, with Ordubad and Julfa showing four and other stations three. Dominant classes were 15.1–21.0 °C at Ordubad and Julfa, 12.1–18.0 °C at Nakhchivan, and 12.1–15.0 °C at Shahbuz and Sharur (Figure 17). In July, minima shifted higher, peaking at 18.1–24.0 °C at Ordubad and Julfa, 15.1–18.0 °C at Nakhchivan, and 15.1–18.0 °C at Shahbuz and Sharur. August distributions were similar to July.

In September, Tmin distributions varied among stations. Ordubad and Julfa peaked at 15.1–18.0 °C (57–63%), with secondary peaks at 18.1–21.0 °C; Nakhchivan was dominated by 12.1–15.0 °C (68%), while Shahbuz and Sharur peaked in mid-range classes (70–84%). In October, minima showed pronounced spatial variability: Ordubad and Nakhchivan peaked at 6.1–12.0 °C, Shahbuz at 6.1–9.0 °C (63%), Sharur at 6.1–9.0 °C (60%), and Julfa spanned 0.1–18.1 °C, with highest recurrence at 6.1–9.0 °C (48%). In November, minima were mainly negative or low positive, with notable spatial variability: −6.0 to −3.1 °C occurred once at Shahbuz, −3.0 to 0.0 °C at all stations (2–29%), 0.1–3.0 °C at 9–59%, 3.1–6.0 °C at 13–71%, and 6.1–9.0 °C at 0–11% (Figure 18).

The results of minimum temperature recurrence across all months and stations are presented in Figure 19. As shown, the temperatures were recorded across 16 gradation intervals, ranging from the lowest –21.0 to –18.1 °C to the highest 24.1–27.0 °C.

Analysis of Tmin distributions in Nakhchivan AR highlights strong altitudinal and orographic effects



September October November

Fig. 18. Repetition of average monthly minimum air temperatures in Nakhchivan AR during autumn months in different gradations

on extreme cold. The lowest class (−21.0 to −18.1 °C) occurred only at Nakhchivan (0.6%) and Sharur (0.3%), while the higher-elevation Shahbuz (~400 m above) showed none, indicating that elevation constrains extreme cold events and underscores topography's role in local climatic responses.

Spatial variations in Tmin classes (−18.0 to −15.1 °C at Julfa and Shahbuz vs −15.0 to −12.1 °C at Ordubad) underscore topographic and local microclimate influences. Non-monotonic, oscillatory patterns across stations indicate multiple thermal regimes and significant statistical heterogeneity in minimum temperature fields.

Station-specific Tmin patterns reveal distinct thermal characteristics. Ordubad spans −3.0 to 21.0 °C with relatively uniform recurrence (10.1–12.7%), Julfa peaks at low-moderate (−3.0 to 3.0 °C) and high (21.1–24.0 °C) classes, Nakhchivan is dominated by moderate temperatures (6.1–21.0 °C), Shahbuz exhibits a narrower range (−3.0 to 3.0 °C and 6.1–15.0 °C) reflecting thermal stability from elevation, and Sharur's 12.1–15.0 °C maxima indicate lower elevation and stronger continental influence.

Tmin distributions indicate that local microclimates modulate regional warming sensitivity. Station variability reflects differential responses to global and regional drivers. Absence of extreme cold at higher elevations and dominance of moderate-to-high classes suggest upward shifts in temperature extremes and reduced severe cold, emphasizing topography and local climate controls on heterogeneous climate change impacts in Nakhchivan.

Conclusion

This study provides a comprehensive assessment of the long-term dynamics of monthly mean maximum and minimum temperature anomalies in the Nakhchivan AR over the period 1961–2023, relative to the 1961–1990 baseline. The results clearly indicate a persistent and seasonally differentiated warming trend across the region.

A key finding is that warming is mainly driven by increases in maximum (daytime) temperatures, which show stronger and more consistent positive trends than minimum (nighttime) temperatures

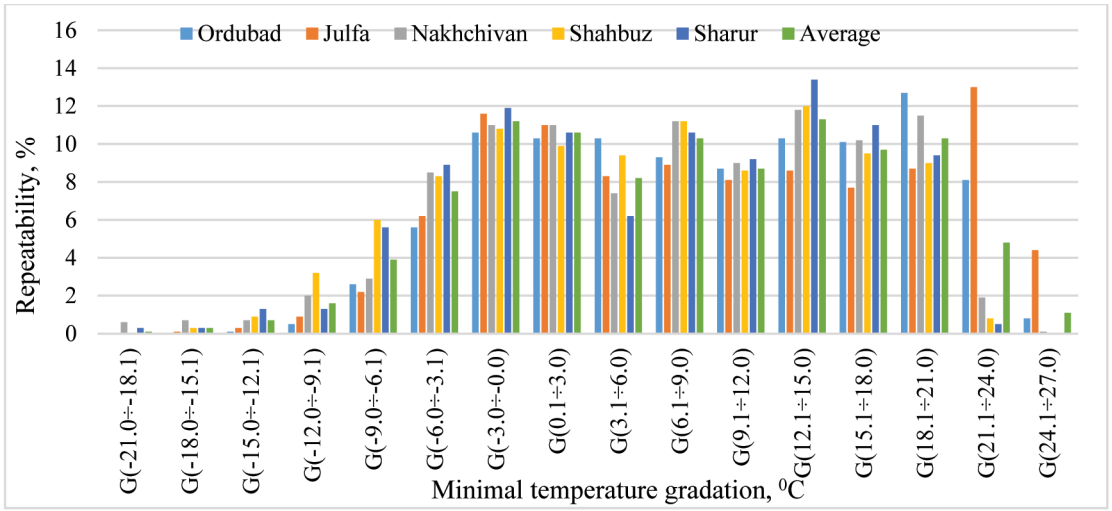


Fig. 19. Repetition of average monthly minimum air temperatures in the Nakhchivan AR in 1961-2023 years period in different gradations

in most months. This asymmetry indicates an intensification of the diurnal temperature range and emphasizes the dominant role of daytime heating in regional climate change.

Seasonal analysis shows that winter warming peaks in February, with significant increases in both temperature types, while other winter months are weaker and more variable. Spring warming occurs in all months, strongest in March, suggesting an earlier onset of warm conditions. Summer warming is significant for maximum temperatures, especially in June and August, whereas minimum temperatures show weaker trends. In autumn, warming is significant in September and October, decreasing toward November.

Another important feature is the clear temporal shift in anomaly patterns. Negative temperature anomalies dominated during the earlier period (1961–1992), whereas positive anomalies became markedly more frequent and intense during the later period (1993–2023). This shift provides strong evidence of an accelerated warming regime in recent decades.

The gradation-based analysis of maximum air temperature (1961–2023) reveals clear seasonal patterns and elevation-dependent spatial variability. Low temperatures dominate in winter, followed by rapid spring warming and dominant summer gradations (30–36 °C), with extremes up to 39–42 °C. In autumn, temperatures decline to intermediate ranges. The wide range (−9 to 42 °C) and 17 gradation intervals indicate high climatic diversity and higher temperature frequencies in lowlands.

Similarly, minimum temperature analysis shows strong seasonal and topographic influences. Low values prevail in winter, while higher Tmin classes dominate in summer. Tmin ranges from −21 to 27 °C (16 intervals). Spatial patterns indicate fewer extreme cold events at higher elevations and broader variability in lowlands, confirming reduced cold extremes and a heterogeneous, locally controlled warming pattern.

Overall, the findings demonstrate that the climate of the Nakhchivan AR has undergone significant warming over the past six decades, characterized by strong seasonal variability and a dominant contribution of increasing maximum temperatures.

The identified warming patterns – particularly the stronger rise in daytime temperatures and seasonal asymmetry – underscore the need for region-specific adaptation strategies. In the Nakhchivan AR, priorities include improved water management under higher evaporation, optimized agricultural practices, and strengthened heat-risk management. The dominance of maximum temperature increases also points to growing heat stress risks, relevant for public health and energy planning.

Future research should address extreme temperature indices (e.g., heatwaves and cold spells) and examine atmospheric circulation and land–atmosphere interactions driving these trends. The use of high-resolution climate models and scenario-based projections, along with sectoral impact assessments (agriculture, hydrology, health), would enhance climate risk evaluation and adaptation planning.

Конфлікт інтересів: автор повідомляють про відсутність конфлікту інтересів

Декларація про використання генеративного штучного інтелекту: автор підтверджує, що під час підготовки рукопису не використовувалися інструменти штучного інтелекту.

Conflict of Interest: The author declares no conflict of interest.

Declaration of use of generative artificial intelligence: The author confirm that no AI tools were used during the preparation of the manuscript.

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Спостережувані зміни щомісячних максимальних та мінімальних температур у Нахчиванській автономній республіці (Азербайджан) між 1961 та 2023 роками

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АНОТАЦІЯ

Дослідження спрямоване на розробку та вдосконалення методів дослідження для виявлення змін, викликаних кліматом, з особливим акцентом на максимальні та мінімальні температури повітря. Зокрема, воно спрямоване на створення надійних статистичних та спектральних методів, які можуть ідентифікувати часові тенденції, добові коливання та екстремальні температурні явища. Інтегруючи спостережувані температурні записи з оптимізованими аналітичними інструментами, дослідження має на меті підвищити точність і надійність регіональних кліматичних оцінок. Температурні аномалії були пов'язані з кліматологічною нормою ВМО 1961–1990 років, а швидкості потепління/похолодання (°C/десятиліття) кількісно визначали часові тенденції. Використання непараметричних методів, рухомих часових вікон та аналізу частоти повторюваності в різних градаціях температури дозволило надійно виявляти довгострокові зміни, нещодавні зрушення та асиметрії в

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розподілі температури. За період 1961–2023 років було встановлено стабільне та широкомасштабне підвищення максимальної температури протягом усіх місяців і на всіх станціях. Найбільш інтенсивне потепління спостерігається взимку, зокрема у лютому (до 1,18°C/десятиліття), навесні – у березні (до 0,78°C/десятиліття), влітку – з червня по серпень (до 1,50–2,09°C/десятиліття) та восени – з вересня по жовтень. Найбільш статистично значущі тенденції Tmax характерні для весни (до 93% випадків) та літа (до 87%), що свідчить про найбільшу стабільність потепління протягом теплого сезону. Аналіз різних кліматичних періодів виявляє інтенсифікацію темпів потепління максимальної температури з часом, особливо після 1980-х років та найпомітніше протягом 1991–2023 років. Мінімальна температура демонструє більш складну та неоднорідну поведінку, включаючи стабільне потепління взимку, змішані тенденції навесні, локалізоване похолодання влітку (липень) та виражені просторові контрасти восени. Було встановлено, що клімат регіону характеризується зростанням екстремумів температур, зростанням частоти класів високих температур та посиленням міжсезонних та міжстанційних контрастів. Швидке підвищення максимальних температур навесні та влітку може негативно вплинути на різні сектори економіки в найближчі десятиліття. Такі дослідження є важливими для розуміння зміни клімату та відіграють вирішальну роль у моніторингу та аналізі кліматичних тенденцій для підтримки політиків у стратегіях пом'якшення наслідків та адаптації.

Ключові слова:

Нахчиванська автономна область Азербайджану, зміна клімату, аномалії максимальної та мінімальної температури, лінійний тренд, градація температури, різні кліматичні періоди, частота класів високих температур, асиметричне потепління максимальних та мінімальних температур/