

ASSESSMENT OF MONTHLY MAXIMUM AND MINIMUM
AIR TEMPERATURE CHANGES TENDENCY IN THE
NAKHCHIVAN AUTONOMOUS REPUBLIC BASED ON
NORMAL VALUES

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Abstract

This study investigates monthly and spatial variations in maximum and minimum air temperatures across the Nakhchivan Autonomous Republic of Azerbaijan. Based on observations from five hydrometeorological stations covering 1961–2020, statistical methods were applied to quantify changes in temperature extremes between the reference periods 1961–1990 and 1991–2020. The analysis also establishes updated climatological norms and evaluates the influence of elevation and seasonal factors on the spatial distribution of temperature patterns.

Key words: Nakhchivan Autonomous Republic, air temperature extremes, climatic normal, spatiotemporal variability, climate change

Introduction. Maximum and minimum air temperatures are key climatic variables influencing ecosystems, agriculture, and socio-economic systems [1]. Beyond mean conditions, temperature extremes significantly affect ecological stability and crop productivity; increasing heat events may reduce global calorie production by up to 4.4% per 1 °C of warming [2].

The diurnal temperature range ($T_{\max} - T_{\min}$) also plays a critical role in crop phenology and physiological processes, while adaptive practices such as improved irrigation and soil management can partially mitigate these impacts [3–7].

Despite extensive research, most studies focus on large-scale patterns, whereas regional analyses remain limited. This study addresses this gap by examining $T_{\max}$ and $T_{\min}$ variability and their implications for regional climate risk.

Previous studies indicate asymmetric warming, with minimum temperatures increasing faster than maximum temperatures, especially since the late twentieth century [8]. This pattern is observed in Europe and Azerbaijan, where warming is particularly pronounced in winter and largely driven by rising minimum temperatures [8–11].

The aim of this study is to assess long-term changes in monthly $T_{\max}$ and $T_{\min}$ in the Nakhchivan AR by comparing climate normals for 1961–1990 and 1991–2020 [12,13], with emphasis on seasonal patterns and asymmetric warming.

The study evaluates monthly changes, their seasonal consistency, altitudinal distribution, and potential impacts on ecosystems, agriculture, and human activities.

The results improve understanding of regional climate change and support monitoring and adaptation. The novelty lies in the comprehensive analysis of $T_{\max}$ and $T_{\min}$ normals based on previously unpublished data.

Materials and methods. Monthly $T_{\max}$ and $T_{\min}$ air-temperature data (1961–2020) were obtained from five meteorological stations in the Nakhchivan AR: Ordubad, Julfa, Nakhchivan, Shahbuz, and Sharur, representing different altitudinal levels and landscape zones (Fig. 1). Elevations range from lowland to mountainous areas, ensuring coverage of the region’s spatial climatic variability [14]. They are suitable for analysis due to their representation of the mountain–plain gradient, long-term continuous observations, and data reliability. They provide a robust basis for regional-scale assessment of temperature variability.

$T_{\max}$ and $T_{\min}$ were calculated as arithmetic means of daily maximum and minimum values. Climate change was assessed through comparison of tempera-

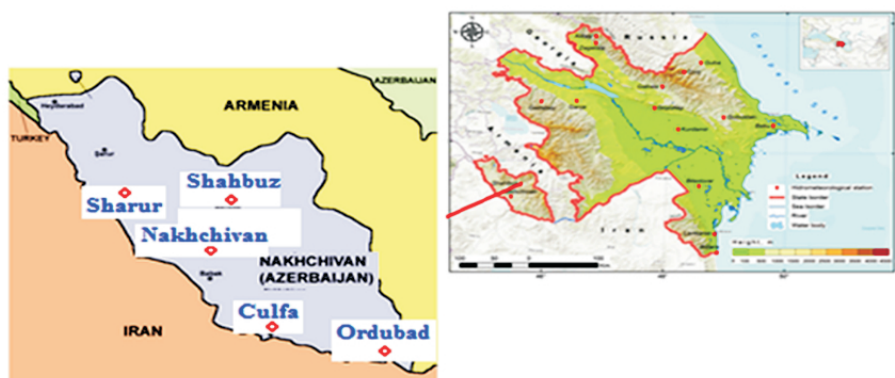


Fig. 1. Location of the study area and spatial distribution of the meteorological stations

ture normals for 1961–1990 and 1991–2020, following approaches applied in IPCC studies [15].

Temporal variability of temperature was evaluated using the root mean square deviation (*RMSD*) [16].

$$(1) \quad RMSD = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2},$$

where x_i denotes the observed values, $\bar{x}$ represents the mean value, and n is the number of observations.

Low *RMSD* values indicate relatively stable conditions, whereas higher values suggest increased variability and potential occurrence of extreme events, with implications for ecosystems and agriculture [16, 17].

To assess the relationship between temperature and altitude, a simple linear regression model was applied:

$$(2) \quad T = a + bH,$$

where T represents the monthly maximum or minimum temperature, H is the station elevation above sea level.

Results and discussion. Figure 2 illustrates the annual pattern of mean $T_{\max}$ recorded at meteorological stations across the Nakhchivan AR during 1991–2020, together with the magnitude of changes relative to the 1961–1990 baseline period.

In winter, $T_{\max}$ showed the highest variability across all stations, with *RMSD* values of 2.1–3.7 °C. Monthly normals averaged 5.0–7.5 °C in December, 2.5–5.3 °C in January, and 7.1–9.8 °C in February (Fig. 2a). Warming magnitude ranged from 0.2–0.4 °C in December, 1.0–1.9 °C in January, and reached the highest values in February (1.8–3.4 °C), indicating the strongest winter increase across the study period (Fig. 2b).

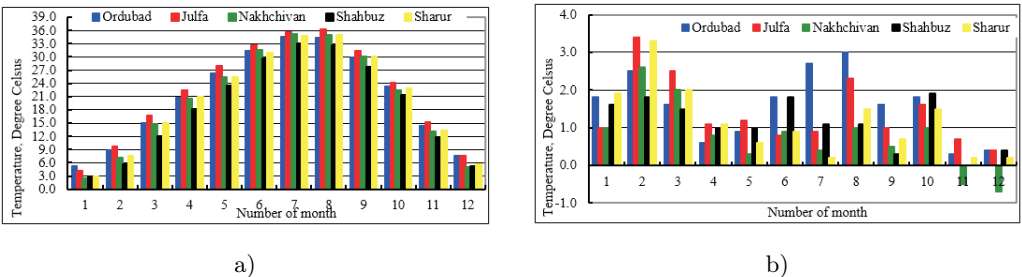


Fig. 2. Annual patterns of long-term monthly mean $T_{\max}$ at various stations across the Nakhchivan AR. a) Climatological normals for 1991–2020; b) Deviations from the 1961–1990 reference period

In spring, $RMSD$ values ranged from 1.2°C to 2.8°C . Monthly normals were $12.0\text{--}16.7^{\circ}\text{C}$ in March, $18.1\text{--}22.4^{\circ}\text{C}$ in April, and $23.5\text{--}28.0^{\circ}\text{C}$ in May (Fig. 2a). Warming was most pronounced in March ($1.5\text{--}2.5^{\circ}\text{C}$), followed by April ($0.6\text{--}1.1^{\circ}\text{C}$) and May ($0.3\text{--}1.2^{\circ}\text{C}$), indicating a clear early-spring intensification of $T_{\max}$ (Fig. 2b).

In summer, $T_{\max}$ exhibited the lowest variability ($RMSD = 1.3\text{--}1.9^{\circ}\text{C}$). Monthly normals averaged $29.7\text{--}32.6^{\circ}\text{C}$ in June, $33.1\text{--}35.7^{\circ}\text{C}$ in July, and $32.7\text{--}36.3^{\circ}\text{C}$ in August, with the highest values observed at Julfa and the lowest at Shahbuz. The strongest warming occurred in August, increasing by 1.0°C at Nakhchivan and up to 3.0°C at Julfa, whereas June and July experienced more moderate rises (Fig. 2b).

In autumn, variability remained relatively low ($RMSD = 1.1\text{--}1.9^{\circ}\text{C}$). Monthly normals declined from $27.8\text{--}31.4^{\circ}\text{C}$ in September to $21.4\text{--}24.2^{\circ}\text{C}$ in October and $11.9\text{--}15.2^{\circ}\text{C}$ in November (Fig. 2a). Warming magnitudes – except for November at Nakhchivan and Shahbuz – were $0.3\text{--}1.6^{\circ}\text{C}$ in September, $1.0\text{--}1.9^{\circ}\text{C}$ in October, and $0.2\text{--}0.7^{\circ}\text{C}$ in November, with October showing the most substantial increase (Fig. 2b).

Figure 3 presents the mean $T_{\min}$ normals for 1991–2020 and their deviations from the 1961–1990 baseline, illustrating how temperature minima evolved across the study area.

In winter, $T_{\min}$ normals ranged from -4.3°C to -1.1°C at Ordubad and Julfa, with January showing the lowest values (Fig. 3a). At Ordubad, temperature in December decreased by 0.4°C , while Julfa showed a slight increase of 0.1°C ; both stations recorded rises of $1.1\text{--}1.8^{\circ}\text{C}$ in the remaining months. In Nakhchivan, $T_{\min}$ ranged from -6.6°C to -3.6°C , increasing by $0.4\text{--}0.9^{\circ}\text{C}$ in January–February but decreasing by 1.1°C in December. Sharur showed -6.6°C to -3.8°C , with increases of $1.6\text{--}1.9^{\circ}\text{C}$ in January–February and a 0.3°C decline in December. Shahbuz showed negligible change (Fig. 3b).

In spring, $T_{\min}$ was positive at all stations. At Ordubad and Julfa, val-

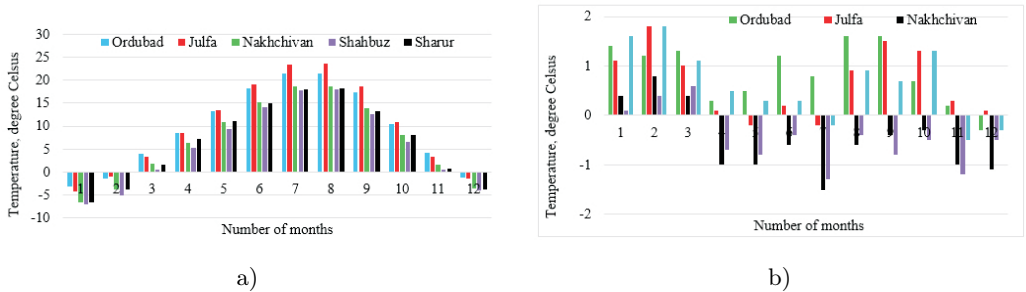


Fig. 3. Annual patterns of long-term mean monthly $T_{\min}$ at various stations across the Nakhchivan AR. a) Climatological normals for 1991–2020; b) Deviations from the 1961–1990 baseline period

ues ranged from 2.6–12.7 °C and 2.4–13.6 °C, with strongest increases in March (1.0–1.3 °C) and April (0.1–0.4 °C), followed by slight decreases in May (Fig. 3a). In Nakhchivan, $T_{\min}$ varied from 1.7–10.9 °C, increasing by 0.5 °C in March but decreasing by 0.9–1.0 °C in April–May. Sharur recorded 1.5–11.3 °C with fluctuations of 0.3–1.1 °C, while Shahbuz ranged from 0.6–9.4 °C, increasing by 0.6 °C in March and decreasing by 0.7–0.8 °C in April–May (Fig. 3b).

During summer, $T_{\min}$ normals varied among stations. At Ordubad and Julfa, values ranged from 18.2–23.5 °C (Fig. 3a). Ordubad showed consistent warming of 1.2–1.6 °C, while Julfa recorded smaller increases, mainly in June (0.2 °C) and August (1.0 °C), with the peak in August. In Nakhchivan, $T_{\min}$ ranged from 15.2–18.6 °C, indicating a cooling of 0.5–1.0 °C (Fig. 3b). Sharur showed 14.9–18.2 °C with moderate warming of 0.2–0.9 °C, while Shahbuz (14.1–18.0 °C) exhibited a similar cooling trend to Nakhchivan.

During autumn (1991–2020), $T_{\min}$ normals at Ordubad, Julfa, and Sharur ranged from 13.3–18.6 °C in September, 8.0–10.8 °C in October, and 0.7–4.2 °C in November (Fig. 3a). Warming was observed in September–October, while Sharur showed slight cooling in November. At Nakhchivan and Shahbuz, $T_{\min}$ varied between 12.6–13.8 °C (September), 6.5–8.0 °C (October), and 6.5–8.0 °C (November), with both stations showing an overall cooling trend of varying intensity across the season.

Temperature asymmetry and elevation dependence. A distinctive feature of recent climatic changes is the asymmetry between daily $T_{\max}$ and $T_{\min}$. Globally, the rate of increase in $T_{\min}$ generally exceeds that of $T_{\max}$ by about a factor of two (≈ 0.1 °C/10 year) [18]. In contrast, observations from the Nakhchivan AR reveal the opposite tendency: $T_{\max}$ have risen more rapidly than $T_{\min}$, indicating a region-specific manifestation of warming dynamics.

Given the applied relevance of temperature extremes, their dependence on elevation was analysed using linear trend equations and correlation coefficients. $T_{\max}$ showed strong negative correlations from February to November, especially between March and October ($r = -0.86$ to -0.98), and weaker relationships in January and December ($r = -0.34$ to -0.55). Lapse rates indicated a decrease of $T_{\max}$ with elevation ranging from 0.52 to 0.92 °C per 100 m. The strongest gradients occurred in March (0.92 °C/100 m), followed by April (0.84 °C/100 m) and May (0.81 °C/100 m). The weakest values were observed in June–July (0.52 °C/100 m), while moderate rates persisted from August to November (0.65–0.70 °C/100 m). Overall, the results confirm a consistent inverse relationship between elevation and $T_{\max}$, with the greatest vertical contrasts appearing in spring (Table 1).

The analysis revealed that correlations between $T_{\min}$ and elevation were generally weak across most months, suggesting that linear regression models are not suitable for such estimates.

T a b l e 1

Calculated monthly values of maximum air temperature at different elevations above sea level

Month	Altitude above sea level, m							
	800	1000	1200	1400	1600	1800	2000	2200
February	8.7	7.0	5.5	3.9	2.4	0.8	−0.8	−2.3
March	15.6	13.8	11.9	10.1	8.3	6.4	4.6	2.7
April	21.4	19.7	18.0	16.4	14.7	13.0	11.3	9.6
May	26.5	24.9	23.6	21.7	20.0	18.4	16.8	15.2
June	31.7	30.6	29.6	28.6	27.5	26.5	25.4	24.4
July	35.1	34.1	33.1	32.1	31.1	30.0	29.0	28.0
August	35.4	34.0	32.6	31.3	29.9	28.6	27.2	25.8
September	30.6	29.2	27.8	26.4	25.0	23.6	22.2	20.8
October	23.4	22.3	21.3	20.3	19.3	18.2	17.1	16.1
November	14.2	13.0	11.8	10.6	9.4	8.2	7.0	5.8

Based on monthly $T_{\max}$ and $T_{\min}$ data for Nakhchivan AR (1961–2020), the main results are:

1) $T_{\max}$ remained positive year-round in 1991–2020, peaking in July–August (32.7–36.3 °C) and lowest in January (2.5–5.3 °C). Most stations show warming relative to 1961–1990, with the strongest increases in February, March, August, and October, especially at Julfa (up to +3.4 °C);

2) $T_{\min}$ were negative in winter (−7.1 to −3.2 °C) and highest in July–August (17.8–23.5 °C). Winter warming is evident at all stations, particularly in February (0.4–1.9 °C), with minor localized cooling in some months;

3) A clear asymmetric warming pattern is observed, with $T_{\max}$ increasing faster than $T_{\min}$, opposite to the global tendency;

4) The $T_{\max}$ lapse rate ranges from 0.81–0.92 °C/100 m in spring and 0.52–0.70 °C/100 m in summer–autumn, indicating a strong inverse altitude–temperature relationship, especially in spring.

Conclusion. The study has several limitations, including data gaps and limited spatial–temporal consistency, while some datasets required homogenization, introducing uncertainties. The linear statistical model may not fully represent complex atmospheric processes, and factors such as land use change, urbanization, and microclimatic variability were not included. The complex topography further limits full representation of local climate variability.

Despite these constraints, results show that $T_{\min}$ increase faster than $T_{\max}$, indicating asymmetric warming. This leads to rising nighttime temperatures and shifts in cold extremes, with important implications for ecosystems, agriculture, biodiversity, phenology, energy demand, and public health.

Overall, long-term $T_{\max}$ and $T_{\min}$ analysis provides a basis for understanding regional climate variability in Nakhchivan and supports adaptation planning and resource management.

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