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Continental–Himalayan controls on shifting temperature extremes: A spatiotemporal assessment of heat and cold days in northern Bangladesh

Md. Moniruzzaman Monir[1]* and Shapla Akhter[1]

[1]*Department of Geography and Environmental Science, Begum Rokeya University, Rangpur, Bangladesh*

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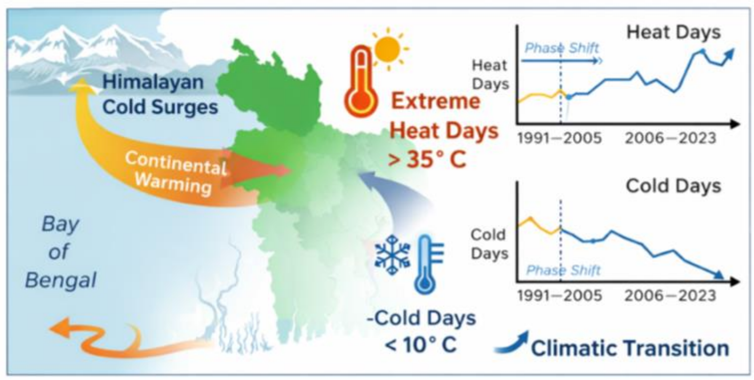
Graphical abstract



Highlights

- *Significant post-2006 increase in extreme heat days (>35°C) detected.*
- *Cold extremes (<10°C) declined sharply during 1991–2005.*
- *Northern Bangladesh is shifting toward a hotter thermal regime.*
- *Continental amplification outweighs Himalayan winter cooling effects.*

Abstract

Understanding shifts in temperature extremes is crucial for agricultural planning and long-term climate adaptation in climatically sensitive regions. This study analyzes daily temperature data from northern Bangladesh (1991–2023) to assess changes in extreme heat (>35°C) and cold (<10°C) days, a region influenced by continentality and limited maritime moderation. After data quality control, trends were evaluated using the modified Mann–Kendall test, and shifts were detected using the Pettitt method. The findings indicate two distinct phases: from 1991 to 2005, cold extremes declined sharply due to weakened Himalayan cold surges, whereas heat extremes showed neutral to slightly negative trends. After 2006, all stations exhibited strong increases in heat days (τ = 2.88–3.49), driven by intensified continental warming and reduced pre-monsoon moisture inflow. Cold-day frequencies remained low, confirming persistent winter warming. Overall, the region is transitioning toward a hotter and less thermally variable climate, requiring targeted adaptation strategies.

*Corresponding author: monirbrur83@gmail.com (MMM)

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1 Introduction

Climate extremes have emerged as one of the most pressing indicators of the accelerating pace of global climate change (Abdullah et al., 2021; Monir et al., 2023). While mean temperature trends provide a broad understanding of warming, the frequency and intensity of extreme temperature events exert the most direct and disruptive impacts on ecosystems, agricultural production, human health, and regional socio-economic stability (Kumar and Sarthi, 2019; Almazroui, 2020; Ehsan et al., 2023). In South Asia, where climatic sensitivity is pronounced, extremes often shift more rapidly than mean conditions, making them a critical focus of contemporary climate research (Roy and Balling, 2005; Roxy et al., 2015).

Northern Bangladesh represents a unique climatic transition zone where both intense summer heat and pronounced winter coolness coexist within a relatively compact geographic area (Khan et al., 2019; Islam et al., 2020). This duality is strongly influenced by continentality, the Himalayan mountain system, and the relative absence of maritime moderation from the Bay of Bengal, collectively shaping the region's thermal regime (Manabe et al., 1991; Chowdhury and Ndiaye, 2017; Fahad et al., 2018). Continental conditions amplify daytime heating and reduce night-time cooling, while the Himalayas govern winter cold surges through western disturbances and snow cover dynamics (Immerzeel, 2008; Hussain et al., 2021). Conversely, the lack of proximate maritime influence diminishes evaporative cooling and moderate temperature extremes less effectively, exacerbating pre-monsoon heat and limiting winter chill (Ullah et al., 2018; Costa et al., 2020).

In recent decades, extreme heat events, commonly defined as days exceeding 35°C have become increasingly frequent, while cold days, those falling below 10°C, have shown a declining trend (Zhang et al., 2005; Oliveira et al., 2016; Mallick et al., 2022). These transitions have direct implications for agricultural timing, winter crop viability, water stress, labor productivity, and public health, particularly for vulnerable rural communities (Rajib et al., 2011). However, most previous studies in Bangladesh have primarily emphasized mean temperature trends, short observational periods, or have concentrated on southern and coastal regions where maritime influences dominate, leaving the northern inland transition zone comparatively underexplored. Yet long-term, station-based assessments of temperature extremes integrating these climatic controls remain scarce (Easterling et al., 2016; Rahman and Lateh, 2017). Furthermore, phase-wise (sub-period) evaluations and extreme-index-based analyses specifically targeting northern Bangladesh are still limited, restricting understanding of temporal shifts and spatial heterogeneity in extreme temperature behavior. Previous studies have primarily focused on seasonal averages or broad national trends (Schweikert et al., 2014; Girma et al., 2020; Monir et al., 2026), leaving critical questions unanswered: do heat extremes rise uniformly across northern Bangladesh, or do microclimatic differences, shaped by continental and Himalayan influences, result in spatial variability? is the decline in cold days consistent, or are there distinct temporal phases corresponding to changes in Himalayan snow cover or monsoon dynamics?

Although temperature extremes in Bangladesh have been examined in earlier research, most analyses have relied on aggregated national datasets, shorter time frames, or single-phase trend detection without explicitly integrating regional climatic controls. The present study advances existing work by combining long-term daily station observations with phase-wise Mann–Kendall assessment and an explicit continental–Himalayan–maritime interpretative framework, thereby offering a process-oriented regional evaluation rather than a purely statistical trend description.

To address these gaps, the present study undertakes a comprehensive spatiotemporal assessment of heat-day and cold-day frequencies across three meteorological stations in northern Bangladesh from 1991 to 2023. Using the non-parametric Mann–Kendall trend test, long-term trajectories of extremes are evaluated, and the record is divided into two sub-periods (1991–2005 and 2006–2023) to detect shifts in trend intensity. By explicitly considering continental–Himalayan controls and the moderating influence of maritime absence, this approach provides a clearer understanding of how regional climate drivers are modulating extreme temperature events over time.

By integrating multi-station data with robust trend detection and climatic interpretation, the study offers a nuanced depiction of temperature-extreme transitions in a climatically sensitive region. The findings provide essential insights for climate-risk planning, agro-meteorological management, and long-term adaptation strategies, highlighting the growing importance of extreme events rather than averages in shaping environmental and socio-economic futures in northern Bangladesh.

2 Data and methods

2.1 Selection of the study area

Northern Bangladesh was selected as the study area because its thermal regime is uniquely shaped by two major geographic controls: its proximity to the Himalayan foothills and its considerable distance from the Bay of Bengal. The region experiences a subtropical monsoonal climate with high seasonal variability in temperature and rainfall, which strongly influences local cropping patterns, soil moisture regimes, and agricultural productivity. These agro-climatic conditions make Northern Bangladesh particularly suitable for examining the spatial and temporal patterns of temperature extremes and their potential impacts on agriculture and livelihoods (Islam et al., 2021). This area lies approximately between 25°20' and 26°37' north latitudes and between 88°50' and 89°53' east longitudes (**Fig. 1**).

2.2 Data types

This study utilizes daily maximum and minimum temperature data collected from the Bangladesh Meteorological Department (BMD) for three stations in northern Bangladesh: Syedpur, Dinajpur, and Rangpur. From these daily observations, the annual counts of heat days (T > 35°C) and cold days (T < 10°C) were derived for the period 1991–2023 to assess long-term changes in temperature extremes. The selected fixed thresholds (35°C for heat days and 10°C for cold days) are consistent with the operational definitions commonly used by the BMD to characterize hot and cold conditions in Bangladesh. In the northern region, maximum temperatures exceeding 35°C are typically associated with heatwave-like conditions during the pre-monsoon season, while minimum temperatures below 10°C are considered cold stress conditions during winter. These thresholds are widely applied in regional climatological assessments and impact-based studies. Although percentile-based indices (e.g., 90th or 10th percentiles) are frequently used in climate extreme studies, fixed thresholds were adopted here to better reflect locally relevant thermal stress conditions and to ensure consistency with national meteorological reporting practices.

Three meteorological stations (Syedpur, Dinajpur, and Rangpur) were used in this study. These sites represent the principal synoptic stations in northern Bangladesh and provide long-term, continuous, and quality-controlled temperature records for the period 1991–2023. These stations are geographically distributed across the northwestern floodplain region and are widely used in regional climatological assessments conducted by the BMD. The spatial proximity of the stations and the relatively homogeneous physiographic characteristics of the northern floodplain reduce large topographic-induced microclimatic variability. Therefore, the selected stations are considered representative of the broader regional temperature behavior.

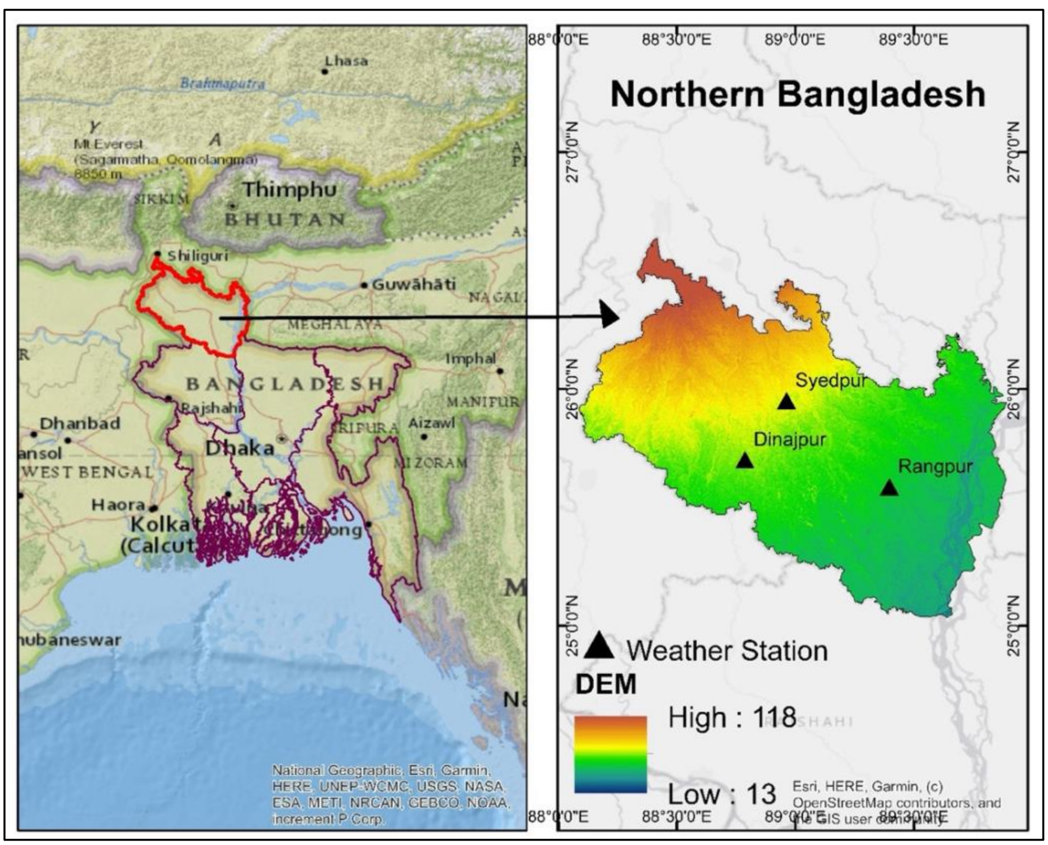

Figure 1. *Geographical location of the study area with the location of weather stations.*

2.3 Methods

2.3.1 Data quality control

Temperature data were checked and corrected using standard procedures. Missing values were filled using the standard ratio method, while outliers were screened with Grubbs' test. Autocorrelation was evaluated using the Durbin–Watson statistic, and record consistency was verified through Alexandersson's homogeneity test. These steps ensured a clean, reliable, and homogeneous dataset for analysis (**Table 1**).

The proportion of missing data was relatively low across the three stations, accounting for 1.8% in Syedpur, 2.3% in Dinajpur, and 1.5% in Rangpur over the study period (1991–2023). These missing observations were primarily associated with short-term instrument malfunction and were infilled using the regression-based standard ratio method with neighboring station data. Outlier detection using Grubbs' test identified 3 extreme values in Syedpur, 2 in Dinajpur, and 4 in Rangpur at the 95% confidence level ($p < 0.05$). These values were cross-checked with original station records and nearby station observations; confirmed anomalous values were corrected through interpolation, while verified extreme climate events were retained.

Homogeneity testing using Alexandersson's Standard Normal Homogeneity Test (SNHT) indicated that the temperature series were statistically homogeneous. The calculated SNHT test statistics (T_0) were 6.12 for Syedpur, 5.48 for Dinajpur, and 6.85 for Rangpur, all below the critical value of 8.5 at the 5% significance level. Therefore, the null hypothesis of homogeneity could not be rejected, confirming the absence of significant breakpoints in the temperature records. The Durbin–Watson statistics ranged between 1.82 and 2.07 across the stations, indicating no significant first-order autocorrelation in the annual extreme temperature indices.

2.3.2 Trend analysis using the modified Maan-Kendall test

The Mann-Kendall test treats y_i and y_j as two subsets of the time series of the n data, where i and j refer to years. j refers to one added year with i. As a result, the Mann-Kendall statistics specified in Eqs. 1, 2, and 3 are as follows:

$$S = \sum_{j=1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \quad (1)$$

Where, y_j is the yearly value for j year, and y_i is the yearly value for i year.

$$Var(S) = \frac{(n(n-1)(2n+5) - \sum_t t(t-1)(2t+5))}{18} \quad (2)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \quad (3)$$

The upward (growing) trend is therefore shown by positive values of "Z", whereas the downward (decreasing) trend is shown by negative values of "Z" (Anand et al., 2020). The significance threshold for the current study was α = 0.05, which had a 95% confidence level.

Table 1. *Overview of quality assurance procedures for temperature data processing.*

Steps	Methods	Statistics	Source
Missing data estimation	Regression-based method (neighboring station based)	$Y = \frac{1}{n}\sum_{i-1}^{n} \frac{N_s}{N_i} X_i$	Widiputra (2015)
Outlier detection	Grubb's test	$T_1 = \frac{\bar{X} - X_1}{S}, T_n = \frac{X_n - \bar{X}}{S}$	Grubbs (1950)
Autocorrelation identification	Durbin-Waston statistics	$d = \sum_{t=2}^{T} (e_t - e_t - 1)^2 / \sum_{t=1}^{T} e_t^2$	Kramer (2011)
Testing homogeneity	Alexandersson's standard regular homogeneity test	$N = \sum_{i=1}^{n-1} (X_i - X_{i+1})^2 / \sum_{i=1}^{n} (X_i - \bar{X})^2$	von Neumann (1941)

2.3.3 Change point detection using Pettit test

The resulting test statistics are stated in Eqs. 4, 5, and 6, when the duration of the study period is denoted by *t* and the shift occurs at *m* years (Zhang and Lu, 2009).

$$u_{t,m} = \sum_{i=1}^{m} \sum_{t+1}^{t} sign(k_i - k_j) \quad (4)$$

$$Z_T = Max U_{t,m} \; 1 \leq t \leq m \quad (5)$$

$$P = 1 - \exp\left(\frac{-6Z_T^2}{K^2+K^3}\right) \quad (6)$$

3 Result and discussion

3.1 Trends in heat extremes (above 35°C)

Analysis of the 33-year dataset (1991–2023) reveals a statistically significant and spatially coherent increase in heat extremes across Syedpur, Dinajpur, and Rangpur (**Fig. 2**). Over the entire study period, the Mann–Kendall test indicates strong positive trends in Syedpur (Z = 4.04) and Rangpur (Z = 2.38), both significant at the 5% level. Dinajpur also exhibits a positive trend (Z = 1.83), though slightly below the 5% significance threshold (**Table 2**). These findings confirm a pronounced intensification of extremely hot days (>35°C) in northern Bangladesh during the past three decades. Similar increases in extreme heat events have been documented globally, including in South Asia, East Asia, Europe, and North America, reflecting a widespread pattern of warming extremes (IPCC, 2023). The observed trends in Bangladesh are consistent with these global patterns and likely arise from a combination of anthropogenic greenhouse gas forcing, altered atmospheric circulation, and land-atmosphere interactions, indicating that local intensification of heat extremes is part of a broader global climate signal.

A phase-wise analysis reveals a distinct temporal asymmetry. During 1991–2005, heat-day trends were negative in all stations (Z = −0.62 in Syedpur, −1.48 in Dinajpur, and −1.91 in Rangpur), none of which reached statistical significance at the 5% level. This indicates that, despite ongoing background warming, the early phase did not yet manifest a statistically robust increase in extreme heat frequency.

In contrast, the 2006–2023 period marks a clear climatic transition. All stations show strong and statistically significant increasing trends in heat days, with Z values of 4.11 (Syedpur), 3.74 (Dinajpur), and 4.26 (Rangpur). These values substantially exceed the critical threshold (±1.96), indicating accelerated and widespread intensification of heat extremes after the mid-2000s. The magnitude and consistency of these trends suggest the emergence of a new thermal regime characterized by more frequent extreme hot days.

This post-2006 escalation aligns with broader regional warming trends across South Asia and but also with observed increases in heat extremes in many parts of the globe, including East Asia, Europe, and North America (IPCC, 2023) and may be associated with strengthened continental heat advection from the Indo-Gangetic Plain and reduced pre-monsoon moisture inflow from the Bay of Bengal (Rahman and Lateh, 2017). Globally, the

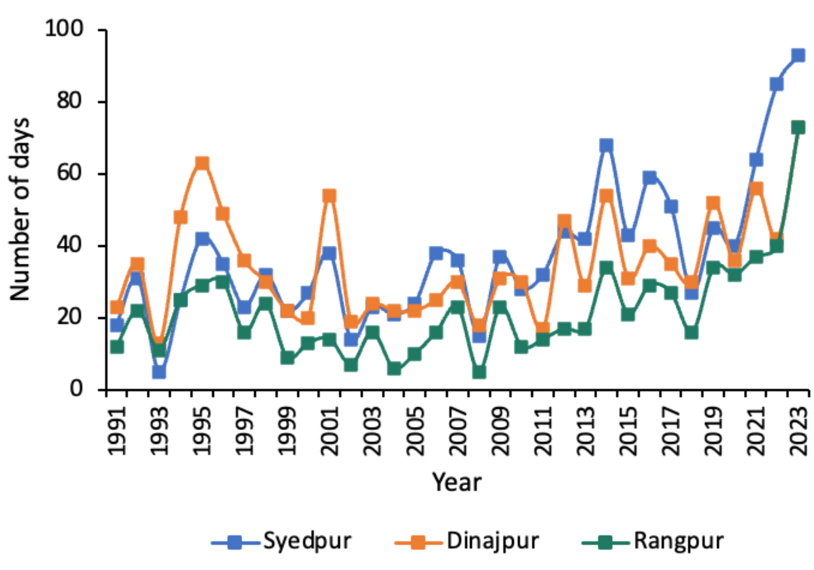

Figure 2. *Trends in annual frequency of extreme hot days (>35°C) across Northern Bangladesh.*

Table 2. *Mann-Kendall test data for heat (above 35°C) and cold (below 10°C) days. The Z-scores at 5% significance level.*

Temporal span	Above 35°C days			Below 10°C days		
	Syedpur	*Dinajpur*	*Rangpur*	*Syedpur*	*Dinajpur*	*Rangpur*
1991-2023	4.04	1.83	2.38	-2.74	-3.12	-3.18
1991-2005	-0.62	-1.48	-1.91	-2.36	-2.41	-2.52
2006-2023	4.11	3.74	4.26	-0.84	-0.52	-1.37

intensification of extreme heat days has been attributed to a combination of anthropogenic greenhouse gas forcing, changes in land-atmosphere interactions, and altered atmospheric circulation patterns. Enhanced continental dominance, coupled with suppressed evaporative cooling during dry pre-monsoon phases, likely created conditions conducive to persistent heat extremes (Khan et al., 2019). Notably, Rangpur historically influenced by relatively cooler Himalayan proximity, shows one of the strongest post-2006 increases, suggesting a reduced moderating influence of regional cooling mechanisms and a growing imprint of continental warming on northern Bangladesh.

3.2 Trends in cold extremes (below 10°C)

Cold extremes exhibit an overall declining trend across northern Bangladesh, although the magnitude and statistical significance vary across temporal phases (**Fig. 3**). For the full period (1991–2023), the Mann–Kendall test reveals statistically significant negative trends in all three stations: Syedpur (Z = −2.74), Dinajpur (Z = −3.12), and Rangpur (Z = −3.18), all exceeding the 5% significance threshold (±1.96). These results confirm a substantial and persistent reduction in the frequency of cold days (<10°C) over the past three decades.

The sub-period analysis highlights that the most pronounced decline occurred during 1991–2005. All stations recorded strong and statistically significant negative trends, with Z values of −2.36 (Syedpur), −2.41 (Dinajpur), and −2.52 (Rangpur). This indicates that winter warming emerged earlier and more consistently than the intensification of summer heat extremes, suggesting an early contraction of cold conditions in the regional thermal regime (Zhang et al., 2022).

In contrast, the 2006–2023 period presents weaker and statistically non-significant trends. Although Z values remain negative in Syedpur (−0.84), Dinajpur (−0.52), and Rangpur (−1.37), none exceed the critical threshold for significance at the 5% level. This suggests that while the decline in cold extremes continued, the rate of reduction slowed compared to the earlier period. Importantly, despite this stabilization in trend magnitude, the overall frequency of cold days remained markedly lower than in the 1990s, confirming a long-term contraction of winter cold conditions (Zhang et al., 2022). The observed reduction in cold extremes may be associated with weakened Himalayan cold-air incursions and altered winter circulation patterns over the Indo-Gangetic Plain, as documented in previous regional studies (Fahad et

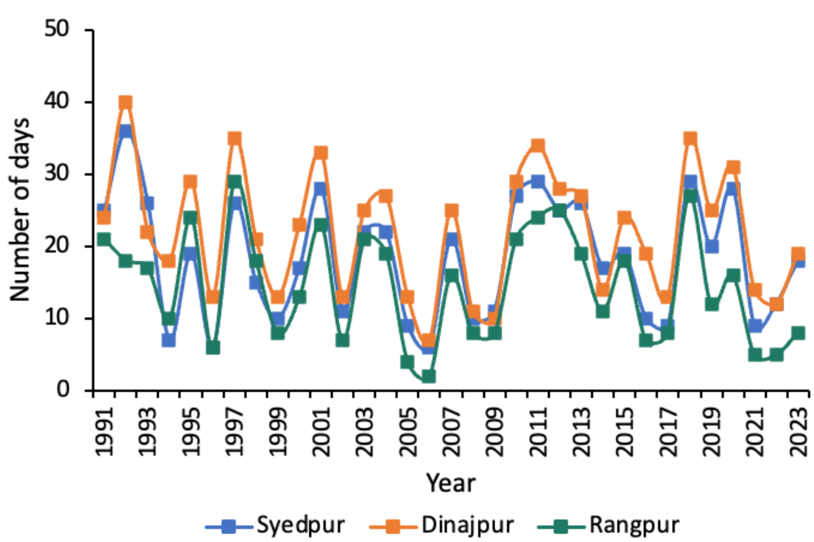

Figure 3. *Trends in annual frequency of extreme cold days (<10°C) across Northern Bangladesh.*

al., 2018). It is virtually certain that the frequency and intensity of cold extremes have decreased on the global scale since the mid-20th century, in part due to large-scale circulation changes associated with global warming and reduced cold-air advection (Russo et al., 2014). Additionally, gradual increases in humidity and regional warming likely reduced nighttime radiative cooling efficiency. Expanding built-up surfaces and intensified land-use activities may have further enhanced local heat retention, reinforcing the decline of winter cold days (Girma et al., 2020). A 2025 study found that surface urban heat island effects are intensifying more rapidly in many cities globally, especially in lower-income economies, highlighting how expanding urban land and impervious surfaces increase local temperature retention and climate extremes (Yuan et al., 2025). However, these mechanisms are interpreted as plausible climatic linkages based on existing literature rather than directly diagnosed atmospheric analyses within the present study.

3.3 Continental–Himalayan controls on thermal extremes

The combined phase-specific trends indicate a dual climatic transformation driven by shifting regional controls. The observed decline in cold extremes is consistent with previous studies suggesting a possible role of weakened Himalayan cold-air incursions (Hussain et al., 2021; Tabassum et al., 2024), though the present study does not directly measure atmospheric circulation or snow-cover variability. Research across the Northern Hemisphere shows that extreme cold surges have weakened in recent decades, consistent with anthropogenic forcing altering circulation and reducing cold event strength (Nie et al., 2025). Therefore, these interpretations should be considered as plausible explanations rather than definitive causes. The early decline in cold extremes and the post-2006 increase in heat days suggest a potential shift in the relative influence of Himalayan and continental factors, although this inference is based on statistical trends rather than direct atmospheric measurements. These findings demonstrate a fundamental reorganization of temperature extremes in a climatically transitional region situated between two major climatic drivers, the Himalayan cryosphere and the Bay of Bengal moisture system (Roy and Balling, 2005; Mallick et al., 2022). This evolving interplay is altering both the frequency and intensity of heat and cold extremes, with far-reaching implications for agricultural productivity, public health, and regional climate resilience.

The Himalayan region is suggested to influence winter temperature extremes in northern Bangladesh by modulating cold surges via western disturbances and snowpack conditions (Kumar et al., 2015; Tabassum et al., 2024). A potential reduction in Himalayan snow cover may contribute to weaker cold surges, possibly resulting in shorter or less intense winter periods, and could indirectly affect pre-monsoon conditions that favor increased heat-day occurrences (≥35°C) (Bhattacharjee et al., 2022). While the Mann–Kendall analysis shows trends consistent with this duality, these associations are inferred from literature and statistical patterns rather than directly measured in this study. This mechanism highlights the importance of Himalayan forcings as a fundamental climatic control over the region's thermal regime (Rawat et al., 2022).

Northern Bangladesh's inland location, far removed from the moderating influence of the Bay of Bengal, further exacerbates the region's temperature extremes through continentality effects. Maritime proximity in southern Bangladesh provides natural thermal buffering via sea breezes and evaporative cooling, reducing both daytime heating and night-time warming (Ghiami-Shamami et al., 2019). In contrast, the northern districts of Syedpur, Dinajpur, and Rangpur experience minimal maritime modulation, resulting in rapid daytime heating and higher maximum temperatures, while nighttime cooling is less constrained, contributing to a large diurnal temperature range. This continental amplification, when combined with regional warming, manifests as a notable increase in heat-day frequency, particularly during pre-monsoon months. Simultaneously, the absence of maritime influence prevents effective mitigation of winter warming, allowing the decline of cold days to persist. The interplay between continentality and Himalayan modulation thus provides a comprehensive explanation for the observed spatiotemporal patterns of temperature extremes in northern Bangladesh, reinforcing the need to consider both large-scale and local climatic drivers in regional climate assessments (Abdullah et al., 2021).

The reliance on data from three stations may not fully capture microclimatic variability; the focus on temperature alone excludes drivers such as humidity, radiation, and wind. Future research should integrate high-resolution regional climate models, evaluate the influences of the Himalayas and the Bay of Bengal through circulation diagnostics, and examine land-use dynamics, such as irrigation intensification and urban expansion, to understand the local feedback on thermal extremes. Expanding the observational network and linking thermal extremes to agronomic and health outcomes would further strengthen climate-risk planning. Despite these constraints, the findings provide robust evidence that northern Bangladesh is experiencing accelerated warming and weakened winter cooling, highlighting the urgency of developing multi-scale adaptation strategies informed by both regional climate drivers and local environmental conditions.

4 Conclusion

This study provides a spatiotemporal assessment of heat and cold extremes in northern Bangladesh, revealing a fundamental climatic shift driven by the interplay of continental–Himalayan forcing and the region's distance from maritime moderation. The results show a pronounced post-2006 escalation in extreme heat days (>35°C) across all stations, reflecting intensified continental warming, reduced evaporative cooling, and weakened pre-monsoon moisture inflow. In contrast, cold extremes (<10°C) have declined steadily since the early 1990s, particularly between 1991 and 2005, consistent with diminishing influence of Himalayan cold surges, reduced snow cover, and altered winter circulation patterns. These trends suggest a shift toward a hotter and less thermally variable climate in a region historically characterized by pronounced seasonal contrasts. The shifting temperature extremes could impact agricultural scheduling, winter crop viability, public health, and broader climate-resilience planning.

5 Data availability statement

The data will be made available upon request from the corresponding author.

6 Ethical statements

Ethical approval was not required for this research.

7 Conflict of interest

The authors declare that there are no financial or personal conflicts of interest that could have influenced the results of this study.

8 Acknowledgement

The authors thankfully acknowledge the BADC for providing the datasets used in this study.

9 Author contributions

Md. Moniruzzaman Monir: Writing – original draft, investigation, formal analysis, data curation, validation, methodology, conceptualization, and supervision. Shapla Akhter: Formal analysis, validation, and writing – review & editing. All authors approved the final version of the manuscript.

10 Copyright statement

References

Abdullah, A. Y. M., Bhuian, M. H., Kiselev, G., Dewan, A., Hassan, Q. K., & Rafiuddin, M. (2021). Extreme temperature and rainfall events in Bangladesh: A comparison between coastal and inland areas. International Journal of Climatology, 42(6), 3253–3273. https://doi.org/10.1002/joc.6911

Almazroui, M. (2020). Changes in temperature trends and extremes over Saudi Arabia for the period 1978–2019. Advances in Meteorology, 2020, 1–21. https://doi.org/10.1155/2020/8828421

Anand, B., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K., & Suresh, M. (2020). Long-term trend detection and spatiotemporal analysis of groundwater levels using GIS techniques in Lower Bhavani River basin, Tamil Nadu, India. Environment, Development and Sustainability, 22(4), 2779–2800. https://doi.org/10.1007/s10668-019-00318-3

Bhattacharjee, S., Naja, M., Jaiswal, A., Rawat, K. S., Sagar, R., & Ananthakrishnan, S. (2022). ARIES ST Radar: The first Central Himalayan wind profiler. Journal of Astronomical Instrumentation, 11(04). https://doi.org/10.1142/s2251171722400050

Chowdhury, M. R., & Ndiaye, O. (2017). Climate change and variability impacts on the forests of Bangladesh – a diagnostic discussion based on CMIP5 GCMs and ENSO. International Journal of Climatology, 37(14), 4768–4782. https://doi.org/10.1002/joc.5120

Costa, R. L., Macedo de Mello Baptista, G., Gomes, H. B., Daniel dos Santos Silva, F., Lins da Rocha Júnior, R., de Araújo Salvador, M., & Herdies, D. L. (2020). Analysis of climate extremes indices over northeast Brazil from 1961 to 2014. Weather and Climate Extremes, 28, 100254. https://doi.org/10.1016/j.wace.2020.100254

Easterling, D. R., Kunkel, K. E., Wehner, M. F., & Sun, L. (2016). Detection and attribution of climate extremes in the observed record. Weather and Climate Extremes, 11, 17–27. https://doi.org/10.1016/j.wace.2016.01.001

Ehsan, M. A., Tippett, M. K., Robertson, A. W., Singh, B., & Rahman, M. A. (2023). The ENSO fingerprint on Bangladesh summer monsoon rainfall. Earth Systems and Environment, 7(3), 617–627. https://doi.org/10.1007/s41748-023-00347-z

Fahad, M. G. R., Saiful Islam, A. K. M., Nazari, R., Alfi Hasan, M., Tarekul Islam, G. M., & Bala, S. K. (2018). Regional changes of precipitation and temperature over Bangladesh using bias-corrected multi-model ensemble projections considering high-emission pathways. International Journal of Climatology, 38(4), 1634–1648. https://doi.org/10.1002/joc.5284

Ghiami-Shamami, F., Sabziparvar, A. A., & Shinoda, S. (2018). Long-term comparison of the climate extremes variability in different climate types located in coastal and inland regions of Iran. Theoretical and Applied Climatology, 136(3–4), 875–897. https://doi.org/10.1007/s00704-018-2523-4

Girma, A., Qin, T., Wang, H., Yan, D., Gedefaw, M., Abiyu, A., & Batsuren, D. (2020). Study on recent trends of climate variability using innovative trend analysis: The case of the upper Huai River Basin. Polish Journal of Environmental Studies, 29(3), 2199–2210. https://doi.org/10.15244/pjoes/103448

Grubbs, F. E. (1950). Sample criteria for testing outlying observations. The Annals of Mathematical Statistics, 21(1), 27–58. https://doi.org/10.1214/aoms/1177729885

Hussain, A., Cao, J., Hussain, I., Begum, S., Akhtar, M., Wu, X., Guan, Y., & Zhou, J. (2021). Observed trends and variability of temperature and precipitation and their global teleconnections in the Upper Indus Basin, Hindukush-Karakoram-Himalaya. Atmosphere, 12(8), 973. https://doi.org/10.3390/atmos12080973

Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. International Journal of Climatology, 28(2), 243–254. https://doi.org/10.1002/joc.1528

Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2021 – The Physical Science Basis. Cambridge University Press. https://doi.org/10.1017/9781009157896

Islam, A. R. M. T., Rahman, M. S., Khatun, R., & Hu, Z. (2020a). Spatiotemporal trends in the frequency of daily rainfall in Bangladesh during 1975–2017. Theoretical and Applied Climatology, 141(3–4), 869–887. https://doi.org/10.1007/s00704-020-03244-x

Islam, A. R. M. T., Shill, B. K., Salam, R., Siddik, M. N. A., & Patwary, M. A. (2021). Insight into farmers' agricultural adaptive strategy to climate change in northern Bangladesh. Environment, Development and Sustainability, 23(2), 2439–2464. https://doi.org/10.1007/s10668-020-00681-6

Khan, M. J. U., Islam, A. K. M. S., Das, M. K., Mohammed, K., Bala, S. K., & Islam, G. M. T. (2019). Observed trends in climate extremes over Bangladesh from 1981 to 2010. Climate Research, 77(1), 45–61. https://doi.org/10.3354/cr01539

Krämer, W. (2011). Durbin–Watson Test. In International Encyclopedia of Statistical Science (pp. 408–409). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-04898-2_219

Kumar, N., Yadav, B. P., Gahlot, S., & Singh, M. (2015). Winter frequency of western disturbances and precipitation indices over Himachal Pradesh, India: 1977-2007. Atmósfera, 28(1), 63–70. https://doi.org/10.20937/atm.2015.28.01.06

Kumar, P., & Sarthi, P. P. (2019). Surface temperature evaluation and future projections over India using CMIP5 models. Pure and Applied Geophysics, 176(11), 5177–5201. https://doi.org/10.1007/s00024-019-02203-6

Mallick, J., Islam, A. R. Md. T., Ghose, B., Islam, H. M. T., Rana, Y., Hu, Z., Bhat, S. A., Pal, S. C., & Ismail, Z. B. (2022). Spatiotemporal trends of temperature extremes in Bangladesh under changing climate using multi-statistical techniques. Theoretical and Applied Climatology, 147(1–2), 307–324. https://doi.org/10.1007/s00704-021-03828-1

Manabe, S., Stouffer, R. J., Spelman, M. J., & Bryan, K. (1991). Transient responses of a coupled ocean–atmosphere model to gradual changes of atmospheric CO_2. Part I. Annual mean response. Journal of Climate, 4(8), 785–818. https://doi.org/10.1175/1520-0442(1991)004<0785:troaco>2.0.co;2

Monir, M. M., Rokonuzzaman, M., Sarker, S. C., Alam, E., Islam, M. K., & Islam, A. R. M. T. (2023). Spatiotemporal analysis and predicting rainfall trends in a tropical monsoon-dominated country using MAKESENS and machine learning techniques. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-41132-2

Monir, M. M., Sarker, S. C., Rahman, M. M., & Islam, M. N. (2026). Analysis of the trend of dry spells and how ocean factors affect their patterns during the summer monsoon in Bangladesh using the Mann-Kendall and frontier atmospheric general circulation model. Geosystems and Geoenvironment, 5(2), 100472. https://doi.org/10.1016/j.geogeo.2025.100472

Nie, Y., Sun, Y., Zhang, X., & Chen, G. (2025). Human-induced changes in extreme cold surges across the Northern Hemisphere. Nature Communications, 16(1). https://doi.org/10.1038/s41467-025-62576-2

Oliveira, P. T., Santos e Silva, C. M., & Lima, K. C. (2016). Climatology and trend analysis of extreme precipitation in subregions of Northeast Brazil. Theoretical and Applied Climatology, 130(1–2), 77–90. https://doi.org/10.1007/s00704-016-1865-z

Rahman, Md. R., & Lateh, H. (2017). Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model. Theoretical and Applied

Climatology, 128(1–2), 27–41. https://doi.org/10.1007/s00704-015-1688-3

Rajib, M. A., Mortuza, M. R., Selmi, S., Ankur, A. K., Rahman, M. M. 2011. Increase of heat index over Bangladesh: Impact of climate change. World Academy of Science, Engineering and Technology, 58, 402–405.

Rawat, K. S., Sahu, S. R., Singh, S. K., & Mishra, A. K. (2022). Cloudburst analysis in the Nainital district, Himalayan Region, 2021. Discover Water, 2(1). https://doi.org/10.1007/s43832-022-00020-y

Roxy, M. K., Ritika, K., Terray, P., Murtugudde, R., Ashok, K., & Goswami, B. N. (2015). Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. Nature Communications, 6(1). https://doi.org/10.1038/ncomms8423

Roy, S. S., & Balling, R. C., Jr. (2005). Analysis of trends in maximum and minimum temperature, diurnal temperature range, and cloud cover over India. Geophysical Research Letters, 32(12). https://doi.org/10.1029/2004gl022201

Russo, S., Dosio, A., Graversen, R. G., Sillmann, J., Carrao, H., Dunbar, M. B., Singleton, A., Montagna, P., Barbola, P., & Vogt, J. V. (2014). Magnitude of extreme heat waves in present climate and their projection in a warming world. Journal of Geophysical Research: Atmospheres, 119(22), 12500–12512. https://doi.org/10.1002/2014jd022098

Schweikert, A., Chinowsky, P., Espinet, X., & Tarbert, M. (2014). Climate Change and Infrastructure Impacts: Comparing the Impact on Roads in ten Countries through 2100. Procedia Engineering, 78, 306–316. https://doi.org/10.1016/j.proeng.2014.07.072

Tabassum, A., Park, K., Shin, J., Jin, H. -G., & Baik, J. -J. (2023). Long-term changes in temperature, specific humidity, and precipitation in Bangladesh revealed by ERA5 data. Theoretical and Applied Climatology, 155(3), 1915–1925. https://doi.org/10.1007/s00704-023-04732-6

Ullah, S., You, Q., Ullah, W., & Ali, A. (2018). Observed changes in precipitation in China-Pakistan economic corridor during 1980–2016. Atmospheric Research, 210, 1–14. https://doi.org/10.1016/j.atmosres.2018.04.007

von Neumann, J. (1941). Distribution of the ratio of the mean square successive difference to the variance. The Annals of Mathematical Statistics, 12(4), 367–395. https://doi.org/10.1214/aoms/1177731677

Widiputra, H. (2015). Nearest neighbour approach with non-parametric regression analysis for multiple time-series modelling and predictions. International Journal of Business Intelligence and Data Mining, 10(3), 253–279. https://doi.org/10.1504/ijbidm.2015.071326

Yuan, Y., Santamouris, M., Xu, D., Geng, X., Li, C., Cheng, W., Su, L., Xiong, P., Fan, Z., Wang, X., & Liao, C. (2025). Surface urban heat island effects intensify more rapidly in lower income countries. Npj Urban Sustainability, 5(1). https://doi.org/10.1038/s42949-025-00198-9

Zhang, S., & Lu, X. X. (2009). Hydrological responses to precipitation variation and diverse human activities in a mountainous tributary of the lower Xijiang, China. CATENA, 77(2), 130–142. https://doi.org/10.1016/j.catena.2008.09.001

Zhang, X., Hegerl, G., Zwiers, F. W., & Kenyon, J. (2005). Avoiding inhomogeneity in percentile-based indices of temperature extremes. Journal of Climate, 18(11), 1641–1651. https://doi.org/10.1175/jcli3366.1

Zhang, Y., Li, Q., Ge, Y., Du, X., & Wang, H. (2022). Growing prevalence of heat over cold extremes with overall milder extremes and multiple successive events. Communications Earth & Environment, 3(1), 73. https://doi.org/10.1038/s43247-022-00404-x

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