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Spatiotemporal Dynamics of Heatwave Hazards and their Influence on Boro Rice Yield in Northwestern Bangladesh

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Abstract

During the Boro rice season, heatwaves have the potential to increase the thermal stress and influence the rice sustainability in northwestern Bangladesh. This study assessed the spatial and temporal patterns of Boro-season heatwaves using daily maximum temperature data from six Bangladesh Meteorological Department stations during 2000–2024. The station-specific 90th percentile of maximum temperature and 3-days or more consecutive days were used to determine heatwaves. Frequency was computed per station, and inverse distance weighting interpolation was applied to map spatial hotspots. The interpolated surface was used to estimate the station-wise mean heatwave frequency and categorized into the hotspots. Boro rice yield data of 2007-2024 of Rajshahi district was also assessed based on case. The findings indicated evident spatial differences in the frequency of heatwave, with Rajshahi (10.72 days/year) recording the highest mean annual frequency, then Ishwardi (9.92 days/year), and Rangpur with the lowest frequency (8.44 days/year). Southwestern regions, particularly Rajshahi and Ishwardi, emerged as intensity hotspots. The number of heatwave days per year was found to be highly interannual with an increasing trend of about 2.02 days/year. The yield evaluation in Rajshahi revealed that the frequency of a heatwave had a weak correlation with the yield of Boro rice (R^2=0.07), indicating that there are numerous climatic and management variables affecting yield variability. The results demonstrate the necessity of the localized heat-risk control, the enhanced irrigation planning, and the heat-

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resistant rice types in the hotspots regions.

Keywords: Boro rice, IDW, Heatwave, Hotspot Mapping, Northwestern Bangladesh

Introduction

Extreme temperatures are increasing in frequency, duration, and severity, worldwide due to climate change, and heatwaves are turning out to be one of the most significant climate risks to the natural and human systems. According to recent global evaluations, the number of heat extremes has risen sharply due to the current increase in warming, and there are strong implications on agriculture, water resources, and food security (Perkins and Alexander, 2013; Alizadeh et al., 2020). Heatwaves may have a direct impact on crop yield, hastening the phenological growth, elevating evapotranspiration, and causing physiological stress, especially at the most vulnerable periods of growth, including flowering and grain filling (Lesk et al., 2022). Consequently, the spatial and temporal dynamics of heatwave hazards has emerged as a priority in climate risk assessment.

It is well known that South Asia is one of the most susceptible areas to increasing extremes of temperature variations with the large population density and the high reliance on the agro-industry that is sensitive to climate (Gu et al., 2025). In this area, Bangladesh is becoming more vulnerable to heat stress particularly in its north-western part, also referred to as the Barind Tract. The region is typified by low rainfall, high variability of temperatures, and low soil moisture retention capacity, which jointly add to increased thermal stress levels during the dry season (Dina and Islam, 2020; Afrin et al., 2024). More recent research has noted a clear increase in temperature extremes and heatwave instances in the area, and this has been of concern in the possible effects on the sustainability of agriculture and rural livelihood in the area (Mamun et al., 2024).

Boro rice season (January-April) is very important in providing food security to the people of Bangladesh, as it gives a significant portion of the total rice production. But this season is also during the dry season when crops are much reliant on irrigation and are more vulnerable to high temperature extremes. High temperatures in the Boro season may interfere with the plant physiological functions, decrease the quality of grains, and eventually cause loss of yield (Jagadish et al., 2007; Matsui et al., 1997). Nevertheless, the production of Boro rice has reacted in complicated ways to climatic stress because of the use of irrigation, high yielding varieties and better agronomic practices which to some extent mitigate the impacts of heat stress (Sarker et al., 2014; Salam et al., 2019)

Despite the growing attention to heatwaves in the world, there are still some significant research gaps regarding the situation in Bangladesh. First, high-resolution spatial analysis of the hazards of heatwaves based on station-based observations is lacking especially in northwestern Bangladesh. There are numerous studies that are based on coarse resolution datasets, and they might not be sufficient to represent the variability in the temperature extremes at the local scale. Second, knowledge concerning the spatiotemporal patterns and hotspots distribution of the heatwaves in the Barind region is limited. Third, the interaction between heatwave variability and crop yield, particularly Boro rice, is not yet well-researched, and most studies have shown more general climatic patterns but not the effect on agriculture, which is more local.

To fill these gaps, the study used a station-based and spatially explicit method to examine the risks of heatwaves in northwestern Bangladesh. The study included a detailed evaluation of the distribution and intensity of heatwaves across districts by incorporating observed temperature data and spatial interpolations. In addition, a temporal trend analysis was conducted to assess changes in the occurrence of heatwaves over time. The study also considered the association between the variability of heatwaves and the yield of Boro rice based on a case study of Rajshahi district. It examined the spatial pattern of heatwave risks during the Boro season in northwestern Bangladesh, identified hotspot areas over time, and analyzed the association between heatwave fluctuations and district-level Boro rice production. By integrating spatial analysis with agricultural impact assessment, the study provided location-specific details on the risk and response of heatwaves and crops, supporting the development of climate-resilient agricultural strategies in drought-prone regions of Bangladesh.

Materials and Methods

Study area and data

The study was conducted in northwestern Bangladesh during the Boro rice growing season (January–April), which is highly sensitive to temperature extremes during reproductive and grain-filling stages. Daily maximum temperature (Tmax) and daily minimum temperature (Tmin) data were obtained from the Bangladesh Meteorological Department (BMD) for six stations Rajshahi, Ishwardi, Bogra, Rangpur, Dinajpur, and Saidpur - covering the period 2000–2024 (Figure 1). The geographic coordinates of these stations are: Rajshahi (24.37°N, 88.70°E), Ishwardi (24.13°N, 89.05°E), Bogra (24.85°N, 89.37°E), Rangpur (25.73°N, 89.23°E), Dinajpur (25.65°N, 88.68°E), and Saidpur (25.75°N, 88.92°E). Administrative district boundary data were used for spatial aggregation. Boro rice yield data (t ha^{-1}) for Rajshahi district during 2007–2024 were obtained from Bangladesh Bureau of Statistics (BBS) and represented the overall district-level Boro yield, including local, high-yielding, and hybrid Boro varieties. These data were used for a case-based heatwave–yield assessment (BBS, 2025). Quality control measures were applied to the temperature data, such as elimination of missing and duplicate data and transforming the variables to the right numeric format. The analysis was restricted to the Boro season (January–April). Duplicate station-date records were removed to avoid bias in heatwave detection. Incomplete records for Rangpur in 2024 were excluded from temporal station-wise analysis.

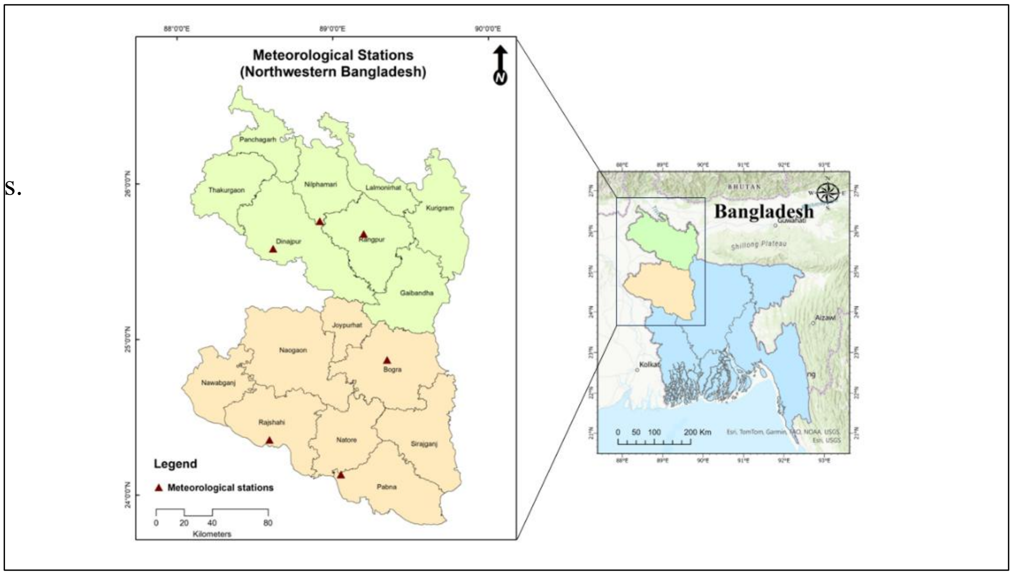

Fig. 1. Map of the study area in northwestern Bangladesh illustrating district boundaries and the locations of six BMD meteorological stations (Rajshahi, Ishwardi, Bogra, Rangpur, Dinajpur, and Saidpur) used for heatwave analysis.

Heatwave identification

A percentile-based approach was used to define heatwaves, accounting for station-specific climatic variability. The 90th percentile threshold of daily maximum temperature was calculated for each station:

$$T90_s = P90\left(T_{max,s}\right) \tag{1}$$

A heatwave day was defined when daily temperature exceeded the station-specific threshold for at least three consecutive days:

$$HW_{d,s} = \begin{cases} 1, & T_{max,d,s} \geq T90_s \; for \; \geq 3 \; consecutive \; days \\ 0, & otherwise \end{cases} \tag{2}$$

This approach is widely used in climatological studies to identify extreme heat events relative to local baseline conditions (Perkins and Alexander, 2013). For nighttime heat stress, Tmin was considered: a Tmin heat stress night was recorded if Tmin >27°C during the reproductive stage (March–April), which is critical for spikelet sterility and grain filling in Boro rice (Jagadish et al., 2007; Matsui et al., 1997).

Station-wise heatwave indices

For each station, total heatwave days and mean annual heatwave frequency were calculated:

$$HW_{mean,s} = \frac{\sum_{y=2000}^{2024} HW_{y,s}}{N} \tag{3}$$

where, $HW_{y,s}$ represents annual heatwave days at station s, and N is the number of study years.

Spatial interpolation and station aggregation

The spatial distribution of heatwave frequency was estimated using the Inverse Distance Weighting (IDW) method, which assigns greater weight to nearby observations:

$$Z(x) = \frac{\sum_{i=1}^{n} w_i Z_i}{\sum_{i=1}^{n} w_i} \tag{4}$$

where Z_i represents observed values at station i, and w_i weights are defined as:

$$w_i = \frac{1}{d_i^p} \tag{5}$$

with d_i being the Euclidean distance between the target and observed locations. The power parameter (P=2) controls the rate of spatial decay in influence, with higher values emphasizing nearby observations (J. Li & Heap, 2014; Shepard, 1968; Lu and Wong, 2008). All interpolated surfaces were generated at a uniform spatial resolution consistent with the study domain.

The interpolated surface was overlaid with location boundaries to calculate station-wise mean heatwave frequency:

$$HW_{station,j} = \frac{1}{m}\sum_{i=1}^{m} HW_i \tag{6}$$

where $HW_{station,j}$ is the average heatwave frequency for station j, and m is the number of grid cells within the station. Locations were classified into low, moderate, high, and very high heatwave categories using quartile-based classification.

Temporal heatwave analysis

Annual heatwave days were calculated by aggregating station-wise heatwave days for each year. A linear regression model was applied to assess temporal trends:

$$HW_y = \mathrm{a} + \mathrm{by} \tag{7}$$

where HW_y is annual heatwave days in year y, a is the intercept, and b is the slope representing the rate of change over time. This approach provides a simple indication of increasing or decreasing heatwave trends (IPCC, 2021).

Heatwave–yield analysis

Due to data availability, the relationship between heatwave occurrence and rice yield was analyzed for Rajshahi district as a representative study. Annual heatwave days were matched with Boro rice yield data (2007–2024). Linear regression was used to examine the relationship:

$$Y = \alpha + \beta \mathrm{HW} \tag{8}$$

where Y is Boro rice yield (t ha^{-1}), HW is annual heatwave days, α is the intercept, and β is the regression coefficient. The coefficient of determination (R^2) was used to evaluate the strength of the relationship.

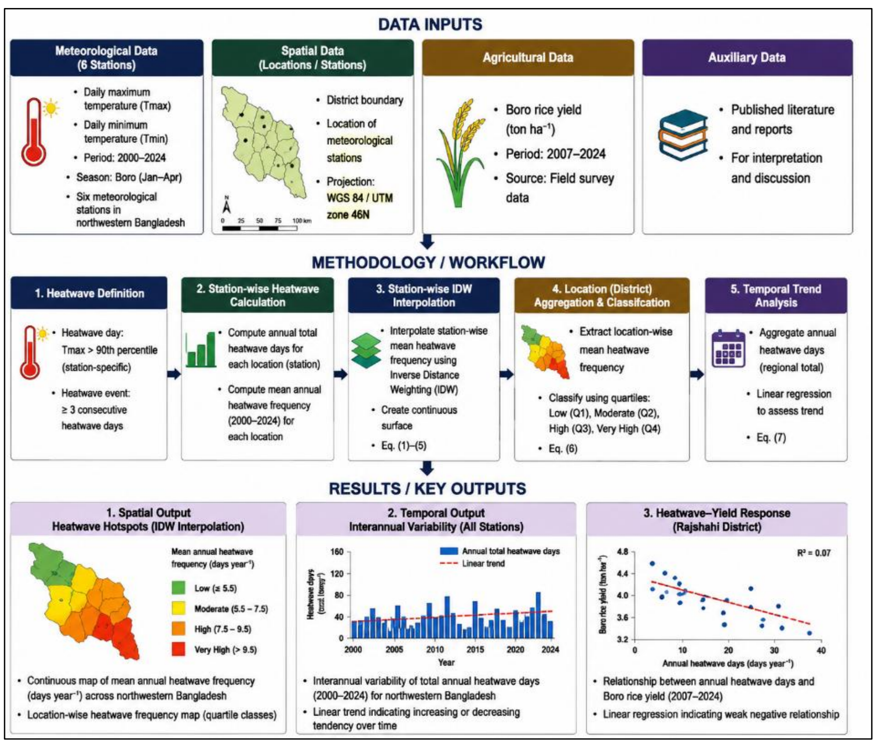

Fig. 2. Methodological and conceptual framework of this study for assessing heatwave hazard during Boro season in northwestern Bangladesh, including spatial and temporal analysis.

Results and Discussion

Station-wise heatwave characteristics

Table 1 and Figure 3 indicate the station-wise distribution of the frequency of heatwave in Boro-season in northwestern Bangladesh in 2000-2024. Out of the six BMD stations, Rajshahi was the most exposed to heatwave with a total number of 268 heatwave days and an average of 10.72 days/year. This means that Rajshahi was the most heatwave prone station in the Boro season. Ishwardi was the second with a total of 248 heatwave days and 9.92 days/year, Dinajpur came in third (9.64 days/year) and Saidpur came in fourth (9.40 days/year). Bogra recorded an intermediate number of heatwave frequency, 8.92 days/year, and Rangpur experienced the least frequency, 8.44 days/year. The pattern station by station indicates a distinct spatial difference in exposure to heatwave. The relatively high values in Rajshahi and Ishwardi imply that there were more thermal stresses in the southwestern section of the study area, and the northern section displayed relatively low heatwave occurrences. This trend is consistent with the subsequent spatial hotspot maps, in which the Rajshahi–Ishwardi area is a significant hotspot of heat waves.

Table 1. Station-wise heatwave statistics, 2000–2024

Station	Lat	Lon	Total heatwave days	Mean heatwave days year^{-1}	90th Percentile Tmax (°C)
Rajshahi	24.36667	88.70000	268	10.72	37.5
Ishwardi	24.13333	89.05000	248	9.92	36.8
Dinajpur	25.65000	88.68333	241	9.64	34.5
Saidpur	25.75000	88.91667	235	9.40	34.4
Bogra	24.85000	89.36667	223	8.92	34.8
Rangpur	25.73333	89.23333	211	8.44	33.5

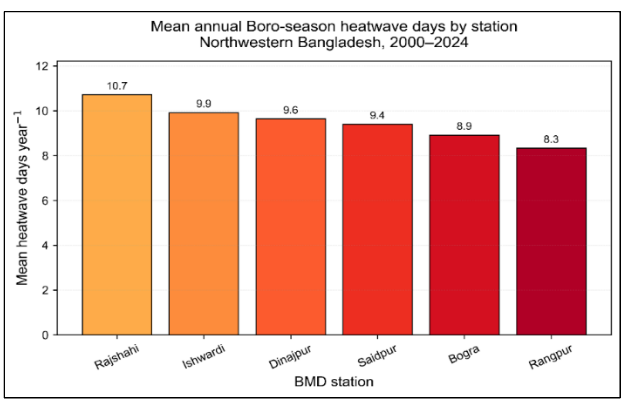

Fig. 3. Mean annual Boro-season heatwave days at six BMD stations in northwestern Bangladesh during 2000–2024, showing the highest frequency at Rajshahi and the lowest at Rangpur.

Stage-separated Heatwave Analysis

The Boro-season heatwave analysis was separated into vegetative (January–February) and reproductive (March–April) stages to identify the periods most critical for rice physiology. Table 2 presents the number of daytime heatwave days (Tmax ≥ 90th percentile) and nighttime heat stress nights (Tmin > 27°C) at each station. The reproductive stage consistently exhibited the highest number of Tmax heatwave days across all stations, ranging from 373 days at Rajshahi to 397 days at Ishwardi, whereas vegetative-stage heat stress was minimal (0–1 day). This indicates that reproductive-stage heat stress is the dominant contributor to potential yield reduction. Nighttime heat stress (Tmin >27°C) was comparatively smaller but noteworthy. Rajshahi experienced 37 Tmin nights and Bogra 30 nights, while other stations had minimal or no nighttime stress.

Table 2. Stage-separated Tmax/Tmin heatwave summary for Boro rice (2000–2024)

Station	Stage	Tmax HW days	Tmin HW days
Bogra	Reproductive	376	30
Bogra	Vegetative	1	0
Dinajpur	Reproductive	391	1
Dinajpur	Vegetative	0	0
Ishwardi	Reproductive	397	0
Ishwardi	Vegetative	0	0
Rajshahi	Reproductive	373	37
Rajshahi	Vegetative	0	0
Rangpur	Reproductive	380	5
Rangpur	Vegetative	0	0
Saidpur	Reproductive	394	0
Saidpur	Vegetative	1	0

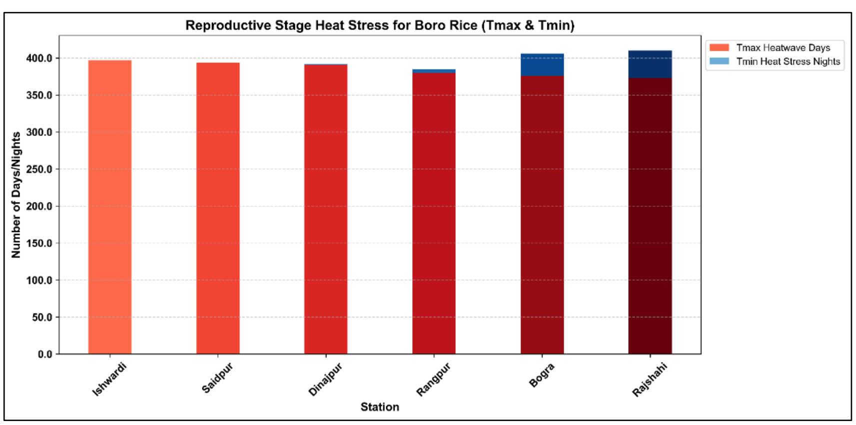

Fig. 4. Reproductive-stage heat stress for Boro rice across stations, showing daytime Tmax heatwave days (red) and nighttime Tmin heat stress nights (blue).

Figure 4 presents a stacked bar chart illustrating Tmax and Tmin contributions during the reproductive stage across all stations. The red portion of each bar represents daytime Tmax heatwave days, while the blue portion represents nighttime Tmin heat stress. The figure highlights the spatial variability of heat stress, showing that stations like Rajshahi and Bogra are exposed to the highest combined stress. In contrast, stations such as Ishwardi and Saidpur experience high daytime heat but negligible nighttime stress, emphasizing that reproductive-stage vulnerability is both stage and location-dependent.

Overall, the table and figure together demonstrate that daytime heatwaves dominate reproductive-stage stress, while nighttime heat stress, although smaller in magnitude, is significant at specific stations. These results underscore the need to account for both Tmax and Tmin when assessing Boro rice vulnerability to high temperature stress and for planning adaptive strategies at the most affected stations.

Spatial distribution of heatwave frequency

Figure 5 shows the Boro-season heatwave frequency spatial distribution over northwestern Bangladesh. The surface of the IDW interpolated (Figure 5a) demonstrates a clear spatial gradient, with a greater level of heatwave intensity in the southwestern section of the study area. The highest hotspot is seen in the area of Rajshahi and Ishwardi where the frequency of heatwave per year is more than 10 days a year. This region constitutes a continuous region of high thermal stress in the Boro season. Conversely, the intensity of heatwave is relatively low in the northern and northeastern regions, especially in the Rangpur, Kurigram and Lalmonirhat, where the mean heatwave frequency is less than 9 days per year. The middle values are concentrated in the central locations like Naogaon, Pabna, and Bogra reveal that there is a transitional area between the high and low heatwave intensity areas. This spatial pattern is further supported by the station-wise aggregation (Figure 5b); the highest mean heatwave frequency is observed in Rajshahi zone then its neighbors which are the southwestern locations. In the meantime, there is a consistent decrease in the values towards the north, which proves a southwest-northeast gradient in the heatwave occurrence. This spatial heterogeneity shows that during the Boro season, exposure to heatwaves is not well distributed but highly concentrated to the southwest.

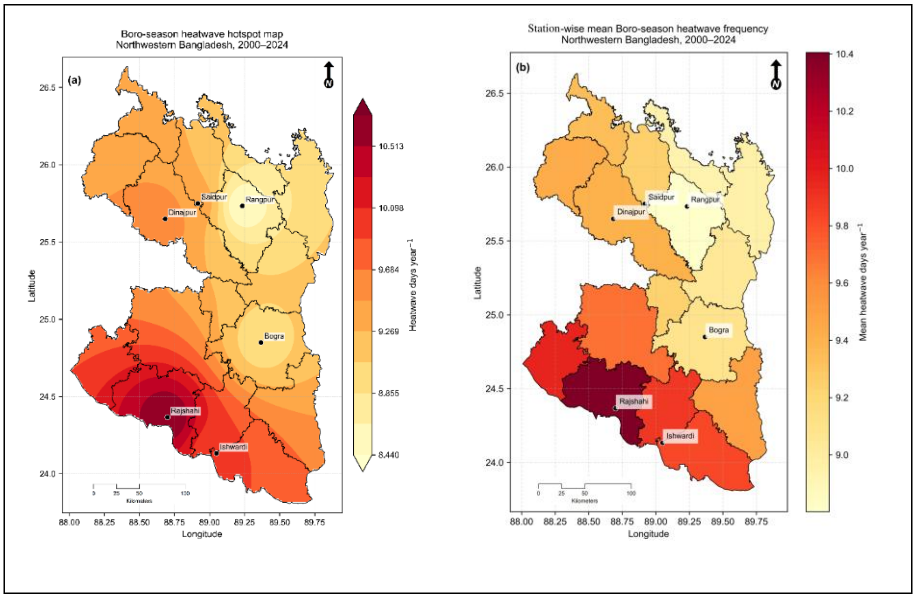

Fig. 5. Boro-season heatwave patterns in northwestern Bangladesh during 2000–2024: *(a)* IDW-interpolated heatwave hotspot map and *(b)* Station-wise mean heatwave frequency. Higher heatwave intensity is concentrated in the southwestern staions, particularly around Rajshahi and Ishwardi.

Hotspot classification

Figure 6 and Table 3 provide station-level of Boro-season heatwave hotspots in northwestern Bangladesh in 2000-2024. The classification indicates the clear spatial difference in the heatwave exposure, with the strongest intensity of which is in the southwestern section of the study area. Rajshahi turns out as the most heatwave-prone area, with a mean annual frequency of heatwave at 10.72 days year^{-1} and is in the very high hotspot category. High hotspots category has Ishwardi and Dinajpur with an average annual heatwave frequency of 9.92- and 9.64-days year^{-1}, respectively. Saidpur and Bogra depict moderate heatwave with 9.40- and 8.92 days year^{-1} and Rangpur has the lowest frequency (8.44 days year^{-1}) and is considered a low hotspot. This ranking shows that the exposure to heatwave is not equal throughout the region, but has a southwest-to-northeast gradient.

This trend is further confirmed by the station-wise hotspot map with very high and high hotspot areas primarily in the Rajshahi- Ishwardi belt, and neighboring southwestern zones. Conversely, the heatwave intensity is relatively less in the north and northeast regions, particularly in the region of Rangpur. This spatial distribution indicates that the Boro rice-producing areas in the southwestern sections have higher exposure to the recurring heat stress during the period of January-April. Agronomically, the distribution of high and very high classes of heatwave in the southwest is significant since Boro rice is vulnerable to high temperatures stress at the reproductive and grain-filled stages. Hence, the Rajshahi-Ishwardi zone might be in need of more focus on heat-tolerant varieties, timely irrigation, and local heat-risks guidance services in the Boro season.

Table 3. Station-wise mean annual Boro-season heatwave frequency and hotspot classification in northwestern Bangladesh, 2000–2024

Station	Mean heatwave days/year	Hotspot class
Rajshahi	10.72	Very high
Ishwardi	9.92	High
Dinajpur	9.64	High
Saidpur	9.40	Moderate
Bogra	8.92	Moderate
Rangpur	8.44	Low

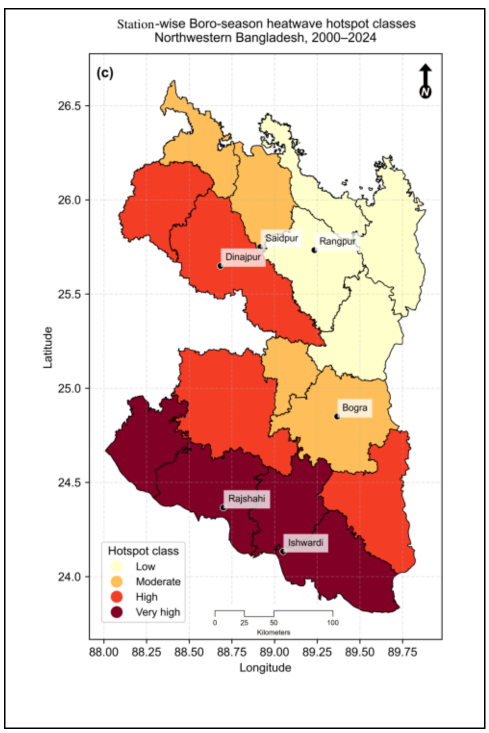

Fig. 6. Spatial classification of Boro-season heatwave intensity across northwestern Bangladesh (2000–2024). Stations are grouped into four hotspot classes based on mean annual heatwave days, highlighting a pronounced concentration of very high intensity in the southwestern stations, while northern and northeastern areas exhibit comparatively lower heatwave occurrence

Temporal variability of heatwave occurrence

Figure 7 shows the interannual variability and trend of total Boro-season heatwave days in northwestern Bangladesh in 2000-2024. The results reveal that there is high variability of the findings on an annual basis with some years having significant peaks and other years having significant troughs. Increased heatwave activity is seen in years like 2010, 2014, 2016, 2021, 2023, and 2024 with a cumulative number of days of heatwave activities surpassing 100 across the stations. Conversely, the presence of relatively low heatwaves is observed in 2002, 2005, 2011 and 2018, which reflects a great deal of temporal variation in the intensity of heatwaves in the Boro season. Despite this variability, the fitted linear trend (Figure 7) indicates a gradual increase in heatwave frequency, with a slope of 2.02 days/year ($p = 0.085$; 95% CI: –0.30 to 4.34). This trend is particularly noticeable in the last decade, where successive years show an increasing number of heatwave days compared to the first decade of the 21st century. The trends indicate that the prevalence of heatwave during the Boro season is on the rise, and this could have significant consequences on the agricultural systems in the area.

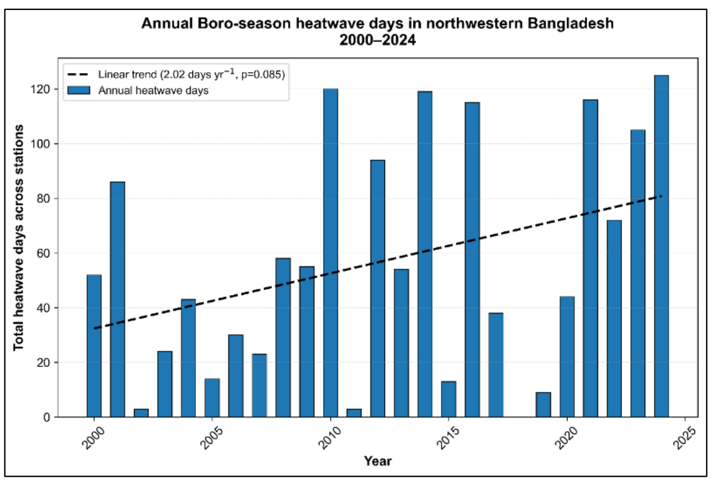

Fig. 7. Annual Boro-season heatwave days across northwestern Bangladesh (2000–2024). Blue bars show total heatwave days per year, and the dashed line indicates a linear trend (2.02 days/year, $p = 0.085$), highlighting a gradual increase in reproductive-stage heat stress

Heatwave–yield relationship in Rajshahi district

The correlation between the incidence of Boro-season heatwave and the yield of rice in the Rajshahi district of 2007-2024 is as given in (Figure 8) with supporting analysis of anomalies as discussed in (Figure 9) and data in Table 4. The scatter plot (Figure 8) shows that there is a weak correlation between the number of days of a heatwave and the yield of Boro rice. The regression line fitted has a low coefficient of determination ($R^2 = 0.07$) and a low positive slope implying that the frequency of heatwave only accounts a small fraction of the variability in yield. Some years when there were high heatwave incidences (e.g., 2010) imply that the yield is lower, whereas other years with high frequency of heatwaves (e.g., 2023 and 2024) have relatively high yield values. In order to further investigate this association, the anomaly-based quadrant analysis (Figure 9) categorizes years into four groups depending on the deviations of heatwaves and yields. The high heatwave-low yield quadrant (e.g., 2010 and 2014) represents several years with possible adverse effects of extreme heat. Nevertheless, several years fall under the high heatwave-high yield category (e.g., 2023 and 2024) as well, indicating that the impact of heat stress can be countered by favorable management or environmental factors. Similarly, years with low heatwave occurrence show both positive and negative yield responses, indicating no consistent pattern.

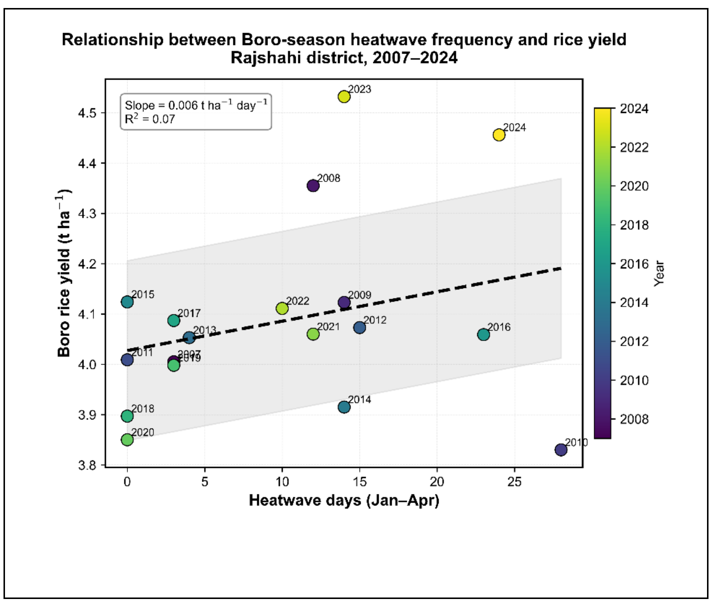

Fig. 8. Relationship between Boro-season heatwave days and rice yield in Rajshahi district during 2007–2024. The dashed regression line and low coefficient of determination ($R^2 = 0.07$) indicate a weak association between heatwave frequency and yield variability

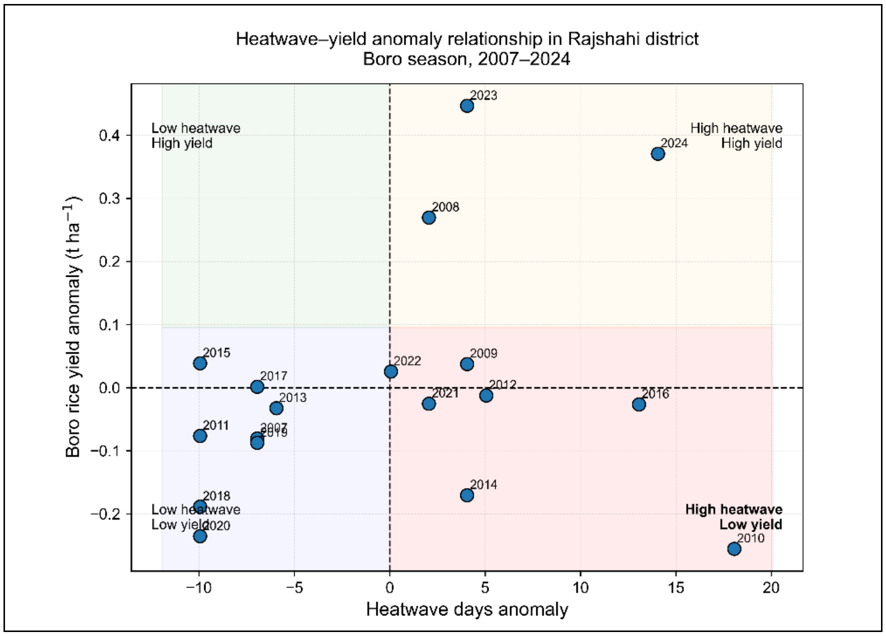

Fig. 9. Heatwave–yield anomaly quadrant plot for Rajshahi district during 2007–2024. The zero lines represent long-term mean conditions, separating years into high/low heatwave and above/below-average yield categories

Table 4. Year-wise Boro-season heatwave days, yield, and anomaly values for Rajshahi district (2007–2024)

Year	Heatwave days	Yield (t ha^{-1})	Heatwave anomaly	Yield anomaly
2007	3	4.005	-6.94	-0.080
2008	12	4.355	2.06	0.270
2009	14	4.123	4.06	0.038
2010	28	3.830	18.06	-0.255
2011	0	4.009	-9.94	-0.076
2012	15	4.073	5.06	-0.012
2013	4	4.053	-5.94	-0.032
2014	14	3.915	4.06	-0.170
2015	0	4.124	-9.94	0.039
2016	23	4.059	13.06	-0.026
2017	3	4.087	-6.94	0.002
2018	0	3.897	-9.94	-0.188

Year	Heatwave days	Yield (t ha^{-1})	Heatwave anomaly	Yield anomaly
2019	3	3.998	-6.94	-0.087
2020	0	3.850	-9.94	-0.235
2021	12	4.060	2.06	-0.025
2022	10	4.111	0.06	0.026
2023	14	4.532	4.06	0.447
2024	24	4.456	14.06	0.371

This response is also confirmed by the year-wise data (Table 4) which indicated that there was a great interannual fluctuation in the number of heatwave days and yield anomalies. The lack of a solid and coherent relationship implies that the yield of the Boro rice in Rajshahi is conditioned by several interacting factors other than temperature extremes such as availability of irrigation, type of crop and the way it is managed. The findings show that despite the heatwave incidence being a significant aspect of climatic stress, its direct effect on the yield of Boro rice is minimal at present. Nevertheless, the frequency of heatwaves could be more threatening in the future especially when coupled with other stressors.

Overall discussion and implications

Findings of the research indicate a steady spatial concentration of the intensity of Boro-season heatwave in the southwestern region of northwestern Bangladesh especially along the stations of Rajshahi and Ishwardi. This trend is consistent with the past research findings that have found the western and northwest parts of Bangladesh to be more susceptible to temperature extremes because of reduced availability of soil moisture and the impact of the continent (Shahid, 2010). South Asian dry-season agroecosystems have also been found to exhibit similar spatial patterns of heatwave intensity (Perkins-Kirkpatrick and Lewis, 2020).

The observed rising pattern in the number of heatwaves is in line with the larger climate change forecasts of a higher number of temperature extremes in Bangladesh and South Asia (IPCC, 2021; Almazroui et al., 2021). The slow rise in the number of days of heatwave throughout the Boro season indicates that the future will probably see the process of thermal stress escalate, especially in those areas that are already hotspots. This is significant to irrigated rice systems, whereby increased temperatures have the potential to elevate evapotranspiration and irrigation needs (Wassmann et al., 2009). Despite the increasing heatwave frequency, the relationship between heatwaves and Boro rice yield in Rajshahi district was found to be weak. This finding is consistent with previous studies showing that irrigated rice systems often exhibit resilience to short-term temperature variability due to controlled water supply and improved crop management practices (Wassmann et al., 2009; Tao & Zhang, 2013). The presence of both high heatwave–high yield and high heatwave–low yield years further suggests that non-climatic factors, such as fertilizer application, irrigation management, and varietal improvement, play a significant role in determining yield outcomes.

Nonetheless, the fact that there are years when the intensity of heatwave and the yield are both high demonstrates that the extreme heat events can have an adverse impact on crop performance under some circumstances. It has been reported that high temperature stress during flowering and grain-filling processes lowers the quality of grains and yield of rice (Jagadish et al., 2007; Morita et al., 2005). Consequently, although existing Boro cultivation regimes seem to be relatively buffered, the frequency and intensity of heatwaves are likely to surpass adaptive capacities in the future. From a management perspective, the identification of persistent heatwave hotspot zones provides a useful basis for targeted adaptation strategies. These may include the development and adoption of heat-tolerant rice varieties, improved irrigation scheduling, and localized climate advisory services. In addition, integrating heatwave risk information into agricultural planning and early warning systems can enhance resilience in vulnerable regions.

Conclusion

This paper has analyzed the spatial and temporal properties of Boro-season heatwaves in northwestern Bangladesh by using daily maximum temperature records of 6 BMD station (2000-2024). Heatwaves were considered at least 3 days with temperatures above the 90th percentile at the station. Findings indicate that there is a clear spatial heterogeneity with the highest frequency in Rajshahi (10.72 days/year) and Ishwardi (9.92 days/year), whereas Rangpur had the lowest frequency (8.44 days/year). There was a southwest- northeast trend, with Rajshahi always being a hotspot. The interannual variation was also high as the upward trend was of about 2.02 days/year ($p=0.085$), which underscores more severe thermal extremes. Rajshahi yield analysis revealed that there is weak correlation between the frequency of heatwave and the yield of Boro rice ($R^2 = 0.07$), and mixed yield variation in identical heatwave conditions, which highlights the buffering effect of irrigation, management, and varietal adaptability. Results stress the importance of hotspot-focused interventions, such as heat-tolerant rice, better irrigation, and location-specific climate advisory services to promote resilience.

Data availability

Data will be made available on request.

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