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Impacts of temperature and rainfall variation on rice productivity in major ecosystems of Bangladesh

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Abstract

Background: Inconsistency in climate regimes of rainfall and temperature is a source of biotic and abiotic stresses in agricultural systems worldwide. Several studies from Bangladesh report that this variability is a cause of poor yield potential and crop failure. This study investigates the impact of temperature and rainfall variation on rice productivity for different ecosystems in Bangladesh. Three ecosystems under investigation include: dry (Rajshahi), terrace (Mymensingh) and coastal (Barisal).

Results: The terrace ecosystem recorded the highest rainfall, followed by coastal and dry ecosystems. The temperature variation, both maximum and minimum, showed an increasing trend; however, the incremental rate was higher in case of minimum temperature. Monsoon rainfall showed an increasing trend, while dry season (November to March) decreased slightly. The climatic variations and impacts were captured using a standardized precipitation index (SPI), diurnal temperature range (DTR) and rice productivity index (RPI). The rainfed rice crop (*aman*) observed a significant trend between RPI and seasonal SPI, and between RPI and seasonal DTR. Overall, the SPI indicated the prevalence of frequent dry and wet periods and DTR recorded a decreasing trend. The multiple regression analysis identified a significant correlation between RPI, SPI and DTR accounting for 41, 45 and 49% of yield variability in dry, terrace and coastal ecosystems, respectively.

Conclusion: Rainfall has shifted with an increasing trend during monsoon and almost static during other seasons. Rice production, especially rainfed rice, is at risk due to frequent drought and decreasing DTR. Stress-tolerant rice varieties requiring less irrigation water and survive at high temperature should be introduced. Research on rescheduling crop calendar and cropping pattern is necessary to mitigate the adverse climatic conditions.

Keywords: Ecosystem, Standardized precipitation index (SPI), Diurnal temperature range (DTR), Rainfed rice, Rice productivity index (RPI)

Background

The landscape of Bangladesh is primarily composed of deltaic floodplains with a predominantly humid tropical climate. The demography of the country is marked by extremely high population density (>1000 persons per km²). In addition to this, the country has a low resource base and high incidence of natural disasters, making it a highly vulnerable region. The agricultural sector is a large contributor to economic development of the country: contributing to 16.33% of its GDP and employing more than 53% of the population [2]. Most scientific surveys list Bangladesh as the most vulnerable country to the impacts of the global environmental phenomenon [32]. Therefore, developing measures that can ensure food and livelihood security, especially in the face of accelerating extreme climate events such as droughts, erratic rainfall patterns, cyclones and floods, is a priority. In recent years, extreme weather patterns have resulted in unseasonable biotic and abiotic stresses in agricultural sectors,

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impacting crop yield potential or resulting in crop failure [31].

Most of the parts of Bangladesh are vulnerable to adverse impacts of climate change. The coastal, dry and terrace ecosystems are particularly sensitive due to their geo-climatic profiles and anthropogenic influences. The coastal region, encompassing about one-fifth of the country's landmass and supporting nearly one-third of the total population of the country, is a sensitive landscape [19]. The northwestern region of the country is also vulnerable as it is drought prone and often impacted by the late arrival or early withdrawal of the monsoon. The terrace ecosystem accounts about 8% of the country`s landmass, which is relatively highland and cannot hold water during monsoon.

Rice (*Oryza sativa*) is the main food crop of Bangladesh, where it is grown thrice in a year in various agroecological landscapes with different temperatures and rainfall profiles. Rice production has increased tremendously in last decade due to technological development such as new varieties and management technologies. However, non-technological events such as drought, flood and prevalence of pests are creating threat to agricultural development in Bangladesh. Climate change in terms of increasing temperatures and uncertainty of precipitation is expected to adversely affect agriculture production [17, 22]. The Intergovernmental Panel on Climate Change (IPCC) estimates for 2050 show that changing rainfall patterns and increasing temperature, along with flooding, droughts and salinity, will possibly decline rice and wheat production by 8 and 23% against 1990 baseline production values [6]. Most scientific studies focus on investigating climate change and extremes at a large scale [33]. Often only densely homogeneous historical- or global-scale datasets are available [20], while few assessments exist at a national level [4, 16]. It is important to conduct studies at a smaller scale due to the large regional differences in surface temperature [15, 20] and rainfall [37]. The IPCC [21] report highlights the need for more detailed information about climate change at regional and local scales. Such initiatives can serve to capture the data and information needs for national-level stakeholders and for different economic groups. There is a lack of qualitative or quantitative information on climate change variability for varied, locale specific, management units such as agroecosystems. These particular gaps exist in datasets concerning Bangladesh. Although it is said that rice production is at vulnerable condition due to climate change, the quantification of yield loss due to variation of rainfall and temperature is not well documented in Bangladesh. Taking note of this concern, this study was designed to understand climate change trends at a regional level, with a specific focus on temperature

and rainfall variation and how such variations impact rice production in different copping seasons, in different agroecosystems.

Methods

Study area

The landscapes in Rajshahi, Mymensingh and Barisal represent the dominant agroecosystems in Bangladesh, classified as dry, terrace and coastal regions, respectively (Fig. 1). Rajshahi is located in the northwest of the country with high temperature (32–36 °C), considerable humidity and moderate rainfall (1400 mm). Mymensingh, located in northern part of the country, records a moderate climatic pattern. In Barisal, a tropical monsoon-type climate and hot and rainy summer and dry winter are often subjected to devastating cyclones originating over the Bay of Bengal.

Dataset and analyses

The normal climatic parameters at a given station at any scale can be assumed to be the mean of over a 30-year period [42]. Using this criterion, the dataset from 1961 to 2009 was employed, which was collected from the Bangladesh Meteorological Department (BMD) for the study locations. The data recorded a few missing values and some overestimations. In addition, the Climate Research Unit (0.5°: CRU TS 2.0) dataset of monthly temperature and rainfall for all three locations was employed. The available observed station data showed consistency with the CRU dataset. For analysis, the monthly data were separated into three clusters, viz. March to June (MAMJ), July to October (JASO) and November to February (NDJF). The climate clusters corresponds to the rice-cropping seasons for *aus* (MAMJ), *aman* (JASO) and *boro* (NDJF). The agriculture statistics representing data and information about the area, production and yield of rice were obtained from the Department of Agricultural Extension (DAE) and district offices and ranged from 1996–1997 to 2008–2009. The annual, *aus* (MAMJ), *aman* (JASO) and *boro* (NDJF) mean temperatures and total rainfall were analyzed using the monthly datasets. In addition, spatial distributions of annual and seasonal temperature and rainfall were analyzed using NCAR Command Language [9] and R (v. 2.14.1) computer software.

Rainfall and temperature trends

The average, standard deviation and variability of monthly, seasonal and annual rainfall were calculated for the time period under investigation. In addition, the proportional contribution of seasonal to annual rainfall was analyzed in order to understand rainfall distribution pattern. Monthly mean (TEM), maximum (T_{max}) and minimum (T_{min}) surface air temperature data were

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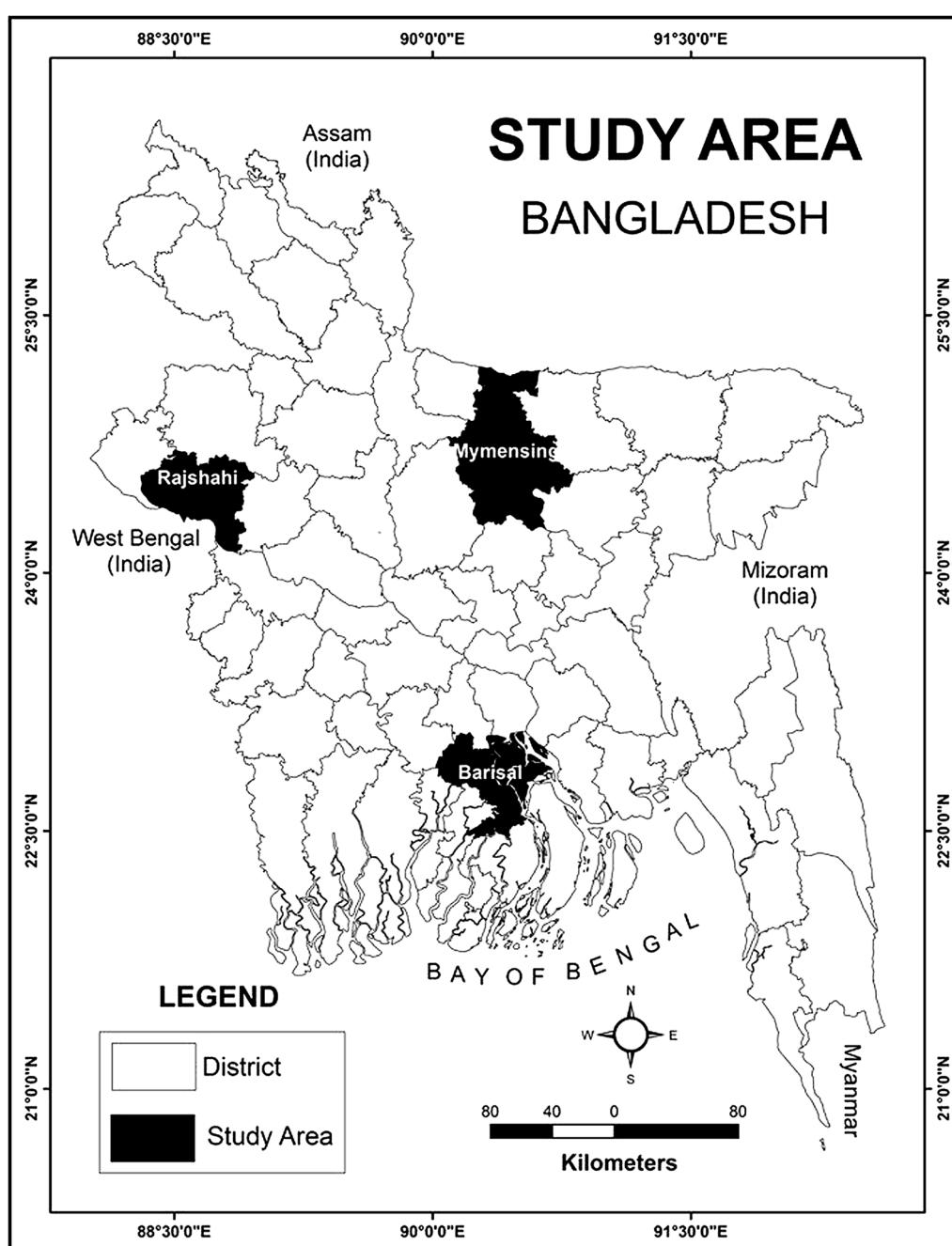
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Fig. 1 Location of the study area

employed to study the variability. Ordinary line regression ((OLR) $\hat{y} = \alpha t + \beta$) is an acknowledged way to capture correlation; where the rate of change is expressed as α and monthly and seasonal temperatures as $\hat{y}$ at the given time, t. The gradient of trends was calculated using the slope of the linear tendencies expressed in °C per decade.

Standardized precipitation index (SPI) and diurnal temperature range (DTR)

The SPI is a widely used drought index because of its simple and useful application [36]. It helps to identify and monitor droughts with a minimum data requirement—long-term ($\geq$30 years) monthly precipitation records [30]. It also helps to assess anomalous and extreme

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precipitation through numeric value substitution, therefore enabling appraisal and comparison of meteorological drought across different climate regimes [33]. The advantages of SPI over other indices include: (a) statistical consistency; (b) capacity to describe short- and long-term drought; and (c) its capacity for drought risk analysis [7]. The long-term data records fit to probability distribution simulation and following that transforms into a normal distribution [13], and SPI is reflective of the number of standard deviations that an observed value digresses from the long-term mean.

$$SPI = \frac{X_i - \bar{X}}{\sigma}$$

where X_i, $\bar{X}$ and σ are ith year precipitation, long-term mean of precipitation and the standard deviation of the mean, respectively.

Changes in the diurnal temperature range ($DTR = T_{max} - T_{min}$) play an important role in growth and yield of crops [3, 29]. Both historical observations [12, 40] and climate models [37] project significant changes in DTR. DTR and SPI are important indicators in determining the impact of climate variability on crop yield [15]; hence, they were utilized in this study.

Rice productivity index (RPI)

Crop productivity is a function of meteorological (rainfall, temperature, relative humidity and incoming solar radiation quality) and non-meteorological factors such as the type of seeds, site characteristics and management practices (including irrigation, fertilizer and pesticide application). It is often a challenging task to differentiate the impact of non-meteorological factors, more specifically the technological inputs. In order to study the pattern of trends and to quantify the growth rate based on technological inputs, the actual productivity was fitted with timer set linear curve over time. The technological productivity (TPi) was calculated by referring to the research of Subash and Mohan [37]:

$$TP_i = \alpha t_i + \beta$$

where α and β are constants determined empirically and $t_i = 1, 2, 3, \ldots$ represented from 1996–1997 to 2008–2009 for rice. To normalize the productivity data, the rice productivity index (RPI) was used that tends to extract the percentage of the technological-driven productivity to the actual productivity. The normalized RPI for the ith year is

$$RPI_i = \frac{(P_i - TP_i)}{TP_i} 100$$

where RPI$_i$ is the rice productivity index of rice for the ith year, P_i is the actual productivity for the ith year and TP$_i$ is the technological trend productivity for the ith year.

Results

Climatic variability: rainfall and temperature trends

Trends

The trend of annual rainfall anomalies shows an increasing pattern across the ecosystems reporting an increasing trend with a significant ($P < 0.05$) value recorded during JASO (Fig. 2). A significant increment in mean annual rainfall per decade was recorded for the terrace ecosystem (59.6 mm) that was followed by the coastal (52.2 mm) and dry (38.6 mm) regions. The increasing trend in rainfall during JASO was 32.2, 25.2 and 21.5 mm per decade for terrace, coastal and dry regions, respectively (Table 1).

Temperature, both maximum and minimum, trends were reported to increase for all regions. Additionally, monthly normalized anomalies and minimum temperature anomalies also note a significant ($P < 0.05$) positive trend (Fig. 3), and the trend for the maximum temperature anomalies was insignificant (Fig. 4). The mean decadal increment of minimum temperature was highest for the dry region (0.21 °C) followed by terrace (0.18 °C) and coastal (0.07 °C). The seasonal variation shows a high increasing trend during NDJF followed by MAMJ and JASO, particularly in the dry region. The decadal increment for coastal was high during JASO (0.09 °C) followed by MAMJ (0.08 °C) and NDJF (0.07 °C) (Table 1). The climate rend for the terrace region was of similar order as the dry region.

SPI and DTR

Figure 5 represents the seasonal and annual drought and wet frequency analyzed for different regions using SPI. The annual SPI was nearly normal (equivalent to −0.5 to +0.5); however, seasonal observations show both symptoms of dry and wet conditions in a time series. In recent years, SPI was normally distributed during March to June, while the wet and dry events were more distinct during JASO in all ecosystems. However, SPI fluctuation was most noticeable in the case of the dry region.

The DTR anomalies reported a decreasing trend for all regions (Fig. 6) with more warming tendency during winter (NDJB) compared to summer season. The time-series analysis of DTRs for the last couple of decades reported a decrease in all cases. During the *aman* rice season (JASO), the trend was less distinct. In terms of agroecological distribution, decreasing trend of DTR was most remarkable in dry region followed by terrace and coastal regions.
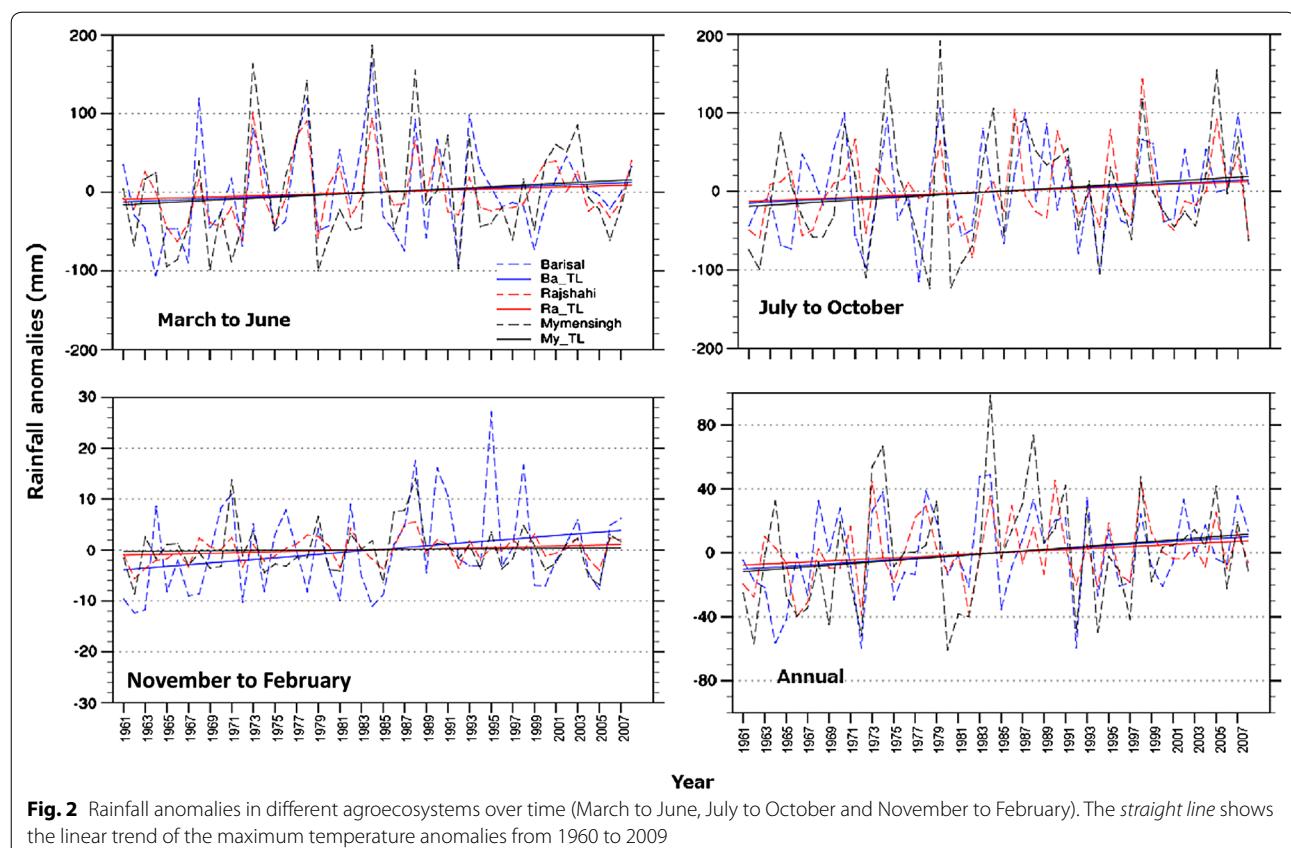
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Fig. 2 Rainfall anomalies in different agroecosystems over time (March to June, July to October and November to February). The *straight line* shows the linear trend of the maximum temperature anomalies from 1960 to 2009

Table 1 Decadal change of rainfall and temperatures over the period of 1960–2009 in the three studied agroecosystems
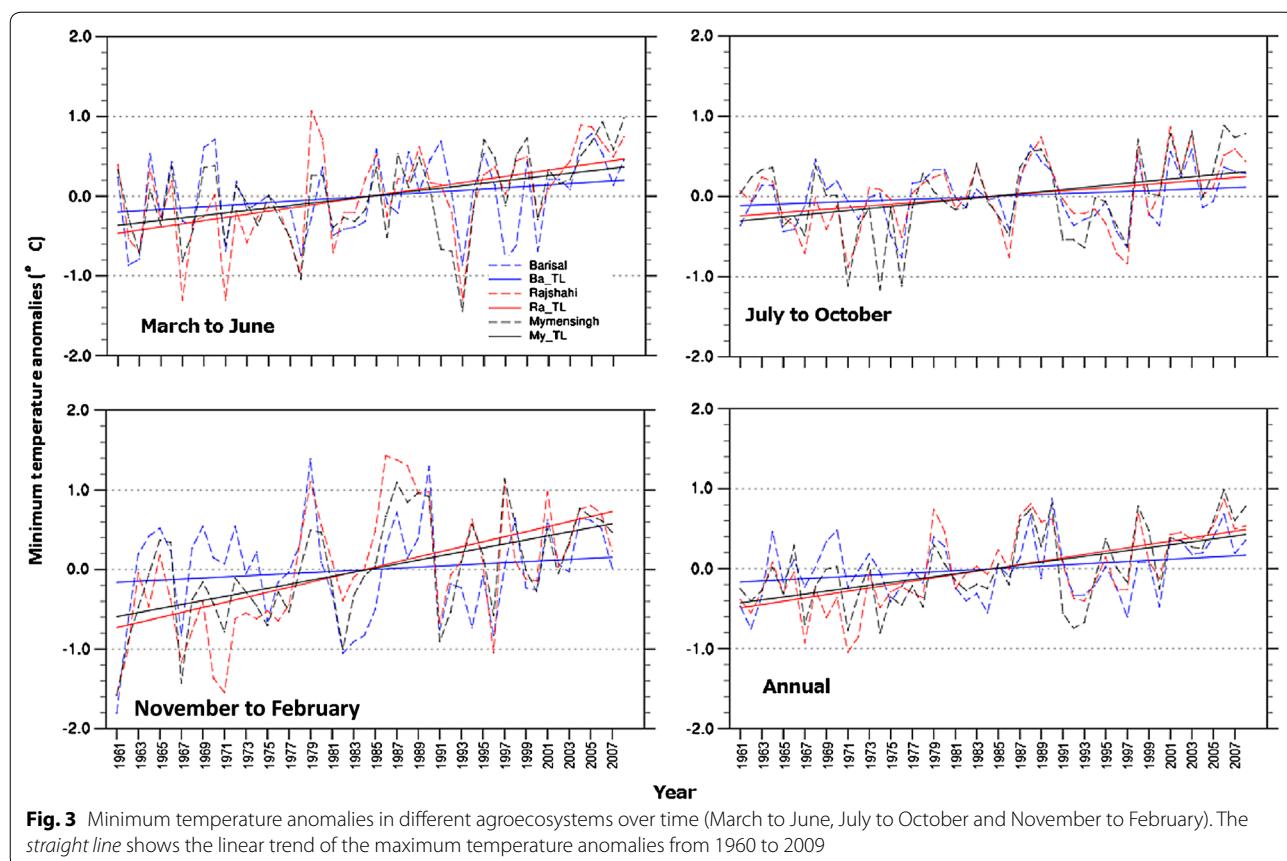
Region	Rainfall		Max temp (°C)		Min temp (°C)	
	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal
Coastal	52.19	25.24	0.007	0.078	0.071	0.094
Terrace	59.60	32.17	0.058	0.087	0.182	0.131
Dry	38.63	21.49	0.065	0.097	0.209	0.104

Crop productivity trends

The regional productiveness of seasonal rice (*aus, aman* and *boro*) crops for 1996/1997 to 2008/2009 reported a high and significant linear regression (R^2 value at $P < 0.05$) (Table 2). Among the ecosystems, the dry region reported the highest production value for all kinds of rice: 50.8 kg ha^{-1} year^{-1} for *aus*; 84.7 kg ha^{-1} year^{-1} for *aman*; and 81.6 kg ha^{-1} year^{-1} for *boro*. The agrarian landscape of the terrace region reported a medium gradient of productivity with values of 50.0, 85.9 and 66.2 kg ha^{-1} year^{-1} for *aus, aman* and *boro*, respectively. The coastal landscape showed a comparatively low production value of 30.1, 57.7 and 52.7 kg ha^{-1} year^{-1} for *aus*, *aman* and *boro*, respectively.

Correlating SPI, DTR and RPI

The results of the multiple regression correlations between RPI, seasonal SPI and DTR are listed in Table 3. At the 0.05 level, for the *aman* rice season, it was observed that the rice productivity index (RPI) and seasonal SPI and DTR are significantly correlated at 0.49, 0.45 and 41 (R^2) for coastal, terrace and dry regions, respectively. These observations indicate that seasonal rainfall (SPI) and temperature (DTR) anomalies accounted for 49, 45 and 41% of production variability of *aman* rice in coastal, terrace and dry regions, respectively. For *aus* rice, the relationship was not so significant, accounting for only 0.19, 0.18 and 0.14% of the variability in coastal, terrace and dry regions, respectively. Very

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Fig. 3 Minimum temperature anomalies in different agroecosystems over time (March to June, July to October and November to February). The *straight line* shows the linear trend of the maximum temperature anomalies from 1960 to 2009

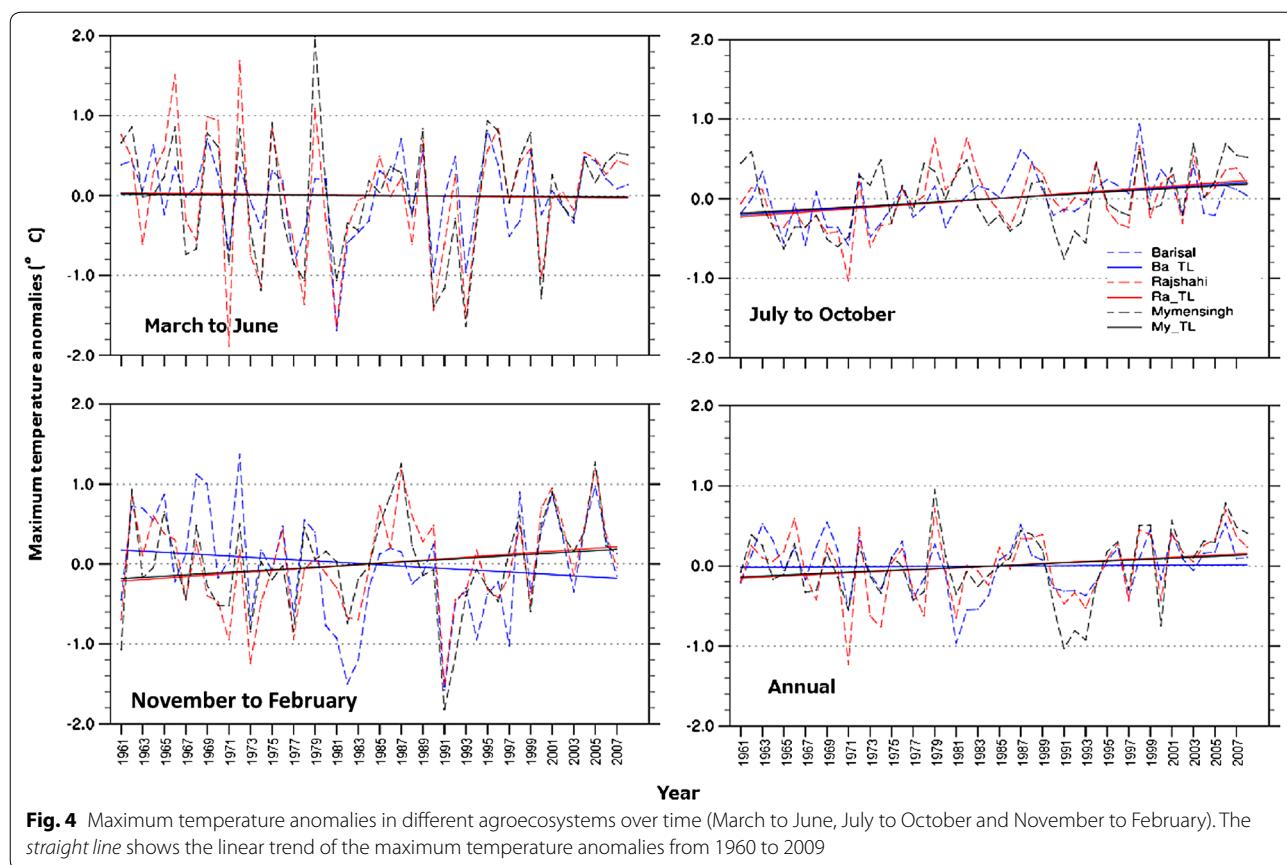poor relationships were recorded during the *boro* rice season.

Discussion

This study examines climate variability and its impacts on rice productivity for different ecosystems in Bangladesh. The annual rainfall trend shows an increasing tendency in different ecosystems with reported values in the order of 59.60 (terrace), 52.19 (coastal) and 38.63 (dry) mm per decade. This tendency was particularly high during monsoon season and almost unchanged during the dry season. Subash and Mohan [37] studied year-to-year variation in the monthly distribution of rainfall during southwest monsoon in Indo-Gangetic region for a long duration and found similar trends of rainfall patterns. The annual temperature also reports an increasing tendency; however, there are distinct differences in the trend for minimum temperature and maximum temperature (minimum temperature increased more rapidly). Our result is in good agreement with Fan et al. [15], who reported a higher increase in minimum temperature than maximum temperature in southwest China. The overall warming rate in the dry and terrace regions exceeds the global mean of 0.14 °C per decade (0.31 and 0.25 °C,

respectively) [5]. The difference between base decade (1960–1969) and recent decade (2000–2009) shows a significant change of the rainfall and temperature regimes in all agroecosystems.

Long-term SPI values are indicative of distinct wet and dry events in the region but may not necessarily show a definite trend. We observed that the JASO period was more vulnerable to drought and wet conditions compared to the others. The downward trend of DTR can be explained by the steeper increasing trend of minimum temperatures compared to maximum temperatures. The increasing trend of minimum temperatures was found in all seasons, but the increasing trend was the highest in the *boro* season, resulting in the decreasing trend in DTR. Our analysis shows a decreasing trend in DTR, because of a greater increase in nighttime temperature than that during the daytime. The decreasing strength of the winter monsoon is associated with the higher rate of increasing in minimum temperatures [41].

The rice productivity for the all ecosystems shows an increasing linear trend during the studied time period (1996–1997 to 2008–2009). The rate of rice productivity increase was highest in the case of *aman* rice, followed by *boro* and *aus* rice. This pattern was common
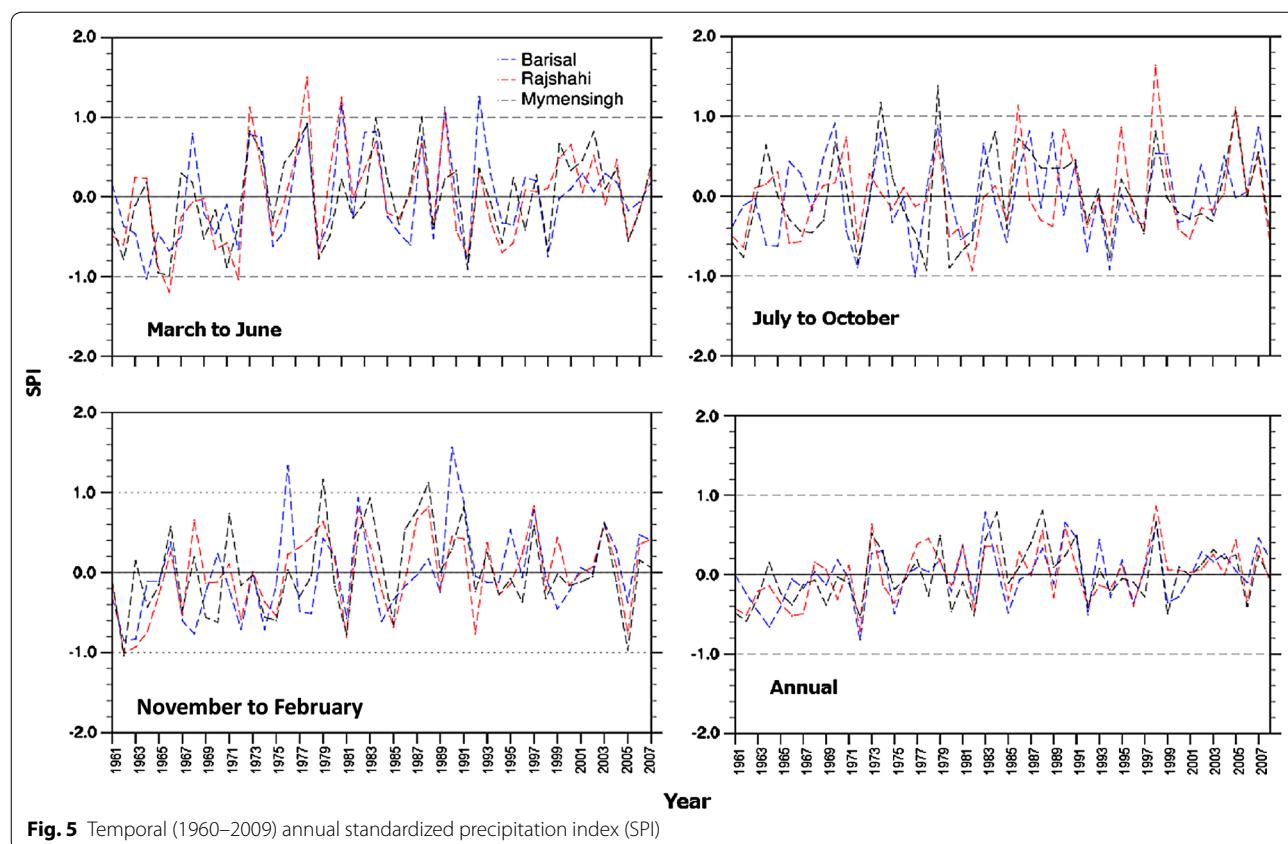
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Fig. 4 Maximum temperature anomalies in different agroecosystems over time (March to June, July to October and November to February). The *straight line* shows the linear trend of the maximum temperature anomalies from 1960 to 2009

for all regions. The increasing rate of rice productivity was maximum for dry (75.03 kg ha^{-1} year^{-1}) region followed by terrace (67.37 kg ha^{-1} year^{-1}) and coastal (47.07 kg ha^{-1} year^{-1}). Modern varieties of seeds along with additional farming technologies and techniques such as fertilizers, pesticides and irrigation facilities lead to improvements in crop productivity, to some extent balancing the direct impact of climate variability [38]. The SPI explains 18 and 16% of the yield variability in *aman* rice for dry and terrace ecosystems, respectively. However, yield variability attributed to SPI was not distinct for other rice seasons, regardless of the agroecosystems under investigation. This observation can be partly attributed to the influence of irrigation on crop productivity, mainly during dry season. This indicates that most cultivation during that time period is irrigation dependent. The statistical correlations indicate that crop productivity is closely integrated with climate variability; more so when the crop production is rainfed. Drought stress due to changing rainfall pattern can cause a loss in annual crop production of up to 40% in south and southeast Asia [23], meaning that this is an important factor in these regions. Li et al. [27] reported high drought risk in rice production,

particularly in rainfed rice, by using ORYZA2000 crop model.

On the contrary, DTR's influence on *aman* rice productivity is high compared to the rice production from other seasons, explaining the yield variability by 34.4, 28.7 and 27.6% in coastal, terrace and dry ecosystems, respectively. Changes in DRT have both positive and negative impacts on crop production [8, 10, 26, 28, 41]. Increasing DTR is responsible for increasing respiration rate during nighttime that decreases the crop yield. Reduction in rice yield due to increasing temperature has been reported by Jagadish et al. [18, 24]. Increasing temperature and decreasing rainfall enhance drought and hamper rice production. A warmer climate scenario, with more uncertain onset of summer monsoon, is likely to mostly affect rainfed crops and also water supplies for irrigation [10]. On reproductive structures, the elevated temperatures have marked impacts as it may decrease crop yield due to spikelet sterility [24]. Rice is hypersensitive to high-temperature stress during panicle development and meiosis causing anomalous pollen maturity and absolute sterility [14, 25].

There is enough scientific evidence to suggest that crop production is increasingly susceptible to frequent

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Fig. 5 Temporal (1960–2009) annual standardized precipitation index (SPI)

extreme weather events related to rainfall intensity, density and frequency distribution that subsequently result in drought and flood [11] and pest and disease infestation [38]. Crop damage due to flooding will make an even larger section of population extremely vulnerable to starvation, malnutrition and even death [35]. Overall, we note an increasing tendency in monsoon rainfall. It is important to note that winter rainfall shows shrinking pattern and could be a concerning factor for winter rice (*boro*) crop, an argument that blends with the observation of Revi [33]. Seasonal variation in weather parameters could also influence pest and disease infestation [1]. Our results, and the findings from other studies, imply that despite technological developments balancing crop productivity, the impact of climate adversity on rainfed cultivation will remain significantly concerning. Although we found decreasing rainfall during dry season, it did not affect winter rice. This is because this rice is irrigation dependent and recently irrigation facilities have been developed tremendously. However, this irrigation water comes by lifting groundwater, which is not wise in long run as water table is being decreased due to prolonged drought and heavy metal, for example arsenic, contamination. However, rainfed rice is affected

more due to changing pattern of rainfall and increasing temperature. It is observed that the number of days without rain is increasing, although the total annual rainfall shows an increasing trend. This erratic pattern of rainfall triggers extreme climatic events such as flood and drought, which have adverse effects on rice yields. As a result, rice production is likely to decline by 8–17% by 2050 [34]. Farmer's observation in many agricultural areas report variability in rice production, strongly influenced by rainfall patterns and gradual shift in the fruiting and flowering season of rice crops [39].

Strengthening the knowledge base and developing information and monitoring systems for regions prone to drought, flood and salinity is a significant dimension in climate change adaptation planning [32]. In general, crop production depends on various biotic and abiotic factors. In this study, we analyzed only rainfall and temperatures to describe their impacts on rice production, which may not the ultimate results. Therefore, other climatic parameters are needed to analyze for explaining the situation more clearly. Additionally it is pertinent to investigate ecologically sustainable agricultural practices that amalgamate environmentally sound planning and economically feasible technologies.
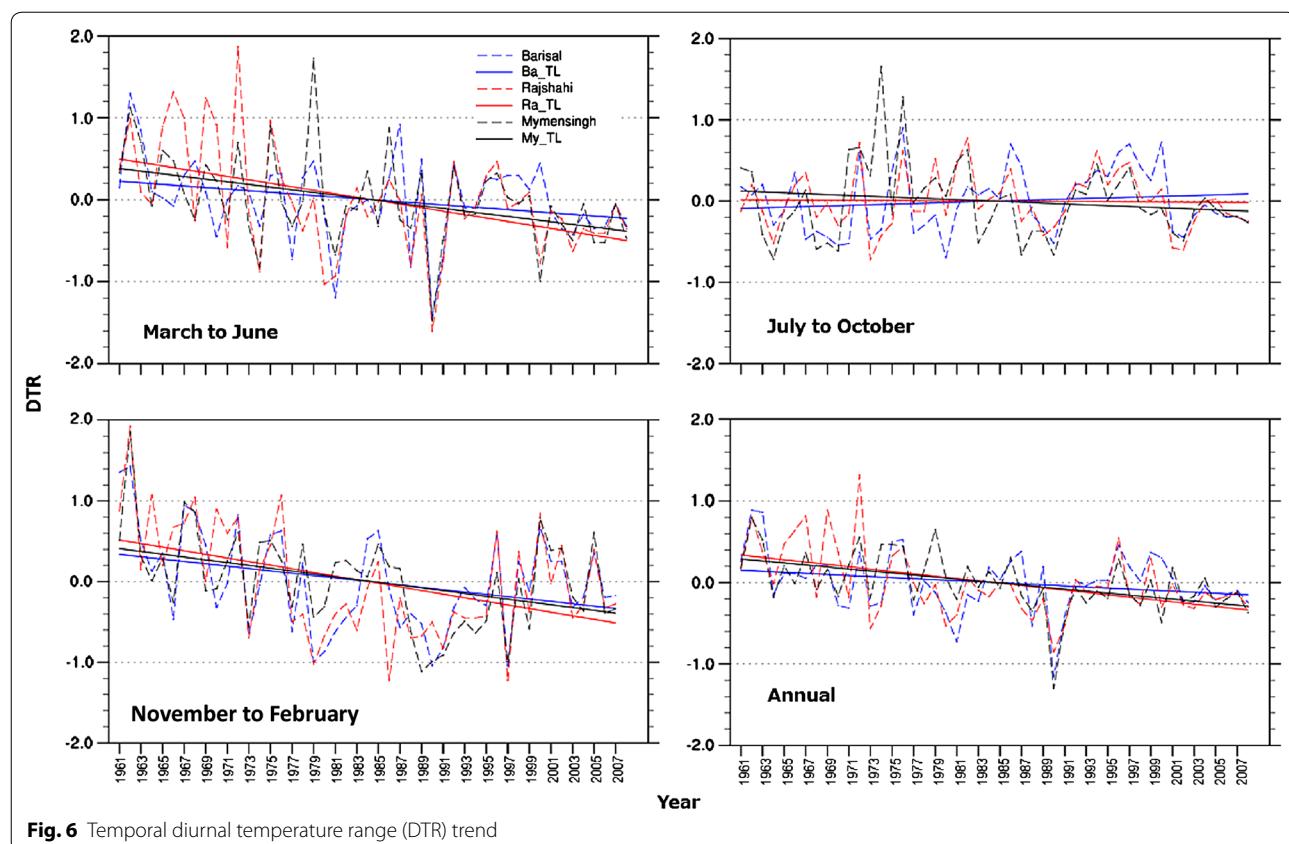
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Fig. 6 Temporal diurnal temperature range (DTR) trend

Table 2 Linear technological trend equations for rice productivity and regression statistics (R^2 and SE) in the three studied agroecosystems

Crop	Dry	Terrace	Coastal
Rice—*aus*	$\text{TRP}t_i = 1.7462 + 0.0588t_i$ ($R^2 = 0.77^*$; SE = 0.0722)	$\text{TRP}t_i = 1.8592 + 0.0501t_i$ ($R^2 = 0.82^*$; SE = 0.0596)	$\text{TRP}t_i = 2.145 + 0.0308t_i$ ($R^2 = 0.52^*$; SE = 0.046)
Rice—*aman*	$\text{TRP}t_i = 1.7826 + 0.0847t_i$ ($R^2 = 0.76^*$; SE = 0.1022)	$\text{TRP}t_i = 1.7646 + 0.0859t_i$ ($R^2 = 0.89^*$; SE = 0.0982)	$\text{TRP}t_i = 2.1369 + 0.0577t_i$ ($R^2 = 0.66^*$; SE = 0.0755)
Rice—*boro*	$\text{TRP}t_i = 3.111 + 0.0816t_i$ ($R^2 = 0.65^*$; SE = 0.109)	$\text{TRP}t_i = 3.0815 + 0.0662t_i$ ($R^2 = 0.87^*$; SE = 0.0768)	$\text{TRP}t_i = 3.3319 + 0.0527t_i$ ($R^2 = 0.45^*$; SE = 0.0844)

$t_i = 1, 2, 3$ ….. for the period from 1996–1997 to 2008–2009

SE standard error, *TRP* technological rice productivity

* Significant at *P* < 0.05 level

Conclusion

It can be stated that world's food security is under pressure due to climate change with different biotic and abiotic stresses. Climate change is unswervingly influencing the human survival through its agricultural impacts by higher temperatures, droughts, floods, soil erosion and rainfall variations affecting the food security of the globe. This study elucidates seasonal and annual rainfall and temperature variability to assess regional and seasonal trends in three agroecological regions for five decades (1960–2009). An increasing trend in the total annual rainfall was observed in the regions, particularly during the monsoon season; however, it remained almost unchanged during the dry winter season. Additionally, maximum (0.07 °C per decade) and minimum (0.21 °C per decade) temperatures note a pronounced rise in dry region when compared to other regions. The indices selected to represent the correlation between rice productivity and climate variation showed a fair degree of response. SPI and DTR captured the *aman* season yield variability in all ecosystems with reasonable accuracy, at 49, 45 and 41% in coastal, terrace and dry regions,

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Table 3 Rice productivity index and seasonal SPI and DTR relationship regression equations and statistics (R^2 and SE) in the three studied agroecosystems

Region	Regression equation	R^2	SE
Rice productivity index (RPI): *aus*			
Dry	RPI $= 17.012 + \text{SPI}_i\,(0.8089) + \text{DTR}_i\,(-17.2472)$	0.14	5.521
Terrace	RPI $= 14.775 + \text{SPI}_i\,(-2.963) + \text{DTR}_i\,(-20.508)$	0.18	5.364
Coastal	RPI $= 27.630 + \text{SPI}_i\,(-8.532) + \text{DTR}_i\,(-54.512)$	0.19	4.697
Rice productivity index (RPI): *aman*			
Dry	RPI $= 12.921 + \text{SPI}_i\,(-8.45) + \text{DTR}_i\,(-23.088)$	0.41*	3.760
Terrace	RPI $= 10.03 + \text{SPI}_i\,(-16.56) + \text{DTR}_i\,(-46.136)$	0.45*	5.087
Coastal	RPI $= 21.178 + \text{SPI}_i\,(-20.172) + \text{DTR}_i\,(-34.498)$	0.49*	4.643
Rice productivity index (RPI): *boro*			
Dry	RPI $= 10.22 + \text{SPI}_i\,(-12.52) + \text{DTR}_i\,(-6.894)$	0.10	3.625
Terrace	RPI $= 5.668 + \text{SPI}_i\,(1.569) + \text{DTR}_i\,(7.779)$	0.16	2.311
Coastal	RPI $= 13.603 + \text{SPI}_i\,(-10.803) + \text{DTR}_i\,(-7.139)$	0.04	4.66

* Significant at $P < 0.05$ level

respectively. It was also noted that SPI and DTR did not affect significantly during *aus* and *boro* rice seasons. It is anticipated that such local-level analysis could serve as policy support tool while planning region-specific climate change adaptation strategies. To alleviate the risk of climate change in rainfed rice production, it is important to adjust the sowing/transplanting period in corresponding to future climate trends. This study may help to develop climate smart agricultural practices through appropriate, environmentally sound and economically feasible technologies. More concerns are needed and sectoral and impact specific plans to avoid any unfavorable situation for food security. Hence, a collective effort is warranted to employ various adaptive and mitigative strategies including research and development activities suitable for crop types, regions and specific problems to cope up effectively with climate change impacts.

Abbreviations
DRT: diurnal temperature range; IPCC: Intergovernmental Panel on Climate Change; JASO: July to October; MAMJ: March to June; NDJF: November to February; RPI: rice productivity index; SPI: standardized precipitation index; TEM: mean temperature; T_{max}: maximum temperature; T_{min}: minimum temperature.

Authors' contributions
All authors planned jointly the study, the hypothesis and the objectives. MAR and SK collected and analyzed the data. MAR and NN designed the quantitative survey and analyzed the data. MAR and RM drafted the manuscript. All authors contributed to manuscript improvement. All authors read and approved the final manuscript.

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