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Full Length Research Paper

An over view of climate change in the southwestern part of Bangladesh in Jessore and Sathkhira districts and rice Yield response; an analysis of aggregate level data

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This study examines the association between the yield of three main rice crops (e.g., Aus, Aman and Boro) and three main climate variables (e.g., extreme temperature, least temperature and rainfall) for Bangladesh especially Jessore and Sathkhira districts. We use time series data for the 1972–2009 period at an aggregate level to evaluate the association between climate variables and rice harvest using both the normal least rectangles and median (quartile) regression approaches. The findings of this study approve that climate variables have had important belongings on rice yields but that these properties vary among three rice crops. Extreme temperature is statistically important for all rice crops with optimistic belongings on Aus and Aman rice and contrary belongings on Boro rice. Lowest temperature has a statistically important bad effect on Aman rice and a significantly confident effect on Boro rice. Finally, rainwater has a statistically important result on Aus and Aman rice. However, the effects of extreme temperature and least temperature are more distinct compared with that of rainfall. Given these special effects of temperature on rice crops and swelling climate change susceptibilities, policy makers should fund the study and progress of temperature lenient rice varieties, mainly for Aman and Boro rice.

Keywords: Temperature, Aggregate, Aus, Aman , Boro

INTRODUCTION

This article is focused on the first research question. Has the Bangladesh climate changed over the last 60 years? Do climate projections indicate future climate changes? Have rice yields in Bangladesh increased over the past 40 years? What is the relationship between climate variables and rice yields since the country's independence in 1971? This article endeavors to answer these questions by:

- Analyzing the changes in major climate variables over the past 60years (e.g., maximum temperature, minimum temperature and rainfall); and
- assessing the impact of these climate variables on rice yields of different varieties using time series data.

To answer these questions, this article commences with a definition of climate change and variability. Then an analysis of climate change for Bangladesh and its variability is undertaken. Rice yield responses to the changes in climate are then examined. Finally, some

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concluding comments are presented.

Defining climate change and variability

Climate change is a prime example of a negative environmental externality (Tol 2009). According to the IPCC (2007), climate change refers to any changes in major climatic variables over a longtime. These changes occur because of either natural variability or human activities. However, according to the Framework Convention on Climate Change,

A change of climate is attributed directly or indirectly to human activities that alter the composition of the global atmosphere (IPCC2007).

Climate change can also be defined as an overall shift in climate conditions such as mean maximum or minimum temperature and average total rainfall in a given region over a long period. Climate variability refers to temporal variation about the mean. Nonetheless, the difference between these two concepts is not absolute, especially as a change in climate per se may induce, *ipso facto*, a change in variability around a changing mean (Rosenzweig & Hillel 2008). It is noteworthy that the severity and frequency of extreme climate events such as flood, drought and cyclone are on the rise due to climate change (IPCC 2007; Rosenzweig & Hillel 2008).

Present climate of Bangladesh

Temperature, rainfall, wind speed and solar radiation mainly characterize the climate system of Bangladesh and determine the four seasons (Islam & Neelim 2010). Bangladesh has a tropical monsoon climate with four distinct seasons (Brammer 1999; Brammer 2002):

a) Pre-monsoon (March–May): This is the hot or summer season characterized with high temperatures and evaporation rates, and occasional line squalls (nor'-westers) by thunderstorm rainfall, strong wind and occasional hail; tropical cyclones (typhoons) are also liable to affect coastal areas.

b) Monsoon (June–September):This season is the period of high intensity rainfall, humidity and cloudiness.

c) Post-monsoon (October–November): The characteristics of this season include a hot and humid period with decreasing rainfall, but sunny and with heavy dew at night.

d) Dry or winter season (December–February): This season is depicted as the coolest, driest and sunniest period of the year.

Mean annual temperature is almost 25°C everywhere in Bangladesh but ranges between 18°C in winter and 30°C in the pre-monsoon season (Brammer 1999). Mean annual rainfall is lowest in the west (1250–1500mm) and highest in the north, east and south (>2500 mm); and it exceeds 5000 mm in the extreme northeast of Sylhet. However, rainfall is very variable, resulting in severe droughts and floods.

Rashid (1991) divided Bangladesh into seven climatic sub-zones (Figure 4.1). These sub- zones are described briefly:

Southeastern sub-zone: This zone consists of greater Chittagong district and Chittagong Hill Tracts and a coastal strip extending from southwest Sundarban to the south of Comilla. Heavy rainfall and small range of mean temperature are the major climatic characteristics of this region.

Northeastern zone: This zone comprises the greater Sylhet district. The salient climatic features of this region include mild summer temperatures, heavy rainfall and a cloudy cold winter.

Northern part of the north: This zone includes the greater Rangpur district and the northern part of the greater Dinajpur district. In terms of climate, this is an area of extremes: heavy rainfall, hot summer temperatures and cold winters are three major climatic characteristics.

Northwestern zone: This area contains the Dinajpur, Bogra, Pabna and Kushtiadistricts. The main climatic conditions are hot summer temperatures and a moderate rainfall.

Western zone: This is the driest and hottest sub-zone which includes the greater Rajshahi districts and parts of adjacent districts. Very hot summer temperatures and relatively low rainfall are the climatic features of this zone.

Southwestern zone: This zone comprises the Khulna, Jessore, Sathkhira and Faridpur districts with fewer extremes. Climatic characteristics are hot summer temperatures and fairly heavy rainfall. This is the area of interest for the farm level analysis.

South central zone: This is an area of mild summers and fairly heavy rainfall. This zone consists of the Dhaka, Tangail, Mymensingh and Barisal districts.

Methods for discovering variability in climate

Three statistical methods are employed to examine the variability of climate. First, descriptive statistics such as mean, standard deviation and coefficient of variation (CV) are used. Second, a simple trend model is used to examine the time trend of variability. Third, a more robust technique of analyzing the strength of association, QR, is used to observe changes in climate variables overtime. Variability of a variable over a long period of time is traditionally explained by a linear trend model fitted by an ordinary least squares (OLS) method (Hazell 1982; 1985; Kwasi 1998; Rimi et al. 2009). But this model based on simple linear regression only measures the rate of change in the mean of the distribution of observations, whereas climate variability can include not only changes in the mean state but also changes in the spread of the data distribution over time (Koenker & Bassett 1978; Timofee & Sterin 2009; Trivedi & Cameron 2009). When analyzing the

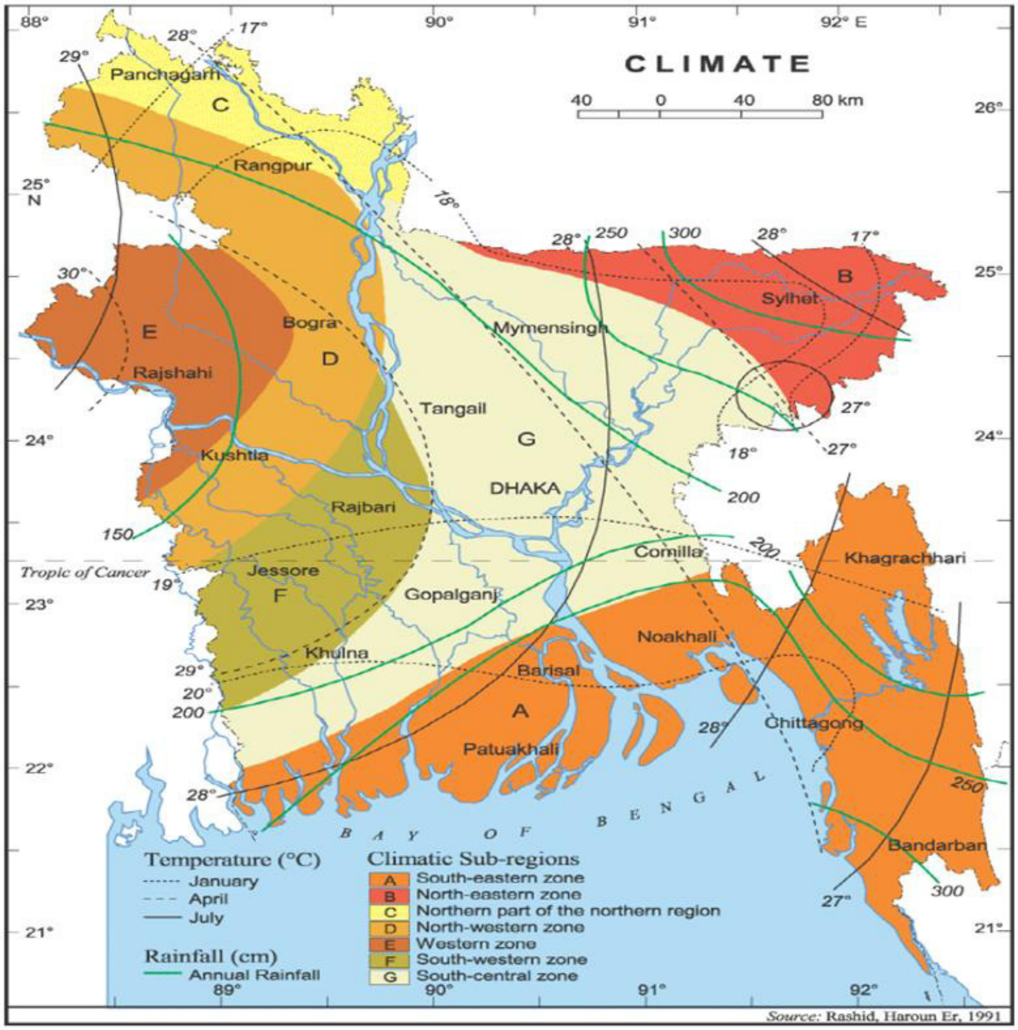

Figure 1
Climate zones in Bangladesh
Source: Rashid (1991),(http://www.banglapedia.org/httpdocs/HT/C_0288.HTM)

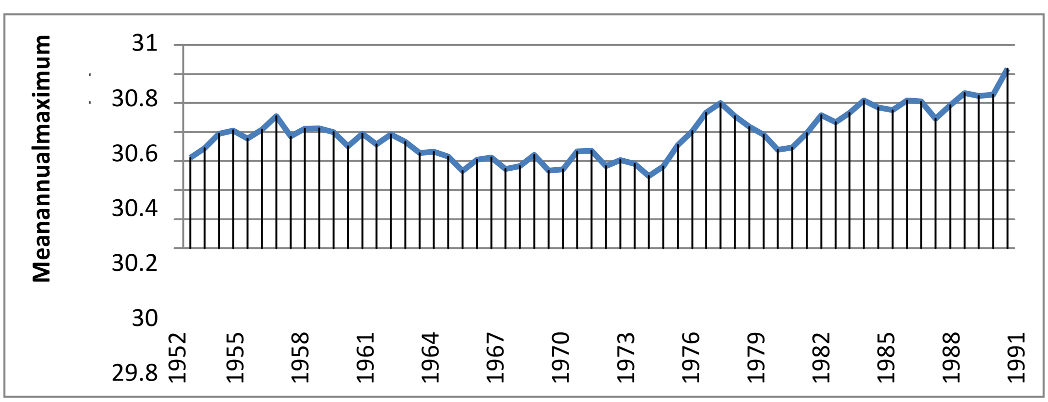

Figure 2 Moving average of mean annual maximum temperature

Table 1 Climate variability in Bangladesh over the 1948–2009period

Major climate variable	Statistical tool	1948–1967	1968–1987	1988–2009
Average annual maximum temperature(°C)	Mean	30.34	30.24	30.56
	Standard Deviation	0.23	0.25	0.31
	Coefficient of Variation(%)	0.77	0.83	1.03
Average annual minimum temperature(°C)	Mean	20.79	21.03	21.37
	Standard Deviation	0.23	0.23	0.25
	Coefficient of Variation(%)	1.10	1.11	1.19
Average annual total rainfall (mm)	Mean	2225.70	2367.34	2475.66
	Standard Deviation	260.65	262.26	262.27
	Coefficient of Variation(%)	11.71	11.08	10.59

Source: calculation based on data collected from BMD (2010) by Sarkar

trend of climate series, the QR method can generate information on trends along the whole range of quantile values from 0 to 1 (e.g., at quantiles 0.1,0.25,0.5,0.75and0.9, corresponding to 10%, 25%, 50%, 75% and 90% of the observations respectively) of the distribution of the dependent variable which is more informative than traditional regression techniques such as OLS. This study has therefore principally employed the QR method along with descriptive statistics and the linear trend model. Using this approach and applying it to Bangladesh time series data for the 1948–2009 period, due to greater availability of data, the changing behavior of climate and its variability overtime is briefly examined in the following section.

Empirical results of climate change and variability

Evidence from the simple statistical methods

Various simple statistical methods are used to assess climate variability. previous sets out the variability in the three commonly used climate variables (average annual maximum temperature, average annual minimum temperature and average annual total rainfall) using those simple tools. These three variables are constructed from daily data from 32 weather stations throughout Bangladesh. Three time periods are considered to observe the variability overtime.

Table1 indicates significant climate variability. First, the mean for both the average annual maximum temperature and the average annual minimum temperature has increased steadily over the three periods. Absolute variability, measured by standard deviation, also increased over the same period but the relative variability, measured by CV, is higher for the average minimum temperature than the average maximum temperature. Mean for the average annual total rainfall has also risen over the three periods. Though absolute variability in rainfall has increased, the relative variability decreased. All these provide evidence of a changing climate in Bangladesh over the last 60 years. A better representation of these changes is illustrated in Table 2 which shows the absolute and relative variability of climate variables over time. There seems to be time trend in both absolute and relative measures of variability.

There are considerable time trends in the mean values of all climate variables. Mean values for maximum and minimum temperature and rainfall increase gradually over the period. However, the growth in minimum temperature is higher than that of maximum temperature. Absolute variability also rises throughout the time horizon. Though CV for maximum temperature increases, CV for minimum temperature and rainfall increases initially and then declines with frequent fluctuations indicating variability in climate.

These aspects of variability become clearer if these observations are plotted against time.

In the above figure the variability in mean annual temperature over the period can be located visually. Mean annual temperature, on average, appears to decrease up to 1985, then tends to increase sharply up to 2009 with some variations over the period. However, the overall trend is up war.

The absolute variability in mean maximum temperature for the 1952–2009 period is shown in Figure 2. It shows a rapid increase to 1961 then it decreases quickly to 1967. From 1967 to 2009 it exhibits a steady increase with some fluctuations over the period. All these indicate the variability in the mean maximum temperature.

The relative variability of the mean maximum temperature against time is plotted in that Figure3. One can locate over all similar characteristics in its behavior to those for absolute variability of maximum temperature. However, there is a difference. This relative variability has increased to a higher average value. One can easily observe a sharp increase in the mean minimum temperature. The speed of increase is higher for the 1985–2009 period compared to the 1952–1984 period. This gives

Table 2 Mean values, standard deviation and coefficient of variation

Year	Average maximum temperature			Average minimum temperature			Average rainfall		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1952	30.22	0.13	0.45	20.69	0.14	0.67	2306.73	176.63	7.66
1953	30.29	0.15	0.51	20.76	0.23	1.12	2295.61	170.90	7.44
1954	30.39	0.13	0.44	20.84	0.19	0.89	2254.60	134.76	5.98
1955	30.41	0.11	0.37	20.86	0.16	0.74	2263.14	128.30	5.67
1956	30.36	0.17	0.56	20.84	0.17	0.82	2364.28	146.09	6.18
1957	30.42	0.18	0.59	20.78	0.24	1.14	2210.36	349.80	15.83
1958	30.51	0.29	0.94	20.81	0.30	1.42	2111.42	371.49	17.59
1959	30.37	0.40	1.32	20.77	0.29	1.40	2209.79	477.42	21.60
1960	30.42	0.42	1.38	20.79	0.29	1.39	2188.69	480.24	21.94
1961	30.43	0.42	1.37	20.82	0.28	1.36	2087.69	425.85	20.40
1962	30.40	0.41	1.35	20.81	0.30	1.44	2148.61	362.94	16.89
1963	30.30	0.30	0.99	20.68	0.16	0.78	2227.69	322.52	14.48
1964	30.39	0.18	0.60	20.76	0.26	1.25	2159.43	185.48	8.59
1965	30.32	0.12	0.39	20.75	0.26	1.24	2204.44	193.12	8.76
1966	30.38	0.09	0.29	20.82	0.31	1.51	2207.09	191.08	8.66
1967	30.33	0.12	0.39	20.88	0.24	1.17	2237.10	146.01	6.53
1968	30.25	0.17	0.55	20.91	0.21	1.01	2241.70	146.71	6.54
1969	30.26	0.17	0.57	20.86	0.17	0.82	2237.05	139.40	6.23
1970	30.23	0.18	0.61	20.94	0.20	0.98	2244.50	145.81	6.50
1971	30.13	0.15	0.50	20.86	0.18	0.86	2292.62	121.43	5.30
1972	30.21	0.25	0.83	20.86	0.18	0.87	2228.90	258.05	11.58
1973	30.22	0.24	0.80	20.93	0.22	1.07	2274.04	285.09	12.54
1974	30.15	0.25	0.82	20.92	0.23	1.09	2309.72	315.52	13.66
1975	30.16	0.25	0.82	20.88	0.19	0.92	2263.12	323.81	14.31
1976	30.24	0.23	0.78	20.94	0.18	0.87	2274.34	327.86	14.42
1977	30.13	0.15	0.51	21.00	0.13	0.60	2431.08	187.24	7.70
1978	30.14	0.15	0.50	20.93	0.10	0.49	2415.91	183.87	7.61
1979	30.27	0.21	0.71	21.07	0.25	1.20	2277.44	266.06	11.68
1980	30.27	0.21	0.71	21.15	0.28	1.31	2267.79	273.75	12.07
1981	30.16	0.28	0.91	21.15	0.28	1.33	2295.24	295.22	12.86
1982	30.21	0.27	0.88	21.14	0.29	1.35	2243.81	257.63	11.48
1983	30.18	0.28	0.93	21.19	0.23	1.10	2326.41	369.57	15.89
1984	30.10	0.17	0.56	21.04	0.23	1.09	2492.38	307.82	12.35
1985	30.16	0.26	0.88	21.00	0.17	0.79	2524.67	257.63	10.20
1986	30.31	0.25	0.82	21.01	0.17	0.79	2495.00	265.56	10.64
1987	30.41	0.30	1.00	21.10	0.26	1.24	2565.56	247.92	9.66
1988	30.53	0.22	0.71	21.20	0.33	1.58	2537.99	216.62	8.54
1989	30.60	0.09	0.30	21.25	0.26	1.21	2417.25	252.62	10.45
1990	30.51	0.24	0.79	21.28	0.26	1.20	2502.44	248.70	9.94
1991	30.43	0.27	0.89	21.32	0.22	1.03	2586.33	267.03	10.32
1992	30.38	0.22	0.73	21.25	0.21	1.01	2435.33	399.07	16.39

Table 2 Continue

1993	30.28	0.18	0.60	21.14	0.14	0.67	2439.97	402.94	16.51
1994	30.29	0.21	0.69	21.17	0.12	0.56	2423.97	420.06	17.33
1995	30.39	0.21	0.71	21.21	0.18	0.85	2378.06	399.35	16.79
1996	30.52	0.25	0.83	21.23	0.20	0.94	2291.17	325.19	14.19
1997	30.47	0.29	0.94	21.18	0.26	1.24	2385.28	241.00	10.10
1998	30.53	0.22	0.72	21.32	0.32	1.52	2398.83	265.02	11.05
1999	30.62	0.31	1.02	21.43	0.35	1.63	2521.06	187.70	7.45
2000	30.57	0.34	1.10	21.38	0.36	1.66	2551.51	182.32	7.15
2001	30.55	0.32	1.05	21.36	0.36	1.68	2580.19	154.80	6.00
2002	30.62	0.27	0.87	21.46	0.23	1.06	2632.57	101.35	3.85
2003	30.61	0.27	0.89	21.39	0.18	0.86	2533.02	148.23	5.85
2004	30.49	0.16	0.52	21.33	0.07	0.33	2549.38	167.73	6.58
2005	30.59	0.18	0.60	21.44	0.19	0.87	2539.01	166.47	6.56
2006	30.67	0.32	1.04	21.54	0.21	0.97	2476.74	227.81	9.20
2007	30.65	0.33	1.08	21.53	0.21	0.98	2512.97	269.42	10.72
2008	30.66	0.32	1.05	21.55	0.20	0.93	2535.84	249.56	9.84
2009	30.84	0.40	1.29	21.60	0.19	0.87	2435.78	251.16	10.31

Sources: Based on data collected from BMD (2010); Notes: Original data series were from 1948 to 2009. Five-yearly moving average is taken to compute mean value series. As a result time period has reduced to 1952–2009. Standard deviations (SD) are based on the corresponding five-yearly figures. CV = [(SD) /Mean]×100.

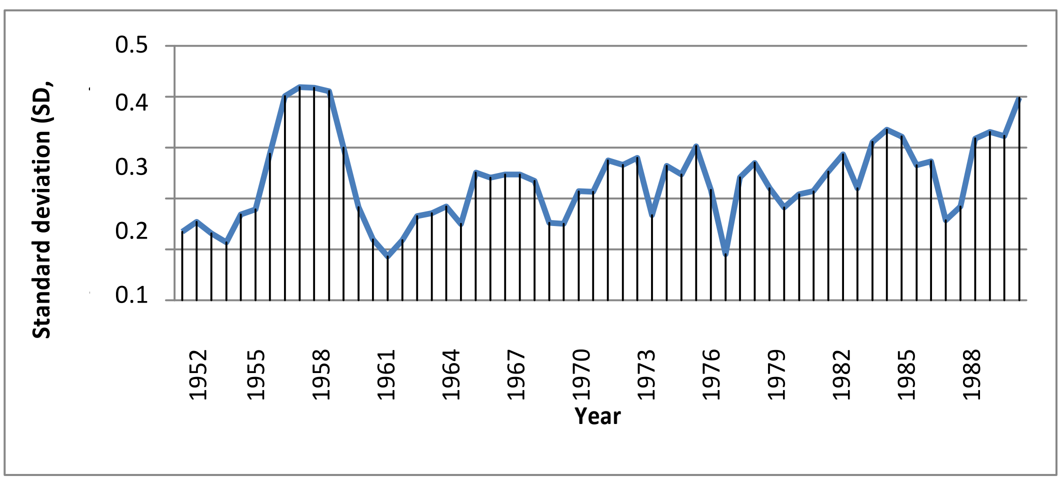

Figure 3 Standard deviation of mean maximum temperature

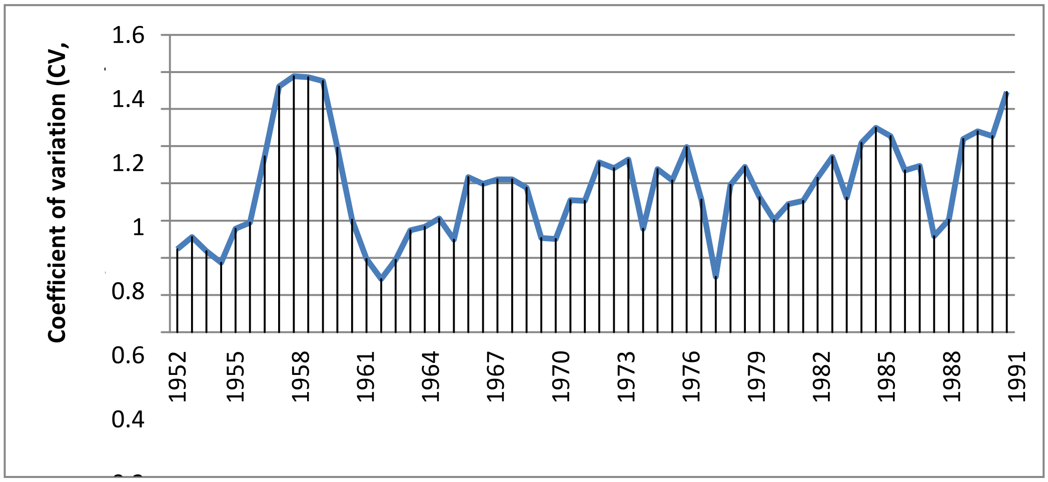

Figure 4 Coefficient of variation in mean maximum temperature

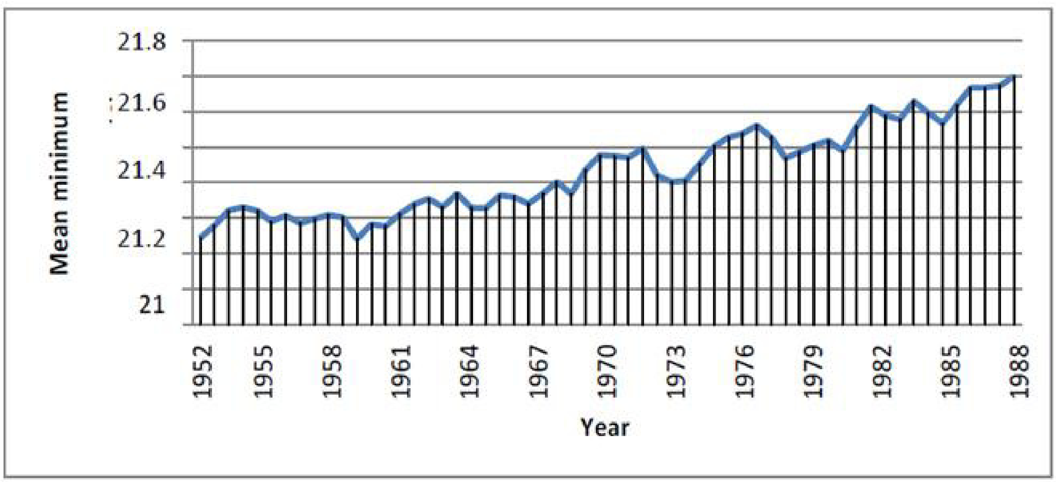

Figure 5 Moving average of mean annual minimum temperature

an indication of a steady increase in the mean minimum temperature over the period. Overall time trend, therefore, can be established. Moreover, if this figure is compared with maximum temperature it becomes clear that the rate of increase in the minimum temperature is higher than that of the maximum temperature.

Thebehaviorofabsolutevariabilityintheminimumtemperatu reovertheperiodis depicted in Figure 6. The overall time trend is not significant. However, there are spurts and dips in absolute variability which provide a vivid image of variability in the minimum temperature.

The relative variability in the mean minimum temperature is portrayed in Figure7. It follows a similar pattern to that for absolute variability. However, the relative variability has a higher average value compared to that for absolute variability.

The mean annual rainfall against time is shown in Figure bellow. This shows a steady increase in the mean annual rainfall over the 1952–2009 period. There is a small but apparent upward trend in the variable for the period. Absolute variability in the mean annual rainfall against time is depicted in Figure 9. From 1955 to 1959 there was a sudden and rapid increase in rainfall variability but it started to decrease rapidly in 1960 and continued to decline to 1964. Since then, the overall absolute variability in rainfall increased until 1994. From 1994 to 2009the average variability of rainfall has declined with a few ups and downs.

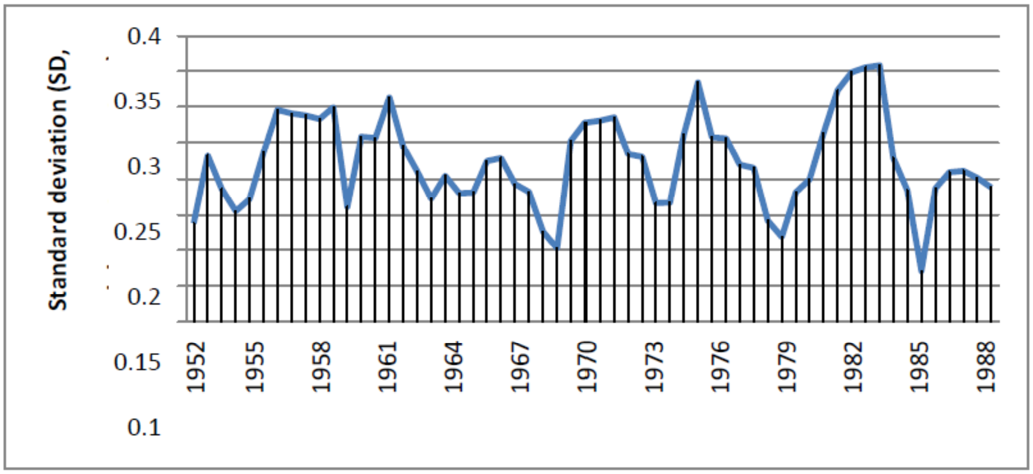

Figure 6 Standard deviation of mean minimum temperature

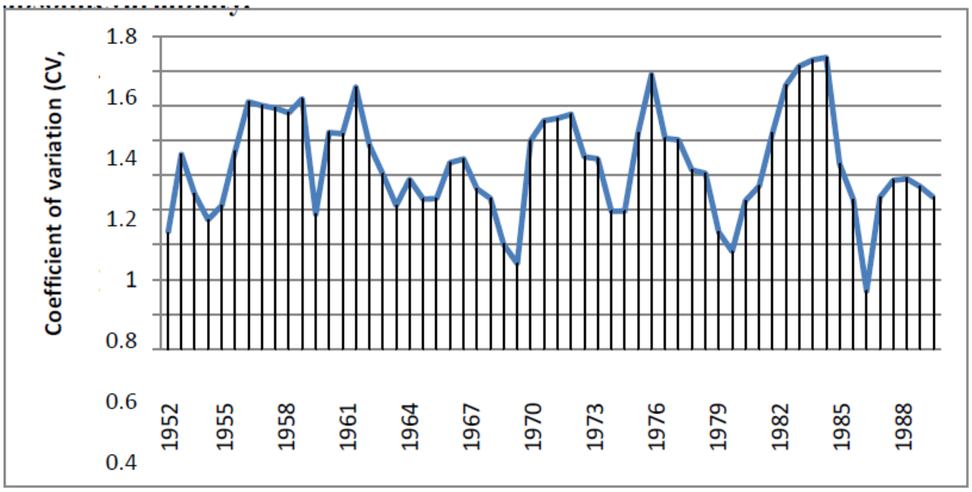

Figure 7 Co efficient of variation in minimum temperature

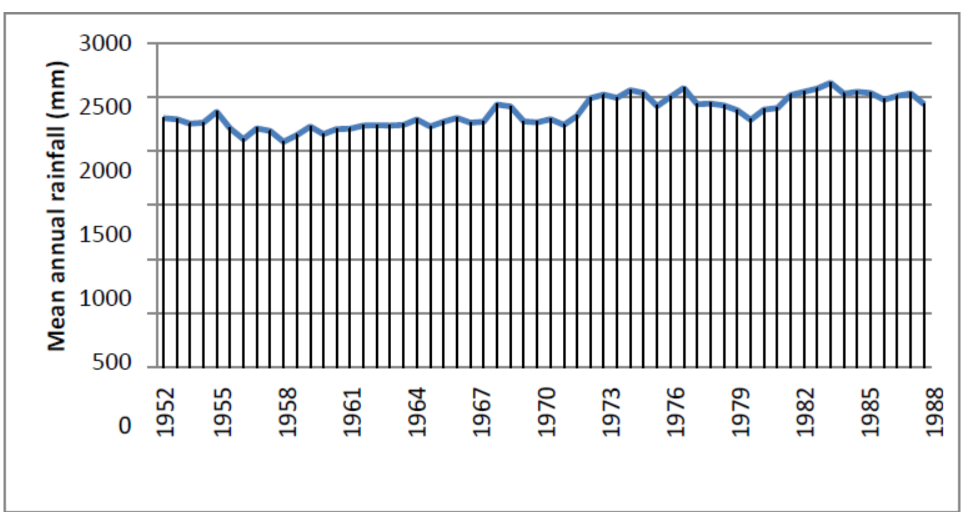

Figure 8 Moving average of mean annual rainfall

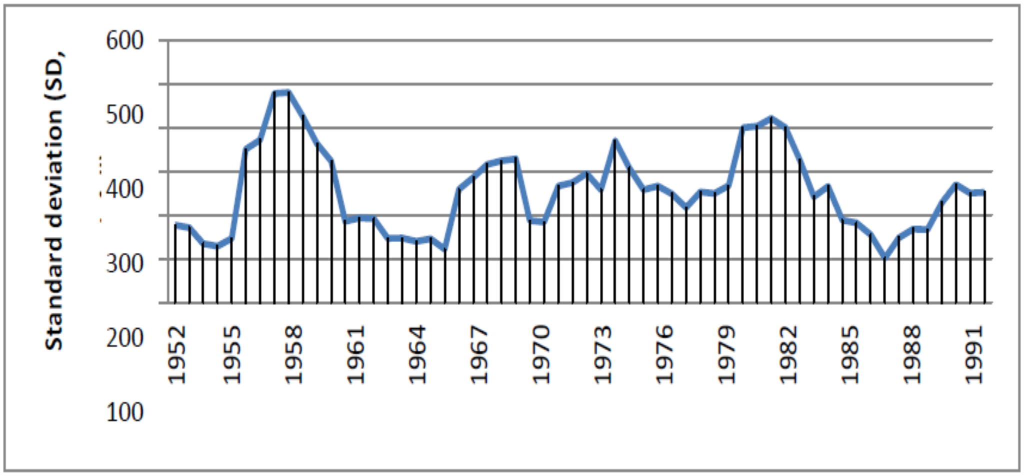

Figure 9 Standard deviation of mean annual rainfall

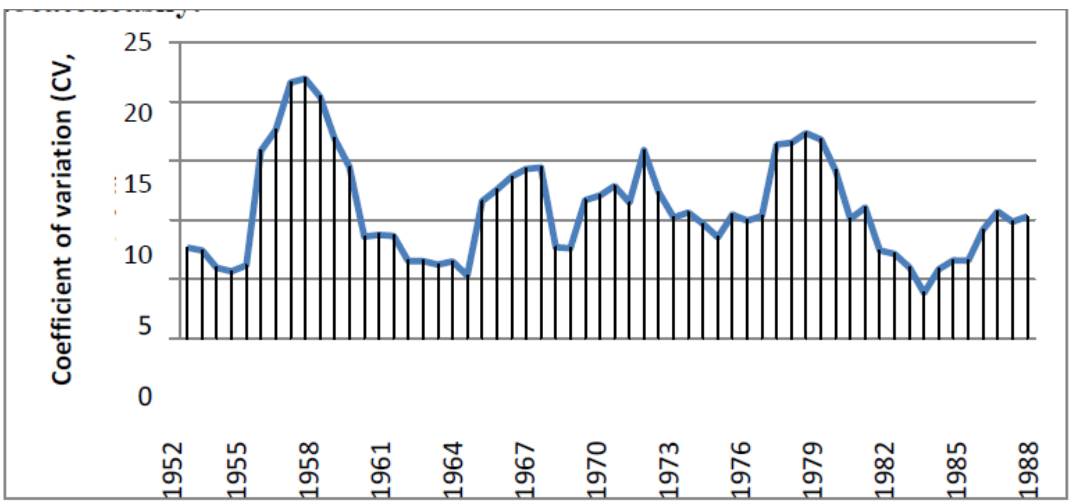

Figure 10 Coefficient of variation of annual rainfall

The relative rainfall variability over the period is depicted in Figure10. The pattern of change in the relative variability is similar to that for absolute variability. No overall trend is seen but a phase specific trend can be located easily.

In terms of the above analyses of absolute and relative variability in climate, there is strong evidence to suggest that there is increased variability in major climate variables over time. A thoughtful observation of the figures reveals different phases of fluctuations in climate which supports the thesis of the existence of overall climate change.

Evidence from trend model

In order to build the quantitative justification for the change of climate variability, linear regression (linear trend model) for three major aggregate climate variables with time(T) as the explanatory variables are estimated over the whole period. Results are illustrated in Table below where equation1(a) represents five-yearly moving average (mean),equation 1(b) indicates the standard deviation and equation 1(c) stands for coefficient of variation for maximum temperature and so on for the other climate variables of minimum temperature and annual rainfall, respectively.

Equations 1(a) and 1(b) clearly exhibit a strong time trend in mean and standard deviation of maximum temperature respectively. Both equations are statistically significant with considerable explanatory power. A strong time trend is also found in equation 2(a) in terms of both statistical significance and explanatory power. This equation has three times higher explanatory power than equation1 (a). Equation 2(b) implies no trend in absolute variability. The estimates for this equation are also poor both in terms of R^2 and t-value.

Equations 3 (a) and 3 (b) are analogous to equation (1) with the statistically significant coefficient and significantly

Table 3 Trends in the variability of three major climate variables,1952–2009

Aggregate climate variables	Dependent variables	Intercept	Coefficient	R^2	t-value	P-value	F-value	Prob. >F
Maximum temperature (Equation1)	Mean(a)	19.59996	0.00544*	0.2950	4.84	0.000	23.43	0.000
	Standard deviation(b)	-2.35420	0.00131**	0.0701	2.05	0.045	4.22	0.044
	Coefficient of variation(c)	-7.43433	0.00415***	0.0659	1.99	0.052	3.95	0.051
Minimum temperature (Equation2)	Mean(a)	-7.15653	0.01425*	0.9028	22.81	0.000	520.31	0.000
	Standard deviation(b)	0.204865	0.0000****	0.0000	0.02	0.984	0.000	0.984
	Coefficient of variation(c)	2.39664	-0.00067****	0.0014	-0.28	0.780	0.08	0.780
Annual rainfall (total) (Equation3)	Mean(a)	-2020333	1050.86*	0.9216	25.67	0.000	658.69	0.000
	Standard deviation(b)	-1467770	77.6537*	0.2611	4.45	0.000	19.79	0.000
	Coefficient of variation(c)	171.9669	-.080805**	0.1290	-2.88	0.006	8.29	0.005

Notes: Superscript *, ** and * denote significance levels at 1%, 5% and 10% respectively, and****denotes not significant.**

higher R^2.As a whole, there is a tendency for the mean and standard deviation of climate variables to increase. Therefore, the absolute climate variability appears to have risen to a higher level over the last 60years which provides clear evidence of a changing climate in Bangladesh.

The trend model based on an OLS provides only a partial view of the relationship between variables. A more complete picture using QR method provides information about the relationship between the response and predictor variables at different points in the conditional distribution of the response variable.

Evidence from quantile regression analysis Quantile regression (QR) expands the estimation technique used above (simple linear regression, SLR) to any part or selected quantile of the dependent variable (e.g., climate variable). This can provide a comprehensive analysis of the pattern of climate change (Timofeev & Sterin 2010; Gruza & Ran'kova 2004). The bellow table compares the results of both the SLR and QR models. Following Timofeev and Sterin (2010), QR parameters for 0.01^{th}, 0.05^{th}, 0.10^{th}, 0.25^{th}, 0.50^{th}, 0.75^{th}, 0.90^{th}, 0.95^{th} and 0.99^{th} quantiles are estimated. To compare the results, the bootstrap method with 500 replications was used for the QR. The results are shown in Table 4 where the QR coefficients are seen to vary considerably from the OLS coefficients, even those for median regression. However, QR coefficients are not the same across the selected quantiles; statistically significant differences in trends are observed when quantile values vary from 0.01 to0.99. Trends for maximum temperature are not statistically significant at the lower quantiles (e.g., at 0.01 and 0.05). However, they are significant at the higher quantiles (e.g., at0.90, 0.95 and 0.99). The explanatory power of the trend model for maximum temperature rises from lower to higher quantiles. However, the trends in minimum temperature are statistically significant throughout the chosen quantiles, whilst the explanatory power of trend is higher in the higher quantiles than those of the lower quantiles. Lastly, trend coefficients of QR for rainfall are clearly different from the OLS coefficients and they are also statistically significant with lower explanatory power in the higher quantiles. Therefore, the QR method provides a more detailed picture of the changing climate at the different points of time. These results are consistent with the studies of Timofeev and Sterin (2010) and Chamaille-Jammes and Murindagomo (2007).

From the above analyses using three different statistical techniques: descriptive statistics, linear trend model and QR, it can be established that there has been a change of climate over the last six decades in Bangladesh. The next sub-section will focus on the future projections of climate change drawn from the literature.

Future climate change projections

Two types of climate change projection studies are available: projections based on observed data and projections based on climate models.

The annual mean changes in temperatures of 1.0°C,1.4°C and 2.4°C by 2030,2050 and 2100 respectively are estimated in the above table. However, the increase in winter (December- February) temperature is

Table 4 Comparing results between OLS and QR estimates at different quantiles

Variable	OLS	QR 01	QR 05	QR 10	QR 25	QR 50	QR 75	QR 90	QR 95	QR 99
Trend for maximum temperature	.0066196 (0.001) R^2=0.16	-.0012437 (0.877)	.0070858 (0.120) R^2=0.09	.0067934 (0.050) R^2=0.06	.004913 (0.098) R^2=0.05	.0039352 (0.122)	.007483 (0.016) R^2=0.08	.0107523 (0.009) R^2=0.15	.0112047 (0.016) R^2=0.22	.0078104 (0.057) R^2=0.26
Trend for minimum temperature	.0144222 (0.000)	.0120676 (0.000)	.0095986 (0.027)	.0160999 (0.000)	.0149156 (0.000)	.0143015	.0154033 (0.000)	.0165238 (0.000)	.0125252 (0.000)	.011157 (0.000)
Trend for total rainfall	1022.77 (0.000) R^2=0.82	856.2787 (0.000) R^2=0.64	866.2059 (0.000) R^2=0.60	863.4118 (0.000) R^2=0.60	1014.22 (0.000) R^2=0.62	1070.941 (0.000) R^2=0.63	1283.929 (0.000) R^2=0.54	1373.2 (0.000) R^2=0.48	1383.12 (0.000) R^2=0.45	1575.875 (0.000) R^2=0.41

Table 5 Future climate scenarios for Bangladesh

Year	Temperature change (°C)mean(standard deviation)			Rainfall change (%)mean (standard deviation)		
	Annual	**DJF**	**JJA**	**Annual**	**DJF**	**JJA**
2030	**1.0(0.11)**	**1.0(0.18)**	**0.8(0.16)**	**+3.8(2.30)**	**-1.2(12.56)**	**+4.7(3.17)**
2050	**1.4(0.16)**	**1.6(0.26)**	**1.1(0.23)**	**+5.6(3.33)**	**-1.7(18.15)**	**+6.8(4.58)**
2100	**2.4(0.28)**	**2.7(0.46)**	**1.9(0.40)**	**+9.7(5.80)**	**-3.0(31.60)**	**+11.8(7.97)**

Source: Adopted from Agarwala et al.(2003)
DJF = December, January and February; JJA = June, July and August

higher than them on soon temperature throughout the projected years. Meanwhile, annual rainfall increases of nearly 4%,6%, and 10% for the same years respectively are observed. The rainfall change in the winter season is negative while it is positive in the monsoon season for all the years under consideration.

Using the General Circulation Model (GCM) for Bangladesh, Ahmed and Alam (1999) reported that there would be an increase of 1.3°C and 2.6°C rise in the temperatures by 2030 and 2075 respectively. They also found a seasonal variation in the temperature of +1.4°C in the winter and +0.7°C in the monsoon by 2030 while the variations are projected to be 2.1°Cand1.7°C for these seasons respectively by 2075. Rainfall will be reduced to an insignificant rate in 2030 while there will not be any noticeable rainfall in the winter by 2075. Yu et al. (2010) projected a median temperature rise of 1.1°C,1.6°C and 2.6°C and a median annual rainfall increase of 1%, 4% and 7.4% by 2030, 2050and 2080 respectively. This study shows that rainfall is subject to huge inter-annual and intra-annual variations. All these scenarios might have severe effects on rice production in Bangladesh. However, the focus of this study is to assess the past effects of climate on rice yields which require an analysis of variability of rice yields.

Detecting variability in rice yields

A study by Tisdell (1991) confirmed that variability in rice yields had increased over the 1947–1985 period in Bangladesh. This was associated with some natural and political factors, such as droughts, flood and the War of Liberation in 1971. The present study examines the yield variability in Bangladesh using simple statistical tools for the 1972–2009 period. These results are shown for two period in that 38years and are reported in Table.

It is clear from Table that absolute variability for all rice varieties, expressed by standard deviation, has increased in the second time period as compared to the first period. Relative variability has also increased in the second period for all varieties except Aman. If a comparison is made among rice yields, it can be observed that the relative variability was highest for Aman in the first period while the Aus yield exhibits maximum variability in the second period. Overall, this simple analysis has proven that the variability in rice yields has increased over the years. This might be attributed to introduction of high yielding varieties (HYVs), extreme climate events such as floods, droughts and cyclones, extreme temperature and so on. The following section concentrates on how much variability in

Table 6 Variability in rice yields for the 1972–2009period

Varieties of rice	Statistical tools	1972–1991	1992–2009
Aus	Mean	395.97	552.13
	Standard Deviation	37.94	94.77
	Coefficient of Variation(%)	9.58	17.16
Aman	Mean	519.50	723.47
	Standard Deviation	63.53	83.24
	Coefficient of Variation(%)	12.23	11.51
Boro	Mean	897.29	1237.51
	Standard Deviation	99.75	174.20
	Coefficient of Variation(%)	11.12	14.08

Table 7 Basic features of climate during three rice growing seasons in Bangladesh

Rice growingseason	maxt(°C)	mint(°C)	rainfall(mm)
Aus(April–August)	33.10–31.22	25.55–24.40	2218–1317
Aman(July–December)	31.02–29.52	23.19–21.77	1903–1020
Boro(December–May)	30.76–28.55	16.35–14.96	809–212

Source: Crop calendar BMD(2015)
Notes: $maxt$ **= mean maximum temperature,** $mint$ **= mean minimum temperature**

rice yields can be explained by climate variables.

Rice yield responses to climate variables; A brief overview of literature

There have been some studies on the impact of climate change at the aggregate level in Bangladesh (Ali1996; Ali1999; WB 2000; Mirza 2002; Mirza et al., 2003; Hutton & Haque 2004; Pouliotte et al., 2009). Most of these studies have focused on the livelihoods of people in the southwestern coastal areas of the country which are vulnerable to cyclones, sea level rise, floods and storm surges. Most importantly, previous studies investigated agriculture as a whole, but there is no study on the agro economic impact of climate change on rice production using any aggregate level data. Some simulation studies have been performed to estimate the impact of climate variability on rice productivity in Bangladesh using either the CERES-Rice or DASSAT models (Karim et al., 1996; Mahmood 1998; Mahmood et al., 2003; Basak et al., 2009; Basak et al., 2010). Nonetheless, there is a need for an empirical study to assess the relationship between climatic variables and rice yields using regression models (Almaraz et al., 2008). A few international studies have been carried out (Lobell et al., 2007; Almaraz et al., 2008). However, these studies, using time series data, did not check the stationary properties of:

- The data which is a requirement for the time series data analysis of more than 20years (Gujrati 2004; McCarl et al., 2008).Thus, the high R^2values found in these studies may be considered to be spurious results. Moreover, the studies did not address the problem of auto-correlation, heteroscedasticity and multicollinearity explicitly. In order to achieve unbiased estimates, these problems need to be taken into consideration (Gujrati2004). The present study will address this gap in the literature. To our knowledge, there is no study on the economic impact of climate variables on rice yields in Bangladesh. Therefore, the objective of this analysis is to verify the relationship between climate variables and rice yields.

Production of different rice varieties in Bangladesh

Three major rice crops (Aus, Aman and Boro) grow in three different seasons. Ausis normally planted in March–April and harvested in June–July. Aman is generally sown in July–August and harvested in November–December. Finally, Boro is planted in December–January and harvested in May–June. To some extent, this rice crop calendar varies from place to place depending on soil texture and elevation of land. These growing seasons practically harmonise with three climatic seasons, namely, the hot summer (March–May), the monsoon (July–October) and the winter (December–February). Table 7 illustrates the fundamental climatic characteristics of the three growing seasons.

Climate always plays a vital role in rice production. According to BRRI (1991), Aus rice needs supplementary irrigation during the initial stage of its growing season while

Table 8 Descriptive statistics of data for the 1972–2009period

Statistics	Variables											
	Yield(kg/acre)			Maximum temperature(°C)			Minimum temperature(°C)			Total rainfall (mm)		
	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro
Mean	470	616	1058	32.1	30.3	29.6	24.9	22.3	15.7	54726	45587	14659
Median	436	610	1003	32.2	30.3	29.6	24.9	22.3	15.6	56180	45914	14239
Maximum	720	855	1560	33.1	31.0	30.8	25.6	23.1	16.4	66908	60465	24261
Minimum	310	396	728	31.2	29.5	28.6	24.4	21.8	14.7	32864	24783	6369
Std.Dev.	105	126	220	0.43	0.35	0.49	0.31	0.30	0.37	8511	8528	4493
Skewness	0.86	0.28	0.57	-0.14	-0.17	0.20	-0.02	0.34	0.13	-0.58	-0.00	0.30
Kurtosis	2.78	1.97	2.52	2.58	2.62	3.03	2.06	3.03	2.24	2.61	2.52	2.36
Jarque-Bera	4.75	2.19	2.42	0.40	0.41	0.26	1.40	0.75	1.00	2.34	0.37	1.26
Probability	0.09	0.33	0.29	0.82	0.81	0.88	0.50	0.69	0.60	0.31	0.83	0.54
Observations (N)	38	38	38	38	38	38	38	38	38	38	38	38

Table 9 Augmented Dickey Fuller test for checking stationarity of the data series

Variable	Integration of order for Aus	Integration of order for Aman	Integration of order for Boro
yield	I (1)	I (1)	I (1)
maxt	I (0)	I (1)	I (0)
mint	I (0)	I (0)	I (0)
train	I (0)	I (0)	I (0)

Aman is almost completely rain-fed rice that grows in them on soon al months, although it requires supplementary irrigation during planting and sometimes in the flowering stage depending on the availability of rainfall. Boro rice is completely irrigated because it grows in the dry winter and the hot summer (Mahmood 1997). More than 90% of Boro rice production is presently irrigated compared with only 5% of Aman and 8% of Aus rice (Ahmed2001).

Data, its sources and properties

To analyze the impact of climate variables on rice yield at aggregate level, climate data were obtained from BMD (2010) and rice yield data from various issues of the *Bangladesh Economic Review* for the 1972–2009 period. The summary statistics of all data are presented in Table 8.

The mean value of yield for Boro rice is the highest, more than two times higher than that of Aus rice. Mean maximum and minimum temperature is highest for Aus rice while it is lowest for Boro rice. The total rainfall in the Aus and Aman period is three and four times higher respectively than the total rainfall in the Boro period. The Jarque-Berastatisticis significantly different from zero and the P-value of the test is reasonably high for almost all of the variables except the Aus rice yield. Therefore, the normality assumption for A us rice yield is rejected. Therefore, the individual time series data might be non-stationary which results in spurious regression. This warrants further investigation of the data series to be stationary before the regression is estimated. Accordingly, an Augmented Dickey-Fuller (ADF) test was carried out to check the stationary of the data series (i.e., presence of unit roots for each variable) and the results are reported in Table 9.

It can be seen that yield for all three rice crops are integrated of order one, I(1), implying non-stationarity of the series. However, the climate variables are all integrated of order zero for the Aus and Boro rice varieties indicating that these data series are stationary in their level form. However, the maximum temperature is of I (1) indicating unit root in the level data for Aman rice. The variables with I (1) need to be first differenced before an estimation can be made (Gujrati 2004; Mc Carl et al .2008). Since all or most of the variables are not integrated at the same order under each model, a co-integration test was not performed; instead, regression analysis using either an OLS with the differenced variables or a QR (quantile at 0.5) can be performed. For the same reason, causality analysis was not performed. Instead, it is assumed that yield changes are caused by climate variations and not vice versa as followed in Lobell and Field (2007).

Table 10 Results from the Aus model

Independent variables	Coefficient	t-value	P-value
Cons	-47.47***	-4.19	0.000
maxt	12.39***	3.50	0.001
mint	-2.03	-0.50	0.617
train	0.90***	4.43	0.000
Model Pseudo R^2 =0.37			
Adjusted R^2 =0.32 Sparsity =0.452			
Quasi-LR statistic =16.81 Prob (Quasi-LR stat) =0.000			

Note: *** represents the level of significance at1%.

Table 11 Results from the Aman model

Independent variables	Coefficient	t-value	P-value
Cons	-34.59***	-2.84	0.007
maxt	5.59*	1.93	0.061
mint	-6.97**	-2.09	0.044
train	0.83***	4.15	0.000
Model Pseudo R^2 =0.54			
Adjusted R^2 =0.50 Sparsity =0.327			
Quasi-LR statistic =43.08 Prob (Quasi-LR			

Note:***,**and *represent the levels of significance at 1%,5% and 10% respectively.

Empirical model selection

The objective of this analysis is to explore the relationship between rice yields and climate variables in order to estimate the potential impact of climate change using regression models and time series data at an aggregate level. This can be done either by using OLS or QR depending on the distribution of the dependent variable. OLS is applied when the dependent variable is normally distributed while QR is employed if the variable is not normally distributed. Median regression is more robust to outliers than mean regression. Furthermore, QR provides a better understanding of the data by assessing the effects of explanatory variables on the location as well as the scale parameters of the model. More importantly, median regression does not require classical assumptions about the distribution of the regression error terms (Cameron & Trivedi 2009). Consequently, quantile or median regression is suitable for heterocedastic data which can correct the model for the problem of heteroscedasticity (Koenker & Bassett 1978; Benhin2008; Cameron & Trivedi2009).

Following Ozkan and Akcaoz (2002), Lobell et al. (2007) and Almaraz et al. (2008), three climate variables (maximum temperature, minimum temperature and rainfall) are used as independent variables. Previous studies used different units of time such as months, phonological period, and growing season for climate variables. However, this study has used growing season average for the temperature variable and growing season total for the rainfall variable. This is because growing season average climate is able to capture the net effect of the whole range of the development process by which yields are affected by climate (Lobell & Field2007). Moreover, growing season average temperature is a key determinant of average yield (Cabal et al. 2010). Growing season monthly average maximum and minimum temperature and growing season total rainfall were used in some studies (Granger 1980; Chang, 2002; Lobell & Field2007; Lobelletal.2008). In this study, the rice yield data for all three crops are regressed on the climate variables in order to estimate their effects on the rice yield. The distribution of each rice crop yield was checked against time by drawing histograms before selecting the regression type: OLS or QR. Inspection of the histograms revealed that the distributions for Aman and Aus rice yields did not follow a normal distribution but Boro rice appeared to have a normal distribution. Therefore, mean regression (OLS) was selected for Boro rice estimation while median regression (QR) was selected for Aman and Aus rice. These methods will best estimate the central tendency of the data. Therefore, on the basis of the distribution of the yields (dependent variables) for three rice crops, the following regression models are employed:

Aus Model:

$$Y_{Aus_t} = + \beta_1 maxt_t + \beta_2 + \beta_3 train_t + \varepsilon_t$$

Where, Y_{Aus} = yield for Aus rice (inkg/acre)
$maxt$ = average maximum temperature (°C) from April to August
$mint$ = average minimum temperature (°C) from April to August
$train$ = total rainfall (mm) from April to August
= error term
t = time (i.e. year)
Median regression (at 0.5 quantile) is employed for the estimation of the Aus model. The

Objective is, thus, to estimate the median of the dependent variable, conditional on the values of independent variables. Median regression minimizes the sum of absolute residuals.

Aman Model:

$$Y_{Aman_t} = + \beta_1 + \beta_2 mint_t + \beta_3 train_t + \varepsilon_t$$

$where$, Y_{Aman}= yield of Aman rice (in kg/acre)

$maxt$ = average maximum temperature (°C) from July to December
$mint$ = average minimum temperature (°C) from July to December
$train$ = total rainfall (mm) from July to December
= error term
t = time (i.e. year)
The regression method employed for Aman rice model is also median regression.

Boro Model:

$$Y_{Boro_t} = \alpha + \beta_1 maxt_t + \beta_2 + \beta_3 train_t + \varepsilon_t$$

Where, Y_{Boro}= yield of Boro rice (in kg/acre)
$maxt$ = average maximum temperature (°C) from December to May
$mint$ = average minimum temperature (°C) from December to May
$train$ = total rainfall (mm) from December to May
= error term
t = time (i.e. year).
The method of estimation for the Boro model is OLS where the objective is to estimate the mean of the dependent variable which minimizes the sum of the squares of the residuals. All variables under each model are log transformed before estimation.

Empirical results and discussion

Results from Aus model

The impact of climate variables on Aus rice yield is shown in Table where it is observed that overall yield is statistically significant implying that the climate variables are able to explain some variation in Aus rice production.

The R^2 value indicates that 37% of the variation in Aus rice yield is explained by climate variability. The t-values for average maximum temperature and total rain fall associated with their P values reveal that these two climate variables are highly significant. Both *maxt* and *train* are statistically significant at 1% level implying a highly significant contribution of these variables on the Aus rice yield. Though *mint* does not appear to be statistically significant, it is negatively associated with the Aus rice yield.

Results from Aman model

The contribution of climate variables on rain-fed Aman rice is presented in Table 4.11. The results are very interesting. The probability of the Quasi-LR statistic ensures the utility of the overall model.

All three climate variables are statistically significant for Aman rice production. However, the effects of maximum temperature and rain fall are positive while minimum temperature has an adverse impact on Aman rice yield. Moreover, 29% of variability in Aman rice yield is explained by the climate variables which signify the crucial role of climate for Aman rice cultivation.

Results from Boro model

Boro rice is grown with irrigation during the dry season. The contribution of the relevant climate variables obtained from the linear regression analysis is illustrated in Table4.12.

The model has an F-value of 4.59 with a pvalue of 0.008. This implies that the overall model is statistically significant at the 1%level.TheR^2valuemeansthat29%ofthe variation in Boro rice yield is explained by the climate variables. Moreover, the Durbin- Watson statistic reveals that the model does not suffer from the problem of serial correlation. This value is an improvement over the study by Ozkan and Akcaoz (2002) with their Durbin-Watson statistic of 1.09 indicating the problem of positive serial correlation. The values of VIF imply that there is no multi-collinearity among the independent variables while the P-value of the Breusch-Pagan chi-square ensures that the model is not suffering from the problem of hetero scedasticity. The t-value of average maximum temperature is 2.49 and that for average minimum temperature is 3.12which indicate both *maxt and mint* are statistically

Table 12 Results from the Boro model

Independent variables	Coefficient	t-value	P-value	VIF
Cons	1.71	1.04	0.305	
maxt	-1.57**	-2.49	0.018	1.71
mint	1.24***	3.12	0.004	1.71
train	0.02	0.99	0.330	1.42
Model, R^2 =0.29 Adjusted R^2 =0.23 Durbin-Watson =1.98				
F-statistic =4.59				
P value of F-statistic =0.008 Breusch-Pagan chi-square (1) =1.05 Prob> chi2 = 0.30				

Note: *** and ** represent the levels of significance at 1% and 5% respectively.

significant. However, the relationship between yield and *maxt* is negative while *mint* has a positive effect on yield. This suggests that both climate variables affect Boro rice yield considerably. Total rainfall during Boro rice period is insignificant because this rice crop grows under completely irrigated conditions. This finding of insignificant effect of total rainfall on Boro rice production is consistent with Rimi et al. (2009) for Bangladesh where a simulation model was applied. However, the results of the present study are more robust than these past studies both in terms of methods and diagnostic tests.

CONCLUDING COMMENTS

The first goal of this chapter was to examine the changes in climate variables at the aggregate level. An examination of the annual maximum and minimum temperatures and rainfall using different statistical techniques has provided evidence of the changing climate over the last six decades in Bangladesh. For all three climate variables, the effects of the trends are statistically significant; however, the increase in minimum temperature is higher than that for maximum temperature. These results are consistent with those of Islam and Neelim (2010). However, the results from current studies are more robust in terms of statistical techniques, particularly the use of the QR method which has provided a complete and better picture of the changes in climate variables over the years.

The second goal was to estimate the relationship between rice yields and climate variables using the aggregate level time series data for the 1972–2009 period. In doing so, both OLS and QR models were used. The overall in dings reveal that three climate variables have substantial impacts on the rice yield of three different crops. For the Aus model, average seasonal maximum temperature and total seasonal rainfall are statistically significant. Moreover, the average minimum temperature is found to affect Aus rice very adversely though this effect is not significant. The overall Aus model is also found to be significant. In the case of Aman rice model, all three climate variables have become statistically significant. However, the direction of effects is not the same. Maximum temperature and rainfall have positive impacts on yield while minimum temperature affects yield negatively. Finally, both maximum and minimum temperatures have substantial effects on yield in the Boro rice model. However, the maximum temperature is found to be negatively related to Boro rice yield. One interesting finding is that rainfall is Significant for Aus and Aman rice which supports the fact that they grow in rain-fed conditions: Aus partially and Aman entirely. In terms of F and R^2values, the three models are of statistical significance and the results for overall goodness for fit are consistent with Lobell (2010).Therefore, two climate variables, namely maximum and minimum temperatures are found to adversely affect Boro and Aman rice yields

respectively. Considering this severe sensitivity of rice yield to climate factors, variety- specific adaptation strategies need to be adopted to reduce the adverse impacts of climate change.

Finally, it is not worthy that aggregate level data is unable to produce any regional variations of climate variables and its impact on crop yield (Chen et al. 2004; Lobell et al. 2007). Analyzing data at the disaggregated level is, therefore, crucial to capturing regional variation and to obtain a more comprehensive and deeper understanding

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