The study of the impact of climate variability on Aman rice yield of Bangladesh

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Abstract

An attempt has been made to investigate the relationship of climate variability with country average Aman rice (Monsoon rice) yield. The country average data of monthly minimum temperature (Tmin) and maximum temperature (Tmax) and rainfall for the growing season (June-November) and Aman rice yield covering the period 1971-2013 have been used. The technological trend of Aman rice yield has been eliminated and the resultant detrended time series (also called yield anomaly) has been used for correlating with climate variables. It is seen that the Tmin for these months does not exhibit correlation with yield anomaly. Tmean and Tmax of June is found to have weak negative correlation. Tmax and Tmax-Tmin of October show high negative correlation. This opposite correlation implies that maximum temperature and Tmax-Tmin higher than normal causes the yield to decrease and lower than normal causes the yield to increase. The correlation analysis of monthly rainfall with yield anomaly shows high negative correlation for June and August and weak positive correlation for October. High rainfall in June and August reveals the impact of excess rainwater flooding, which causes damage to Aman rice. The future objective is to develop statistical model to predict the climate based yield model, which will also be able to capture the impacts of climate change on rice yield.

KEY WORDS: *Climate Variability, Rainfall, Temperature, Bangladesh, Aman rice yield*

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1. Introduction

Bangladesh is situated in the northeastern part of South Asia within 20°34'-26°38' N and 88°01'-92°42'E. The country occupies an area of 147570 km^2, has a common border with India in the east, west and north and with Myanmar in the southeastern corner, only the south being open to the Bay of Bengal. All the major rivers of Bangladesh originate in the Himalayan Mountains and flow over thousands of kilometers via several countries before flowing through Bangladesh into the Bay of Bengal.

The country is characterized by monsoon rainfall, which occurs during the period June-September. The monsoon rice (locally called as 'Aman' rice) is traditionally cultivated using natural irrigation during the period June-November. The Aman rice season begins in the months of June with the preparation of seed beds; planting takes place mainly in the months of July and early August; August and September constitute the vegetative growth period; while in October the reproductive stage (booting and flowering) occurs and maturity stage takes place by the end of October and November.

The country has an average minimum temperature of 25°C and an average maximum temperature of 30.1°C from June-October, while the average maximum temperature decreases to 29°C in November. The monthly mean rainfall is 300-400mm from June – September and drops to 200mm in October . Rainfall is sufficient for the natural irrigation of Aman rice during these months. However excessive rainfall causing severe floods and extreme lack of rainfall causing severe droughts can both affect Aman rice cultivation and yield. Quadir et al. (2003) has shown that monsoon rainfall up to an optimum level is favourable for Aman rice yield and harmful beyond that level. Quadir (2007), using the data from 1971-2001 has shown that certain levels of rainfall in August and temperature maximums in October have a negative correlation with yield, while rainfall in October has a positive correlation. The impact of climate variables on Aman rice yield has been studied by Sarker et al. (2012), Amin et al. (2015), Chowdhury and Khan (2015) and Mamun et al. (2015), who show the important relationship of rainfall, humidity and temperature with rice yield. All these studies have shown adverse impacts of an increase in maximum and minimum temperature and rainfall beyond the optimum requirement. Kabir (2015) found a contradictory result, showing that the maximum temperature has positive impact and minimum temperature has a negative impact on Aman rice production. Choudhury and Khan (2015) have shown that the Aman rice yield has gradually increased by almost 3 fold from 1972 to 2014. Such rapid temporal trend is considered to be caused by biotechnological improvement of rice variety; and technological factors were not considered in the analysis.

In the present paper, the impact of climate variables (minimum temperature (Tmin), maximum temperature (Tmax), mean temperature (Tmean), difference between maximum and minimum temperature (Tmax-Tmin) and rainfall) for the months of June-November have been investigated in relation to Aman rice yield using up-to-date data. The impact of technological factors has been eliminated from the time series of yield prior to the investigation of the impacts of climatic variables on Aman rice yield.

2. Data used and Methodology

The data of Aman rice yield of Bangladesh from 1971-2013 have been collected from Bangladesh Bureau of Statistics (BBS) and the country average monthly data of rainfall and minimum and maximum temperature derived from the observations of 29 stations of Bangladesh Meteorological Department (BMD) for the same period (Figure-1).

The increasing trend of rice yield is considered to be correlated with biotechnological development in rice variety and improved agricultural management systems. The trend analysis shows that polynomial regression produces the best fit equation of the form:

$$y_{trend}(t) = a + bt + bt^2 \qquad (1)$$

Then the trend is eliminated from y(t) for using the following arithmetic operation:

$$Y'(t) = Y(t) - Y_{trend}(t) \qquad (2)$$

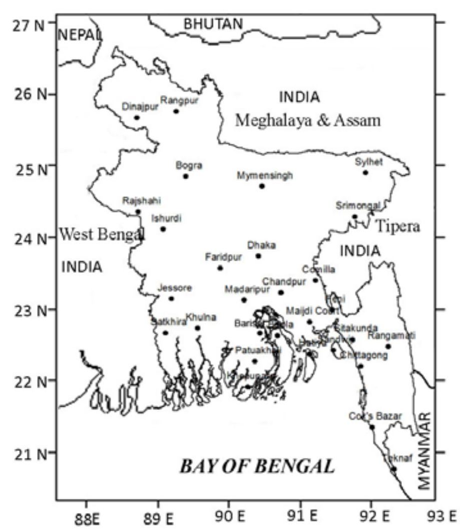

Figure-1: Map of Bangladesh showing the location of the meteorological stations

Here $Y'(t)$ is the yield anomaly which is supposed to be sensitive on weather, which is used for correlation analysis with respect to the monthly climatic variables-Tmax, Tmin, Tmean, Tmax-Min and rainfall for the individual months June-November.

3. Results and Discussions

The yield data are plotted as function of time in Figure-2(a), which depicts that the yield has strong increasing trend. The best fit second order polynomial regression analysis provides the following equation:

$$y' = 1356.83770 - 1.390042t + 0.0003562t^2 \quad \text{(with } R^2\text{=0.946)}$$

The detrended yield (also known as yield anomaly) is estimated as $\Delta y = y - y'$ which is ultimately used as the time series for correlation analysis with climatic variables. The time series plot of the yield anomaly has been shown in Figure-2(b). The impact of climate variations on the rice yield is complex. Low rainfall, especially in the month of October would lower Aman rice yield. Figure-2(b) shows reduced yields in the years 1972, 1982 and 1995. These events coincide with drought like situations characterized by low rainfall and high maximum temperature especially in the month of October (Figure-3(a-d). Islam et al. (1991) have suggested that supplementary irrigation is highly beneficial to reduce the impact of drought on rice yield.

The investigation of the rainfall data showed that the years 1974, 1987, 1988, 1998 2004 and 2007 had strong positive anomalies of monsoon rainfall when severe floods had occurred. It is seen from Figure-2(b) that these years show lower yields, which correspond to the crop damages caused by the severe floods. The year 1998 experienced the biggest flood in the history of Bangladesh. The yield loss was very high in this year. On the other hand, the years of low rainfall and high maximum temperature in the month of October showed decrease of yield due to drought impacts on the rice crops in the reproductive phase.

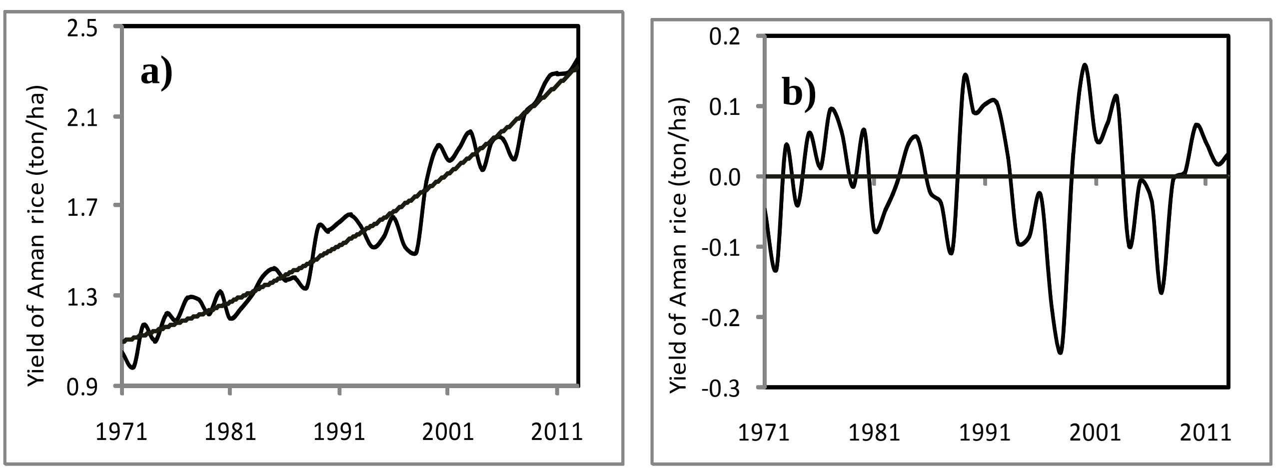

Figure-2: The temporal plots of Aman rice yield (M. Ton/Hectare); the red line shows the linear trend representing the technological trend (a) and the detrended time series (b) of the same.

Correlation analysis has been performed with Aman rice yield and the minimum temperature (Tmin), maximum temperature (Tmax), mean temperature (Tmean), Tmin-Tmax and rainfall for the individual months from June-November, covering the whole growing period for Aman rice. The results of the correlation analysis are shown in Table-1.

The mean temperature does not show much correlation except for in June which shows a negative correlation of -0.32. However, the maximum temperature of the month of June and October is negatively correlated with Aman rice yield with correlation coefficients (CC) of -0.29 and -0.34 respectively. The correlation with Tmax-Tmin is rather high for the month of October (CC=-0.41). The negative correlation of Tmax in June and October implies that high temperature affects the soil moisture due to high evapotranspiration thereby affecting seeding in June and grain formation in October. The Tmax-Tmin represents the amplitude of day and night temperature variation, which is high for dry soil and low for wet soil and is a good indicator of droughts. Thus the high negative correlation in October indicates that the high values of Tmax-Tmin causes reduction of the Aman rice yield. Low values of Tmax-Tmin imply high moisture content in the soil which enhance the yield. Rainfall shows negative correlation for July and August (-0.39 and -0.37), which implies that excess rainfall in these months causes severe floods which cause crop damage.

Table-1: The correlation Coefficients of Aman Yield anomaly with climatic parameters

	T_{max}	T_{min}	T_{mean}	T_{max}-T_{min}	Rainfall
June	-0.29**	-0.20*	-0.32**	-0.25*	0.25*
July	0.08	0.01	0.02	0.14	-0.39***
August	0.16*	-0.02	0.15	0.27**	-0.37***
September	-0.14	-0.20*	-0.20*	-0.04	-0.08
October	-0.34**	0.14	-0.07	-0.41***	0.28**
November	-0.20*	-0.23*	-0.19*	0.09	-0.23*
June - November	-0.16	-0.14	-0.16	-0.07	-0.21*

**Indicates higher than 90% level of significance, **indicates higher than 95% level of significance and ***indicates higher than 99% level of significance . The highlighted box with pink indicates highly significant and with yellow moderately significant.*

A similar study by Quadir (2007) shows relatively high negative correlation with October Tmax, positive correlation with October rainfall and high negative correlation with August rainfall, using data from 1971-1999. Figure-3 shows that the relative phases of the climate variables with respect to yield anomaly drastically changes in from 2003-2013 which has caused the correlation to decrease during the last decade. The 11 year sliding correlation of yield anomaly with some of these climate variables also illustrates a similar picture (Figure-4). Figure 4 shows that correlation has decreased and in some cases reversed for rainfall in July, August and October and Tmax and Tmax-Tmin in October. It may however be noted that in recent years severe drought conditions have been combatted with supplementary irrigation, especially in October (BBS, 2012, 2013).

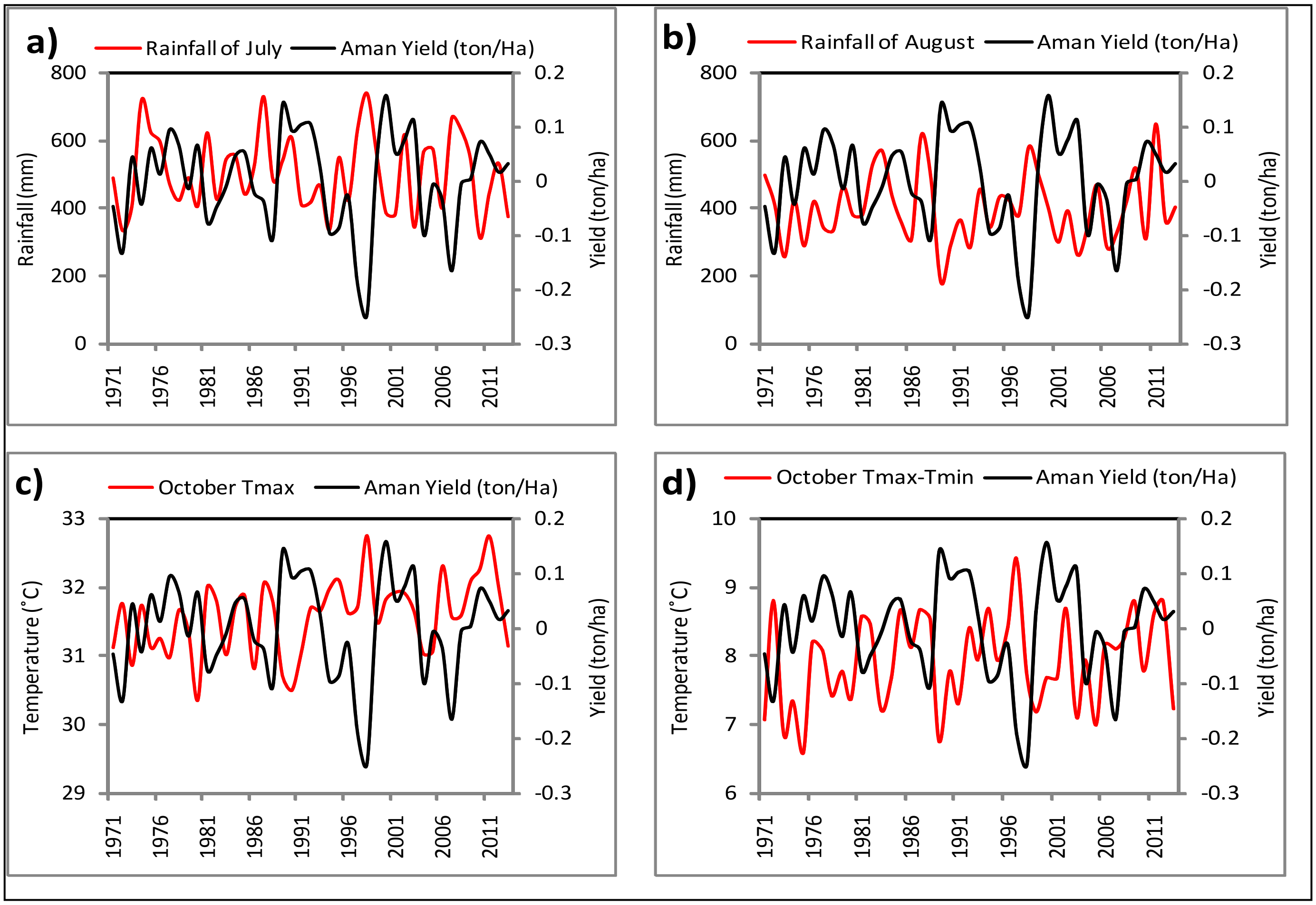

Figure-3: The inter-annual variation of Aman rice yield anomaly (ton/ha) over the period 1971-2013 with respect to the weather variables: rainfall (mm) in July(a) and August (b); Tmax (^{0}C) in October (c) and Tmax-Tmin (^{0}C) in October (d). Weather variables are shown in the primary vertical axis and the yield anomalies in the secondary vertical axis.

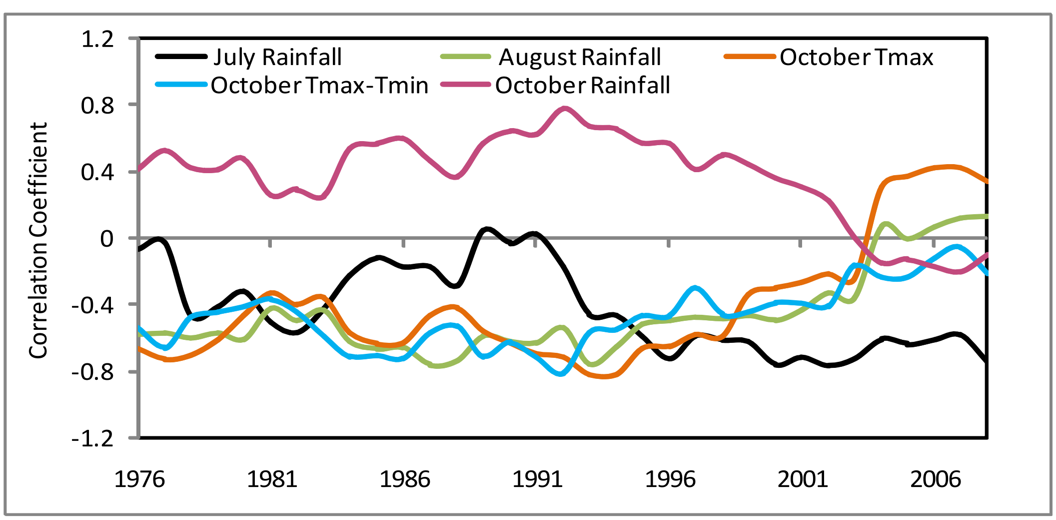

Figure-4: The temporal distribution of correlation coefficient (CC) using 11 year sliding window.

4. Conclusions

1) The second order polynomial trend has been subtracted from the time series of Aman rice yield to partition the climate sensitive component of the yield and the result is referred to as yield anomaly.
2) The correlation analysis of yields with the monthly climate variables Tmax, Tmin, Tmean, Tmax-Tmin and rainfall has been performed for the months June-November. It is seen that the minimum temperature is not correlated with yield anomaly. The mean temperature of June showed weak correlation (CC= -0.32).
3) The maximum temperature of June shows a negative correlation with Aman rice yield with a CC of -0.29. Tmax in October shows moderate correlation with a CC of -0.34. This shows that high maximum temperatures increase evapotranspiration affecting seed germination in June and grain formation in October.
4) The Aman rice yield shows relatively high negative correlation with Tmax-Tmin of the month of October (CC= -0.41), which indicates that drought conditions in October severely affect the yield.
5) In the case of rainfall, negative correlation is found for July and August (-0.39 and -0.37), which implies that rainfall in these months causes crop damage because of monsoon floods.
6) Variation of temperature and rainfall of October with respect to the yield anomaly shows drastic phase change in the years from 2003-2013 which has caused the decrease of correlation compared to those found for the years 1971-1999 in a previous study. This indicates that the yield improvement has occurred through increased supplementary irrigation from the early 2000s.

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