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Impact of seasonal climatic variability on rice yield in Bangladesh

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ABSTRACT

In Bangladesh, 75% of the total cultivable area is under rice cultivation producing 25 million tons of rice and plays a vital role in the country's GDP. The climatic variability is playing an important role in affecting the rice production. In this study, the impact of climatic variability (average maximum temperature (*aMaxTemp*), average minimum temperature (*aMinTemp*) and average rainfall (*aRainfall*)) on rice yield was determined in two different regions (northern and southern) of Bangladesh.The variability of rice yield and climate factors was determined by using the Ordinary Least Square (OLS) method. The data was analyzed over the 44-years period (1971 to 2014) in order to estimate the magnitude of these fluctuations statistically and graphically. We observed that the climate variables had significant effect on rice yield that varies among three rice crops (e.g., Aus, Aman, and Boro rice). We observed that, *aMaxTemp* has positive effects for Aus and Aman rice yield but negative effect on Boro rice yield. On the other hand, *aMinTemp* has negative effects on Aus and Aman rice yield but has positive effect on Boro rice yield. The *aRainfall* has a positive relationship with all rice yields in both the regions.

Keywords: Rice yield, climate variability, test of normality, ordinary least square.

Rice (*Oryza sativa* L.) is the most important cereal crop which is a staple food around 158 million people of Bangladesh and more than half of the world's population (Ma *et al.*, 2007; Fageria, 2007). The seasonal climatic variability is severely decreasing the yield of rice and may frighten the food safety of the increasing population. Approximately 90% of the people of Bangladesh consume 410 g of rice head^{-1} day^{-1}. Around 85% of the rural people are directly or indirectly involved in agriculture and they play an important role by contributing to 16.33% of GDP in Bangladesh (Bangladesh Bank, 2014; GOB, 2017). The variability in temperature and rainfall have increased and unpredictable, and the occurrence of climate related extreme events such as floods, droughts, heat waves, and cyclones are anticipated to increase in the future (FAO, 2006; IPCC, 2007; Yu *et al.*, 2010; Bal and Minhas, 2017). Country is predicted to experience an increase in daily average temperature of 1˚C by 2030 and of 1.4 ˚C by 2050 (FAO, 2006; IPCC, 2007). Rainfall is showing irregular distribution, which has adverse effects on rice yields (Alauddin and Hossain, 2001; GOB and UNDP, 2009). It is observed that the variation of rainfall has more impact than the change in temperature on crop production (Rivington *et al.*, 2011). To mitigate the impact of rainfall, timely irrigation can contribute to increased crop yield (Adams *et al.*, 1995).

In recent times, some studies have investigated the effects of weather variation on agronomic production of rice in developing countries (Haim *et al.*, 2008; Deressa and Hassan, 2009; Bhuvaneswari *et al.*, 2014; Karmokar *et al.*, 2019). To estimate the effects of climate variability on rice production of Bangladesh, the investigators (Karim *et al.*, 1996; Basak *et al.*, 2010; Vysakh *et al.*, 2017) used CERES-Rice model and the DASSAT model. Sandhu *et al.* (2013) analyzed 12 years' data to ascertain the impact of meteorological parameters in seasonal variability on rice production in central Punjab, India. Also the regression models over historical data to find a relationship between climate variables and crop yield (Isik and Devadoss, 2006; Mallick *et al.,* 2007; Joshi *et al.*, 2011; Sarker *et al.*, 2012; Dari *et al.,* 2017; Karmokar *et al.*, 2019). But they didn't check the data variability like the area of rice cultivation, regional variations and rice yield during the year of 1971-2014. The main objective of our study is to estimate the effects of climate parameters on rice yield of growing seasons. For our study we have considerd northern and southern regions of Bangladesh because these two regions cultivate Aus, Aman and Boro rice.

MATERIALS AND METHODS

The historical rice yields were collected for the period of 1971 to 2014 for both northern and southern regions of Bangladesh. Data related to weather variables were collected from the Meteorological Observatory, Bangladesh Meteorological Department (BMD) and the locations of the

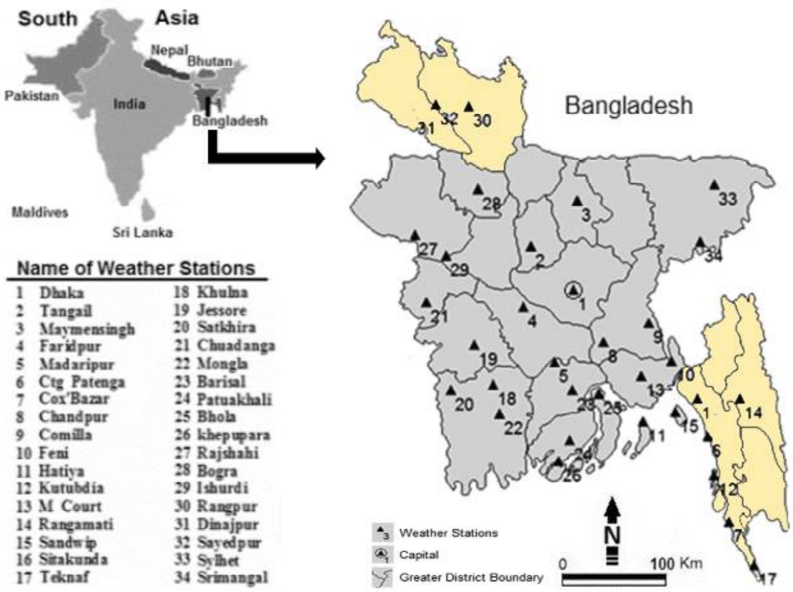

Fig.1: Study area with location of meteorological stations of BMD

weather stations are shown in Fig. 1. Also Rice production and cultivated land area data was collected from Bangladesh Rice Research Institute (BRRI). The time series of measurements was used during analysis and we considered four stations: Dinajpur, Rangpur, Chittagong, and Rangamati. The missing data was interpreted by calculating the average value of the same month data.

Tests of normality of dependent variables are shown in Table 1. The model was calibrated and validated with experimental data of each crop. The daily historical weather data were analyzed to determine climatic variability trends by regression model. To analyze possible effects of climatic factors on rice yield by identifying the incremental variations to climatic parameters and applying these changes uniformly to baseline climate was employed in the present study. Since the samples of this study are less than 50 years, we used Kolmogorov-Smirnov and Shapiro-Wilk test to determine the distribution of rice yield of three growing seasons in Bangladesh.

Since the p-value (significance) in Kolmogorov-Smirnov and Shapiro-Wilk test the yield of Aus and Boro in both regions was higher than 0.05, so that they followed the normal distribution. But the yield of Aman in both regions was less than 0.05, so we checked the distribution using z-value of Skewness and Kurtosis which is shown in Table 2. Since the z-value between -1.96 to +1.96 than the yield of Aman followed the normal distribution. Therefore, we used Ordinary Least Square (OLS) method for the estimation of the coefficient of determinants. The relationship between climate factors and rice yield was not always linear since the increase of temperature or rainfall would be advantageous for rice yield at a limited effect over this factors. The OLS equation is estimated by taking Ln in both sides (Chung *et al.*, 2015). Therefore, the regression models are employed on the basis of distribution of the yields (dependent variables) for three rice variety as following:

$$Ln\,Y_{rt} = \delta_0 + \delta_1 Ln(aMinTemp) + \delta_2 Ln(aMaxTemp) + \delta_3 Ln(aRainfall) + \epsilon_t \quad (1)$$

Where Y_{rt} is yield of rice (ton acre^{-1}) of three growing seasons, *aMinTemp* is the average minimum temperature (°C) by seasons, *aMaxTemp* is the average maximum temperature (°C) by seasons, *aRainfall* is the average rainfall (mm) by seasons, $\in_t$ is the error term and t is the time (year).

RESULTS AND DISCUSSION

The summary statistics for all the data in northern region and southern region are presented in Table 3. This table also illustrates the fundamental climate characteristics during three rice growing seasons in Bangladesh. But, these descriptive statistics do not provide any evidence of variability in climate that impacted on rice production. In order to provide the quantitative justification for climate variability affected on rice yield during different growing seasons, the OLS method was used. This method is employed to identify the effects of climate variation (i.e., *aMaxTemp*, *aMinTemp*, *aRainfall*) on the seasonal Aus rice model, Aman rice model and Boro rice model results are presented in Table

Table 1: Tests of normality of dependent variables

Variables	Northern region				Southern region			
	Kolmogorov-Smirnov		Shapiro-Wilk		Kolmogorov-Smirnov		Shapiro-Wilk	
	Statistic	Sig.	Statistic	Sig.	Statistic	Sig.	Statistic	Sig.
Yield_Aus	0.08	0.20	0.97	0.36	0.09	0.20	0.95	0.08
Yield_Aman	0.15	0.02	0.92	0.01	0.17	0.00	0.88	0.00
Yield_Boro	0.11	0.20	0.95	0.05	0.08	0.20	0.97	0.22

Table 2: Tests of normality using z-values

Cases	Skewness			Kurtosis		
	Measure	Std. Error	z-value	Measure	Std. Error	ż-value
Northern Aman_Yield	0.56	0.36	1.55	-0.29	0.70	-0.41
Southern Aman_Yield	0.46	0.36	1.27	-1.31	0.70	-1.87

Table 3: Summary statistic of the Northern region and Southern region of Bangladesh

Regions	Selected Stations	Rice Varaity	aMaxTemp (^{0}C) Mean	aMaxTemp (^{0}C) Std	aMinTemp (^{0}C) Mean	aMinTemp (^{0}C) Std	aRainfall (mm) Mean	aRainfall (mm) Std	Yield (ton/acre) Mean	Yield (ton/acre) Std
Northern region	Dinajpur Rangpur	Aus	31.95	1.49	23.18	0.97	255.65	63.51	0.44	0.08
		Aman	29.99	1.42	21.63	0.52	216.52	66.37	0.67	0.15
		Boro	29.54	1.83	18.48	0.95	127.99	41.55	1.16	0.20
Southern region	Chittagong Rangamati	Aus	31.63	1.29	23.80	0.66	354.10	66.27	0.62	0.14
		Aman	30.15	1.31	22.45	0.41	268.93	63.63	0.77	0.18
		Boro	30.35	1.57	20.38	0.69	178.96	46.80	1.09	0.09

4, Table 5 and Table 6, respectively. Graphs are provided that demonstrate the variations of climate with comparison of rice yields in these period. The effect of climate factors on three growing rice seasons are presented in Fig. 2 and Fig. 3, respectively.

The OLS method was applied to provide the quantitative justification and to establish the relationship between climate factors and rice yield in three different growing seasons. The significance of three models are shown by F-value which indicated that for this data, the overall regression models were good. The R-square values show the variation of rice yield with climate factors in different seasons. The variation of rice yield can be explained by climate variables involved in the model for Aus, Aman and Boro seasons are 3%, 4% and 19%, respectively in the northern region and also 4%, 3% and 13%, respectively in the southern region. Dubin-Watson statistics were not too low which indicates that the regression models did not suffer from serial correlation. The value of D-W statistic is an improvement in the study by Ozkan and Akcaon (2002) which indicate the problem of positive serial correlation. Multicollinearity among independent variables was shown by VIF (Variance Inflation Factor) values, which indicates that there is no multicollinearity. In addition, p-values of Breusch-Pagan Chi-Square values were more than significant level at 5%, so that we accepted the null hypothesis about heteroscedasticity which means that the regression models did not suffer from the problem of heteroscedasticity. Also t-ratio of *aMaxTemp* and *aMinTemp* in both regions indicate that both *aMaxTemp* and *aMinTemp* are statistically significant.

The effects of the climate variables on Aus and Aman rice yield are presented in Table 4 and Table 5. From both the tables, we observed that, Rainfall and *aMaxTemp* has significantly positive impact on rice yield and *aMinTemp* has negative impact on rice yield of both the regions. From BRRI 2015, during the initial period of Aus rice growing, and the planting and flowering time of Aman rice yield a lot of irrigation is required. In addition, Aman is cultivated in July or August month and this month are the rainy seasons of

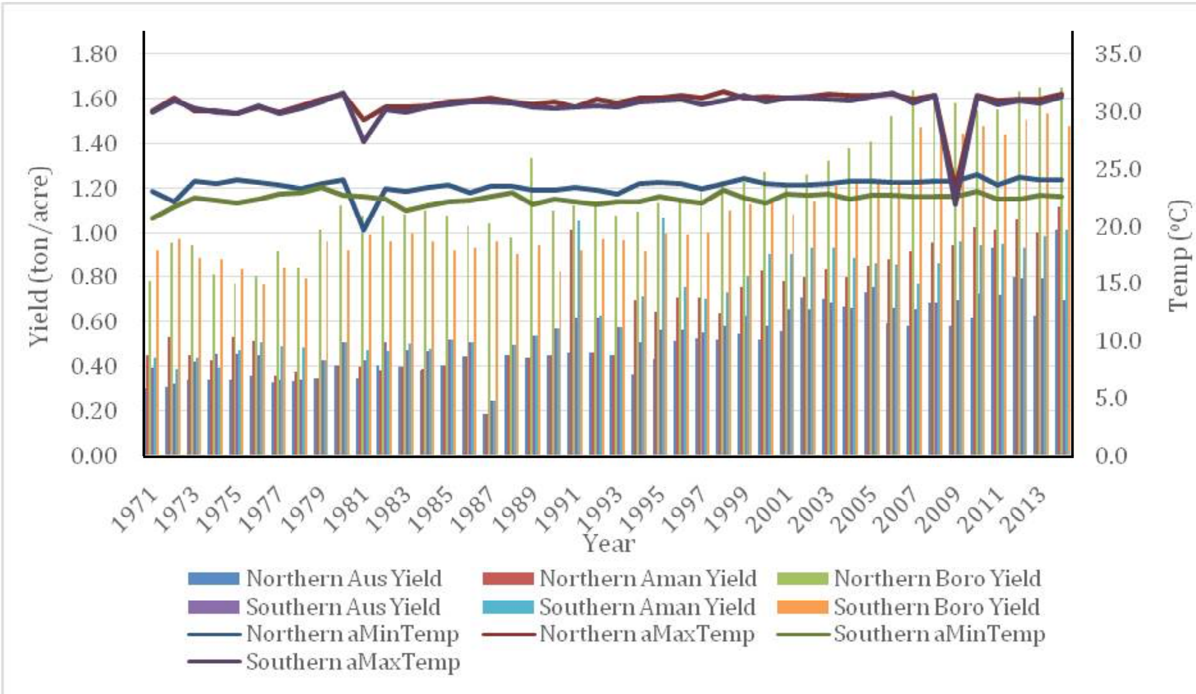

Fig. 2: Effects of annual temperature on rice yield in different seasons of both Northern and Southern region.

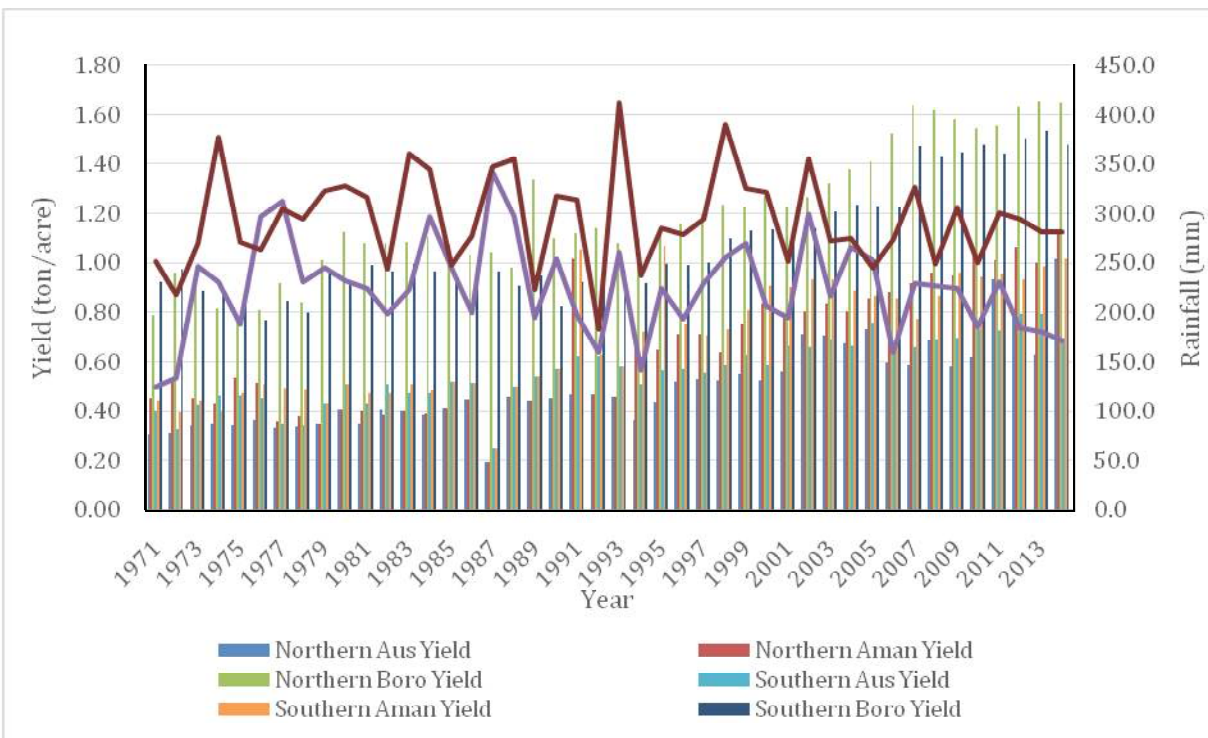

Fig. 3: Effects of annual average rainfall on rice yield in different seasons of both Northern and Southern region.

Bangladesh. This is because, *aRainfall* and *aMaxTemp* has a positive effect on Aus and Aman rice yield and only 8% of Aus rice and 5% of Aman rice are required irrigation (Ahmed, 2001).

On the other hand, for Boro rice yield (Table 6) we observed that, *aRainfall* and *aMinTemp* has positive impact and *aMaxTemp* has negative impact on rice yield. Because Boro rice is cultivated in December or January, and harvested in May or June month which is the dry season in Bangladesh. In this time, the temperature is not too high and rainfall is too

Table 4: The results for the seasonal Aus rice model

Variables	Northern region				Southern region			
	Coefficients	Std. Error	t-ratio	VIF	Coefficients	Std. Error	t-ratio	VIF
Intercept	1.76	5.52	0.32		4.03	6.91	0.58	
Ln (aMinTemp)	-1.17	1.63	-0.72	1.00	-2.11	2.04	-1.04	1.00
Ln (aMaxTemp)	3.91	1.52	2.63	1.06	4.22	1.42	3.91	1.04
Ln (aRainfall)	0.40	0.26	0.81	1.02	0.43	0.39	0.96	1.02
R-square	0.03				0.04			
Adjust R-square	0.05				0.03			
F value	0.33				0.58			
Dubin-Watson test	0.06				0.12			
Breusch-Pagan chi-square	1.32				1.76			
P-value of chi-square	0.04				0.10			

Table 5: The results for the seasonal Aman rice model

Variables	Northern region				Southern region			
	Coefficients	Std. Error	t-ratio	VIF	Coefficients	Std. Error	t-ratio	VIF
Intercept	2.82	6.56	0.43		2.85	6.73	0.42	
Ln (aMinTemp)	-1.22	1.92	-0.63	1.00	-1.31	1.97	-0.67	1.00
Ln (aMaxTemp)	2.14	1.74	0.48	1.02	1.20	0.96	0.26	1.02
Ln (aRainfall)	0.31	0.45	0.19	1.02	0.35	0.35	0.34	1.01
R-square	0.04				0.03			
Adjust R-square	0.06				0.05			
F value	0.14				0.19			
Dubin-Watson test	0.03				0.04			
Breusch-Pagan chi-square	1.76				1.32			
P-value of chi-square	0.07				0.06			

Table 6: The results for the seasonal Boro rice model

Variables	Northern region				Southern region			
	Coefficients	Std. Error	t-ratio	VIF	Coefficients	Std. Error	t-ratio	VIF
Intercept	0.99	1.72	0.58		1.12	1.31	0.61	
Ln (aMinTemp)	0.55	0.45	1.23	1.10	0.64	0.38	1.68	1.09
Ln (aMaxTemp)	-0.79	0.33	-2.42	1.01	-0.11	0.21	-0.53	1.04
Ln (aRainfall)	0.04	0.06	0.73	1.11	0.10	0.05	2.11	1.09
R-square	0.19				0.13			
Adjust R-square	0.13				0.06			
F value	3.21				1.95			
Dubin-Watson test	0.45				0.34			
Breusch-Pagan chi-square	8.36				5.72			
P-value of chi-square	0.23				0.14			

low in comparison with other two rice seasons. That's why rainfall has a positive impact but it is very low, 4% and 10% for northern and southern regions, respectively. So Boro rice yield requires adequate and regular irrigation (Mahmood, 1997).

CONCLUSION

The main objective of this study was to estimate the effects of climate parameters on the rice yield for Aus, Aman and Boro seasons. The relationships between rice yield and climate factors were found using Ordinary Least Square (OLS) method. From this study, we observed that the impacts of climate variables vary among rice growing seasons.In the case of Aus rice, the seasonal *aMaxTemp* and *aRainfall* was positively impacted whereas it was negatively impacted by *aMinTemp* on both the regions. In contrast, we observed that the rice yield in Aman season was negatively impacted by *aMinTemp* whereas it was positively impacted by the climate factors (i.e., *aMaxTemp*, *aRainfall*). In addition to this, the rice yield in Boro season was positively impacted by the climate factors (i.e., *aMinTemp*, *aRainfall*) whereas it was negatively impacted by the *aMaxTemp* in both the regions. However, the magnitude of the effects are not same. The rice models have been found to be statistically significant and the results of overall goodness are suitable in terms of R^2 and F-values. In Bangladesh, climate change is a serious issue and impacting negatively on rice cultivation. Moreover, the population of our country is raising day by day. So the demand of the era is to increase the rice production. These experimental results can be used to establish an environment for determining the impact of climate change on rice production whereas the need of other factors can be measured and applied as per requirement to have a sustainable and enhanced rice production system. In the future, division-wise or district-wise impact of climatic parameters on rice production can be studied for more precise information.

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