Re-examine the relationship between the climatic factors and rice yield in Bangladesh

ABSTRACT

The agriculture of Bangladesh, especially rice production is indissolubly linked climate and also be affected with the change in different climatic variables. The main focus of the study is to examine the relationship between the yield of three seasonal rice (e.g., Aus, Aman and Boro) and climatic factors/variables mainly maximum temperature, minimum temperature and rainfall for Bangladesh. Time series data have been used for the period 1990 to 2020 at an aggregate level to assess the relationship between climatic variables and rice yield using the Ordinary Least Squares (OLS) method. The findings of this study confirm that climate variables have had significant effects on rice yields but these effects are seen to vary among three rice crops. Maximum temperature is statistically significant with positive effects for the yields of Aus and Boro rice. On the contrary, statistically insignificant with adverse effects on Aman rice. On the other hand, Minimum temperature has a statistically significant with negative effect on Aman rice and a significantly positive effect on Aus and Boro rice. However, rainfall has a statistically significant effect on Aus, Aman and Boro the rice yields and has adverse effect on Boro rice. Also, the influences of maximum temperature and minimum temperature are more pronounced compared with that of rainfall.

Key words: Climate change, rice production, Aus, Aman, Boro, maximum temperature, minimum temperature, rainfall

1. INTRODUCTION

"Being the principal food of Bangladesh; rice is the most widely cultivated food grain in Bangladesh" [1]. "Three rice crops i.e. Aus, Aman and Boro are considered to be the major food crops grown in Bangladesh. These crops are cultivated in different distinct seasons. The seedlings of Aus is typically planted in March-April and harvested in June-July. Whereas Aman is generally sown in June-July and harvested in November- December. Finally, Boro rice is planted in December-January and harvested in May-June" [2]. "Coincidentally three climatic periods, for example the summer (March-May), the monsoon (July-October) and the winter (December-February) match with these growing periods. According to report" [3], at the initial stages of production Aus rice needs extra water while Aman rice is fully rain dependent as it is grown in monsoon. On the other hand; as Boro is cultivated in hot summer and dry winter, it is completely irrigated rice.

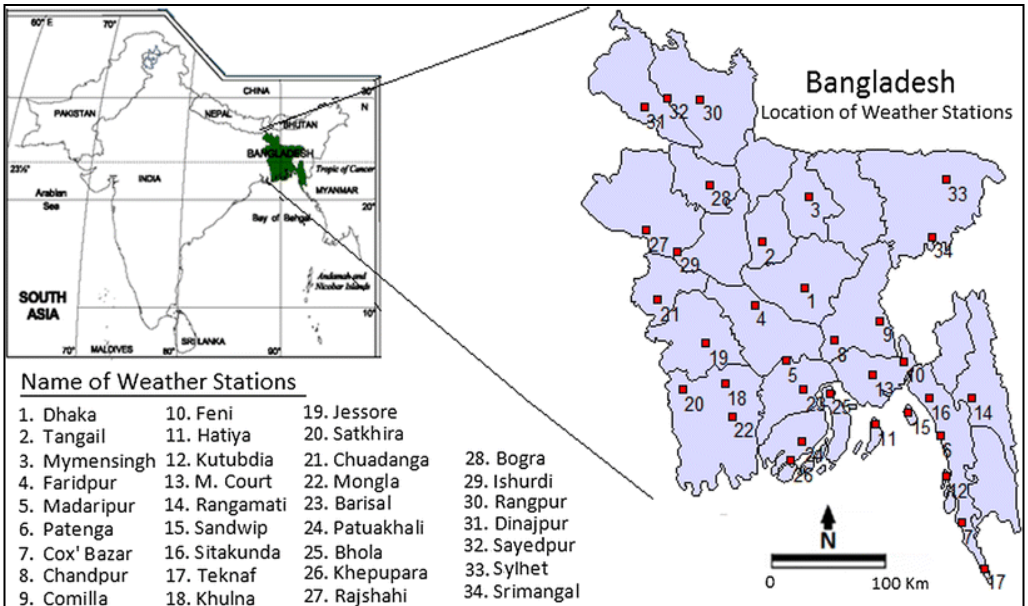
Being one of the most climate susceptible countries, the live and livelihoods specially food production of Bangladesh are severely affected by different climatic conditions [4]. "Because of the geographic position of this country, it is vulnerable to variant year-round climatic conditions. Agriculture in Bangladesh is always prone to critical weather conditions and climatic disasters such as cyclone, heavy rainfall drought which not only affect the agricultural production but also hamper the national economy and overall food security of the country" [5]. "Since rice production sector is already in pressure of increasing its production because of increasing demand, agricultural land degradation and water level depletion; this climatic change issue is making this pressure more severe" [19-21].

"As climate is the most vital component in rice production; a small change in climatic factors possesses an intense impact on its production" [6]. According to report [7], "by 2050 the production of rice is likely to fall by 8–17% because of adverse environmental and climatic condition which will create an alarming situation for Bangladesh. Since in Bangladesh, crop agriculture is primarily characterized by rice monoculture where nearly 80% among the total cultivated areas is planted with rice which occupies more than 90% of total food grain production" [8] [9]. "The percentage share of rice in total value is more than 60% of the total crop agriculture. Moreover, agriculture counts for nearly 20% of total gross domestic product (GDP), and almost 66% of total labour force in this country depends on agriculture for their employment" [10]. "Despite of massive progress in technology, any change in climatic elements might have a significant impact on the yield of rice. Another concern for Bangladesh is that, because of global warming and increasing temperature the country is going to face more hot and dry days and heat weaves which will adversely affect the yield of grain crops like rice"[11].

Being the growing concern for the researchers of the world; many researches had been conducted on this burning issue of measuring the effect of different climatic factors on the yield of different agricultural products. Ghose et al. (2021), Sikder and Xiaoying (2014) measured "the impact of climate change on agricultural production in Bangladesh". A study was conducted by Hossain et al. (2019) to measure the effect of climate change on rice production at Khulna district in Bangladesh. Kabir and Ismal (2015), Chowdhury and Khan (2015) studied the change in the production of rice in Bangladesh due to change in the climatic conditions of the country. Moon (2023) measured the effect of climate change on the health and food security of Bangladeshi people. The economic impact on the crop farmers of Bangladesh because of climate change was measured by Hossain et al. (2019). Rahman et al. (2016) measured the impact of climate change in Asian countries. Olabanji et al. (2021) measured the impact and potential adaptive measures of climate change on crop production in South Africa. According to the demand of recent time, this study intends to assess the relationship between climate change and rice yields. This study intends to assess the empirical relationship between rice yield and three climatic variables like Maximum temperature, Minimum temperature and Rainfall of three crops (Aus, Aman and Boro) using aggregate level time series data from Bangladesh over the period from 1990 to 2020. Besides, the study is conducted with OLS (Ordinary Least Squares) method which is considered to be the most efficient linear regression estimator. Therefore, the conducted study is able to figure out the most effective result for examining the relationship between climatic factors and rice yield.

2. METHODOLOGY

The study was conducted on all over the Bangladesh. The Geographical location is in South Asia, between 20°34' to 26°38' north latitude and 88°01' to 92°41' east longitude. Maximum extension is about 440 km in E-W direction and 760 km in NNW-SSE direction *(Source: www.banglapedia.com)*



(*Source : Environ Earth Sci (2016) 75:1026*)

Figure 01: Geographical Location with weather stations of Bangladesh

2.1 Data Sources

Monthly data on maximum temperature, minimum temperature and total rainfall were obtained from the Bangladesh Meteorological Department (BMD) for all 34 weather stations, which cover all of Bangladesh for the 1990–2020 period. These monthly data were then converted as the average of the growing periods for three rice crops: Aus, Aman and Boro. And, the climate variables are represented by maximum and minimum average temperature and total rainfall for the growing seasons of the concerned rice crops for the 1990–2020 period. Aggregate rice yield data by variety for the same time period (1990–2020) were obtained from various issues of the Bangladesh Economic Review, BBS and BRRI.

2.2 Analytical Tools and Techniques

Data-collection techniques facilitated to collect information systematically about all the objects of study (people, objects, phenomena) and about the settings in which they occur. In the collection of data, we have to be systematic. If data are collected haphazardly, it will be difficult to answer our research questions in a conclusive way. However, descriptive statistical technique was used in this study to analyze the data. The tool those was used to implicate the techniques for analyzing data, are simple MS Excel and SPSS Software.

2.3 Empirical Model Selection

The study was accomplished by using ordinary least squares (OLS) to explore the relationship between rice yield and climate variables to estimate the potential effects of climate change using regression models and time series data at an aggregate level.

Here, three climate variables such as maximum temperature, minimum temperature and rainfall were used as independent variables. However, in this study, an average growing season temperature was used with the total growing season rainfall because the average growing season climate is able to capture the net effect of the entire range of the development process in which yields are affected by climate. The monthly average growing season maximum and minimum temperature and the total growing season rainfall have been used.

The rice yield data for all three crops are regressed on the climatic variables to estimate their effects on the rice yield. Therefore, mean regression (OLS) was selected for the Boro, Aman and Aus rice. This method is best suited to estimate the central tendency of data. On the basis of the distribution of the yield (dependent variable) for three rice crops, the following regression models are employed.

Aus model:

$$Y_{AUS_t} = Maxt_t + M\,\mathrm{int}_t + Train_t + \varepsilon_t$$

where Y_{AUS} is the yield for Aus rice (in kg per acre), maxt is the average maximum temperature (^{0}C) from March to August, mint is the average minimum temperature (^{0}C) from March to August, train is the total rainfall (mm) from March to August, ε_t is the error term and t is the time (i.e., year).

Aman model:

$$Y_{Aman_t} = Maxt_t + M\,\mathrm{int}_t + Train_t + \varepsilon_t$$

where Y_{Aman} is the yield of Aman rice (in kg per acre), max t is the average maximum temperature (^{0}C) from June to November, min t is the average minimum temperature (^{0}C) from June to November, t rain total rainfall (mm) from June to November, ε_t is the error term and t is the time (i.e., year). The regression method that is employed for the Aman rice model is also median regression.

Boro model:

$$Y_{Boro_t} = Maxt_t + M\,\text{int}_t + Train_t + \varepsilon_t$$

where Y_{Boro} is the yield of Boro rice (in kg per acre), max t is the average maximum temperature (^{0}C) from December to May, min t is the average minimum temperature (^{0}C) from December to May, t rain is the total rainfall (mm) from December to May, ε_t is the error term, and t is the time (i.e., year).

The method of estimation for the Boro model is OLS, for which the objective is to estimate the mean of the dependent variable that minimizes the sum of the squares of the residuals. All variables under each model are log transformed before estimation.

3. RESULT AND DISCUSSION

3.1 Descriptive Statistics

The summary statistics for all of the data are presented in Table 1 which also illustrates the fundamental climatic characteristics during three rice growing seasons in Bangladesh. According to the table, the mean value for the Boro rice yield is the highest and more than twice than the yield of the Aus rice. The highest mean maximum and minimum temperatures are observed for the Aus rice and Aman rice respectively. The lowest temperatures were observed for the Boro rice. In contrast, total rainfall in the Aus and Aman periods is approximately five and six times higher, respectively, than the total rainfall in the Boro period. Islam et al. (2021) in his study also observed that Aus production required highest temperature and the yield of Boro rice needed lowest temperature. He also found the yield Boro rice required lowest level of rainfall among the three types of rice which is similar as this study found.

Table 1. Descriptive statistics for the data for the 1990-2020 period

Statistics	Factors/Variables											
	Yield (kg per acre)			Maximum temperature (^{0}C)			Minimum temperature (^{0}C)			Rainfall (mm)		
	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro	Aus	Aman	Boro
Mean	676.	804.	1358	33.	32.	24.	23.	23.	16.	5713	6681	1780

	75	29	.46	19	06	91	25	98	18	3.06	0.06	7.8
Std. dev.	211.81	140.57	246.43	0.97	0.69	0.97	1.71	2.04	1.27	7053.16	8324.64	4546.06
Maximum	1076.49	1064.35	1715.90	34.84	33.36	27.03	25.63	26.06	18.35	72115	83195	28838
Minimum	433.02	607.04	991.50	30.53	30.73	23.05	21.24	21.09	14.06	40425	53304	10031
Skewness	0.538	0.160	-0.16	-0.74	-0.27	0.123	-0.10	-0.54	0.26	0.20	0.30	0.72
Kurtosis	-1.08	-1.28	-1.52	0.57	-0.84	-0.06	-1.81	-1.69	-0.97	0.12	-0.93	-0.13

Source: BRRI, BBS, BMD (2020)

3.2 Trend Graph and Map

In addition to explaining descriptive statistics and analyzing linear trend between time and climate variables, graphs and maps are constructed with time (t) as an explanatory variable to observe the spectacular impression about variation and changes in trend among the three climatic variables over the period (1990-2020) (Figures 2-4). Maximum temperature fluctuated gradually, but the overall trend is observed to increase for Aus and Aman season and small variations in the last two years for Boro season.(Figure 02).High variations are noticed in minimum temperature for all the seasons. Besides, upward trend is seen in the boro season (Figure 03). For rainfall, small variations are noticed in case of boro season and high variations in case of aus and aman season with an upward trend (Figure 04). However, investigation is done to confirm whether these climatic trends and fluctuations affected crop yields in the later section.

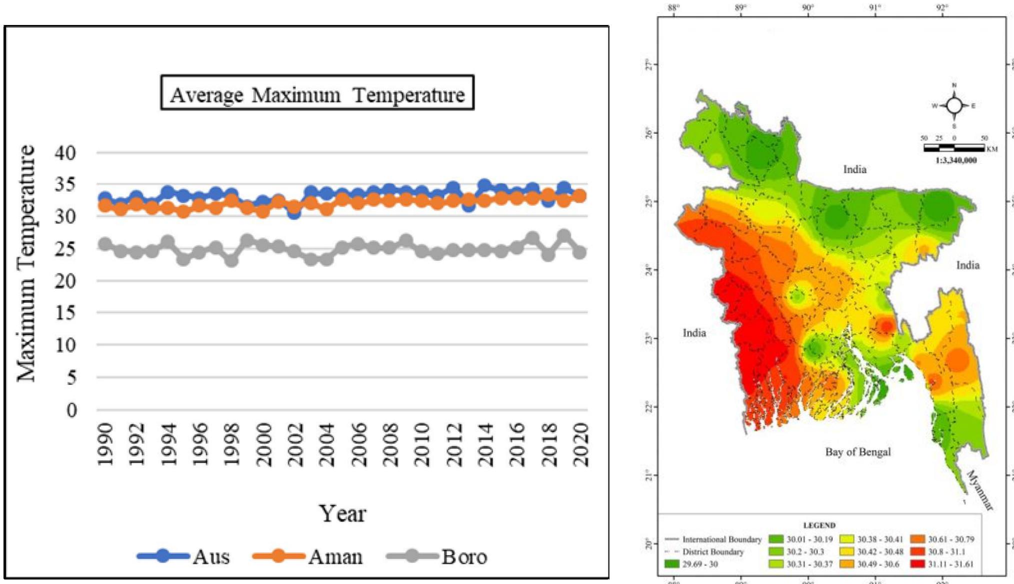


Figure 02: Trends and variations of average maximum temperature for three rice crops from 1990-2020 in Bangladesh

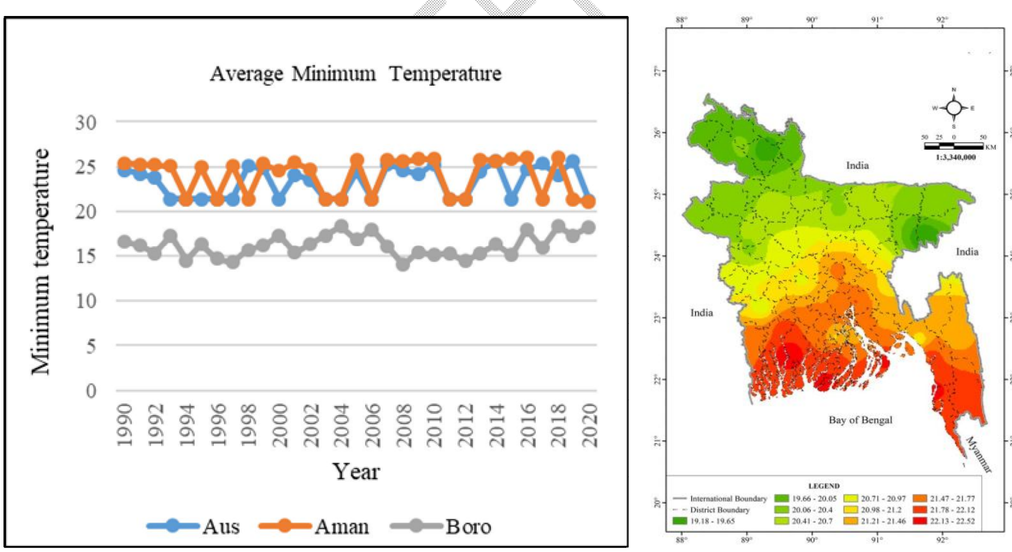


Figure 03: Trends and variations of average minimum temperature for three rice crops from 1990-2020 in Bangladesh

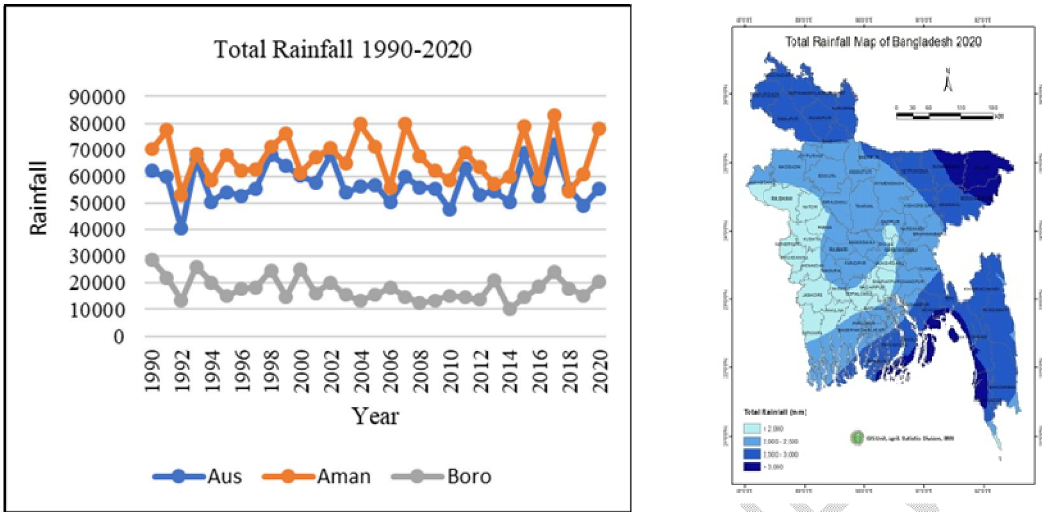


Figure 04: Trends and variations of average total rainfall for three rice crops from 1990-2020 in Bangladesh

Source:

3.3 The Results for the Aus model

The effects of the climate variables on the Aus rice yield are shown in Table 2. The F-value of the model is 2.31 which implies that the overall model is statistically significant at the 5% level. The R^2 value indicates that 20.4% of the variation in the yield of Aus rice can be explained by the climate variables. Moreover, the Durbin–Watson statistic reveals that the model does not suffer from the problem of serial correlation and the VIF values imply that there is no multi-collinearity among the independent variables; along with, the p-value of the Breusch–Pagan chi-squared value ensures that the model does not suffer from the problem of heteroscedasticity. However, the overall yield is statistically significant and implies that the climate variables are able to explain some of the variation in Aus rice production. The t-values for average maximum temperature, average minimum temperature and total rainfall associated with their p-values reveal that these three climate variables are statistically significant at the 5% level; thus, this result implies a highly significant contribution of these variables to the Aus rice yield.

Table 2. The results for the Aus model

Independent Variables/factors	Coefficient	t-Value	p-Value
Constant	-2985.346	-1.991	0.057
Maxt	94.472	2.382	0.025
Mint	18.055	0.849	0.403
Train	0.002	0.340	0.736
R^2	0.204		
Adjusted R^2	0.115		
Durbin-Watson	1.82		
F-statistics	2.301		
Breusch-pagan chi-square (p value)	0.792		

(at 5% level of significance)
Source:

3.4 The Results for the Aman model

The contribution of the relevant climate variables obtained from the OLS method is illustrated in Table 3. According to the table, the model has an F-value of 13.79 that implies that the overall model is statistically significant at the 5% level and the R^2 value indicates that 60% of the variation in Aman rice yields is explained by the climate variables. Moreover, the Durbin–Watson statistic reveals that the model does not suffer from the problem of serial correlation. The VIF values imply that there is no multi-collinearity among the independent variables, and the p-value of the Breusch–Pagan chi-squared value ensures that the model does not suffer from the problem of heteroscedasticity. However, the effects of maximum temperature and rainfall are positive, whereas minimum temperature has an adverse influence on Aman rice yield. The result conveys that being the rain-fed crop regular monsoon rainfall and medium to higher temperature is necessary for the abundant production of Aman rice whereas minimum temperature can hamper the production [15].

Table 3. The results for the Aman model

Independent Variables/factors	Coefficient	t-Value	p-Value
Constant	-3971.359	-4.809	0.000
Maxt	155.795	6.368	0.000
Mint	-9.597	-1.144	0.263

Train	0.000	0.070	0.944
R^2	0.605		
Adjusted R^2	0.561		
Durbin-Watson	1.91		
F-statistics	13.790		
Breusch-pagan chi-square (p value)	0.386		

(at 5% level of significance)

3.5 The Results for the Boro model

Boro rice is grown using irrigation during the dry season. The contribution of the relevant climate variables obtained from the OLS method is illustrated in Table 4. As the model has an F-value of 3.136 that implies that the overall model is statistically significant at the 5% level. The R^2 value indicates that 25% of the variation in Boro rice yields is explained by the climate variables. Moreover, the Durbin–Watson statistic reveals that the model does not suffer from the problem of serial correlation. The VIF values imply that there is no multi-collinearity among the independent variables, and the p-value of the Breusch–Pagan chi-squared value ensures that the model does not suffer from the problem of heteroscedasticity. The t-value of the average maximum temperature is 1.57, and that for the average minimum temperature is 1.54, which indicate that both Maximum temperature and Minimum temperature are statistically significant. However, the relationship between yield, Maximum temperature and Minimum temperature have positive effect on yield. This result suggests that both climate variables affect Boro rice yields considerably. Total rainfall during the Boro rice period is also significant but negative. This finding of an significant effect of total rainfall on Boro rice production is consistent with the results obtained for Bangladesh. Chowdhury and Khan (2015) in their study also observed the negative effect of rainfall on the production of Boro rice as it is a fully irrigated crop. However, the results of the current study are more robust than the past studies in terms of both methods and diagnostic tests.

Table 4. The results for the Boro model

Independent Variables/factors	Coefficient	t-Value	p-Value
Constant	-695.779	-0.571	0.573
Maxt	66.942	1.572	0.128
Mint	51.227	1.548	0.133
Train	-0.025	-2.2679	0.012
R^2	0.258		
Adjusted R^2	0.176		
Durbin-Watson	1.98		
F-statistics	3.136		
Breusch-pagan chi-square (p value)	1.05		

(At 5% level of significance)
Source:

4. CONCLUSION

Overall, the results show that the rice yield of three distinct crops is significantly impacted by three climate variables. All three climatic variables are statistically significant for the Aus model. Furthermore, it is discovered that the overall seasonal rainfall has a negative impact on Aus rice, albeit a noteworthy one. It is also determined that the Aus model as a whole is relevant. Both the total seasonal rainfall and the average seasonal minimum temperature were statistically significant for the Aman rice model. While minimum temperatures have a negative impact on yields, maximum temperatures and rainfall have a favorable effect. Finally, all the climatic variables are found to have substantial effects on yields in the Boro rice model. However, the total rainfall is found to be negatively related to Boro rice yields. One intriguing discovery is that rainfall is important for all types of rice; this study confirms that these types—Aus and Boro partially and Aman completely—grow in rain-fed environments. The three models achieve statistical significance in terms of the F and R2 values, and the overall goodness of fit is determined by the results. Consequently, it is discovered that minimal temperatures have a negative impact on Aman rice output. Rice yields are extremely sensitive to climate conditions, so in order to mitigate the negative consequences of climate change, variety-specific adaptation methods must be implemented. The supply of timely climate information and the development of climate-resilient (temperature-tolerant) varieties are two key options that the policy makers of Bangladesh should urgently address. However, the breeding of new rice varieties requires substantial funding over significant time periods; thus, the public sector should be involved because of the associated positive spills over effects of crop research.

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