Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data

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ABSTRACT

This study examines the relationship between the yield of three major rice crops (e.g., Aus, Aman and Boro) and three main climate variables (e.g., maximum temperature, minimum temperature and rainfall) for Bangladesh. We use time series data for the 1972–2009 period at an aggregate level to assess the relationship between climate variables and rice yield using both the ordinary least squares and median (quantile) regression methods. The findings of this study confirm that climate variables have had significant effects on rice yields but that these effects vary among three rice crops. Maximum temperature is statistically significant for all rice yields with positive effects on Aus and Aman rice and adverse effects on Boro rice. Minimum temperature has a statistically significant negative effect on Aman rice and a significantly positive effect on Boro rice. Finally, rainfall has a statistically significant effect on Aus and Aman rice. Nonetheless, the influences of maximum temperature and minimum temperature are more pronounced compared with that of rainfall. Given these effects of temperature on rice crops and increasing climate change vulnerabilities, policy makers should fund the research and development of temperature-tolerant rice varieties, particularly for Aman and Boro rice.

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1. Introduction

Because of increasing emissions of anthropogenic greenhouse gases as a result of human activities, climate change has emerged as a key concern for environmentally and economically vulnerable countries, such as Bangladesh. Combined with the potential increase in global temperature, rainfall has already become variable and unpredictable, and the occurrence and strength 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; Ahsan et al., 2011). One great concern regarding these changes is the potentially disastrous consequences on crop agriculture and food security in many parts of the world, particularly in developing countries (FAO, 2007; IPCC, 2007; Mertz et al., 2009; WB, 2010; Roudier et al., 2011). The scientific and policy communities have recognised the susceptibility of crop agriculture to climate change and questioned the ability of farmers to adapt because of the direct and strong dependence of crop agriculture on climate (Reid et al., 2007; Mertz et al., 2009; Roudier et al., 2011).

Bangladesh is considered one of the countries that is most vulnerable to climate change because of its location in the tropics, the dominance of floodplains, its low elevation from sea level, its high population density and its low economic and technological capacity (MOEF, 2005; DOE, 2007; Shahid and Behrawan, 2008; Pouliotte et al., 2009; Huq and Rabbani, 2011). Temperatures in Bangladesh have been increasing, particularly during the monsoon season, for the last three decades (GOB and UNDP, 2009). Moreover, the country is predicted to experience an increase in average day temperatures of 1.0 °C by 2030 and of 1.4 °C by 2050 (FAO, 2006; IPCC, 2007). Rainfall has become increasingly variable and has demonstrated an uneven distribution. The number of days without rain is increasing, although the total annual rainfall essentially remains the same. This erratic pattern produces extreme events, such as floods and drought, which have noticeable adverse effects on rice yields (Alauddin and Hossain, 2001; UNDP, 2008; GOB and UNDP, 2009). As a result, rice production is likely to decline by 8–17% by 2050 (BBS, 2005; IPCC, 2007).

Crop agriculture in Bangladesh is chiefly characterised by a rice monoculture. Almost 80% of the total cropped area is planted with rice, which accounts for more than 90% of total grain production (Alauddin and Tisdell, 1987, 1991; BBS, 2009; Asaduzzaman et al., 2010). The percentage share of rice in value is more than 60% of the total crop agriculture (Asaduzzaman et al., 2010; Yu et al., 2010). Moreover, agriculture accounts for nearly 20% of gross

domestic product (GDP), and almost 66% of the labour force depends on agriculture for employment (GOB, 2010). Given the dependence of rice yield on climatic variables and the higher percentage of the total population dependent on agriculture for their livelihoods, there is a vital need to assess the potential effects of climate change on rice productivity to ensure food security and economic growth.

2. Crop agriculture and climate change

Earlier studies on the influence of climate change on agriculture have focused on developed countries, particularly the USA (Kaiser et al., 1993; Mendelsohn et al., 1994; Adams et al., 1995, 1999; Rosenzweig, 1989). Some studies have recently investigated the economic effects of climate change on agricultural production in developing countries (Lansigan et al., 2000; Chang, 2002; Gbetibouo and Hassan, 2005; Kurukulasuriya and Ajwad, 2007; Kabubo-Mariara and Karanja, 2007; Haim et al., 2008; Sanghi and Mendelsohn, 2008; Deressa and Hassan, 2009; Moula, 2009; Wang et al., 2009). All of these studies reveal that crop agriculture in developing countries is highly susceptible to climate change. Despite the status of Bangladesh as a country that is highly susceptible to climate change, empirical investigations of the influence of climate change on crop agriculture in this country have been limited (Mahmood, 1998; Paul, 1998; Ali, 1999; Rahman, 2000; Rashid and Islam, 2007). One strand of these studies is descriptive in nature (Paul, 1998; Ali, 1999; Rashid and Islam, 2007). Ali (1999) discussed the influence of climate change by considering extreme climate events, such as cyclones, storm surges, coastal erosion and backwater effects. His study revealed that sea level rises on the eastern part of Bangladesh would result in large agricultural land losses fuelled by beach erosion. The study also identified some adaptive measures, such as the construction of embankments and cyclone shelters and the introduction of new rice varieties that are suited to higher salinity and temperatures; however, he did not estimate the effects of temperature and rainfall on the coastal agriculture. Rashid and Islam (2007) identified droughts, floods, soil salinity and cyclones as the major extreme climatic events that have affected agricultural production adversely. Changes in behavioural patterns, human practices and international actions are suggested as anticipatory adaptive measures in the study. Paul (1998) showed that the drought in 1994 and 1995 negatively affected 15 distinct crops in northwestern Bangladesh. The most affected crop was transplanted Aman (T. Aman) rice, which is the principal crop in the region. Wealthy farmers executed some adjustment measures, such as crop replacement, irrigation, gap filling and the inter-cropping of wheat and Kaon (a local food crop), whereas poor farmers were unable to practise any of these measures because of their inability to purchase irrigation equipment. However, this study did not undertake any comprehensive estimate of the effects of the drought on rice production using rigorous statistical techniques. Islam (1988) considered the disastrous effects of natural hazards on crop production and emphasised the need to gain knowledge of the decision-making behaviour of farmers in terms of their resource allocation and crop choices by considering random elements in devising an effective national crop production plan. However, in the absence of a required cross-section time series of farm-level data, this study proposed undertaking a project at the national level to generate short- and long-term data for the estimation of the model of farmer behaviour.

Another strand of empirical studies was undertaken to estimate the effects of climate variability on rice productivity in Bangladesh using the CERES-Rice model and the DASSAT model (Karim et al., 1996; Mahmood, 1998; Mahmood et al., 2004; Basak et al., 2010). These studies primarily focused on the influence of higher air temperature and higher atmospheric CO_2 concentration on rice yield. However, these studies were confined to simulation modelling to assist in identifying the physiological effects of high temperatures on crop yield (Schlenker and Roberts, 2008). Regression models that use historical data on both climate variables and yields are more capable of providing accurate estimates of the changes in crop yield as a result of changes in climate variables (Isik and Devadoss, 2006; Lobell and Field, 2007; Almaraz et al., 2008; Joshi et al., 2011). Thus, there is a need for empirical studies of the relationship between climatic variables and crop yields. To our knowledge, no empirical studies have employed econometric techniques to examine the effects of climate variables on rice yield in the context of Bangladesh. On an international level, several studies have been conducted to examine the effect on crop production (Ozkan and Akcaoz, 2002; Lobell et al., 2007; Almaraz et al., 2008) but have not explored the effects on rice yield. These studies have used time series data but have not determined the stationarity properties of the data, although this determination is a precondition for performing a regression analysis with time series data for a period of 20 years or longer (Chen et al., 2004). As a result, these studies might have produced spurious results due to the misspecification. Furthermore, different crop varieties are affected differently (Deressa et al., 2005; Isik and Devadoss, 2006; Kabubo-Mariara and Karanja, 2007); thus, crop variety-specific research is warranted to devise better policy implications. Therefore, the objective of this study is to assess the empirical relationship between three climatic variables and rice yields of three crops using aggregate-level time series data from Bangladesh over the period from 1972 to 2009.

3. Production techniques of different rice crops

Rice, the main staple food in Bangladesh, occupies nearly 80% of the total net cropped area of the country. Three major rice crops (namely, Aus, Aman and Boro) constitute 100% of total rice production and grow in three different seasons. Aus is typically planted in March or April and harvested in June or July. Aman is generally sown in July or August and harvested in November or December. Finally, Boro is planted in December or January and harvested in May or June (Islam, 1988; BBS, 2009). To some extent, this common rice crop calendar varies marginally in different places depending on soil texture and land elevation. These growing seasons are practically harmonised with three climatic seasons: the hot summer (March–May), monsoon season (July–October) and the winter season (December–February). Further, the geographical distribution of all three crops is constant over time.

Climate has always played a vital role in rice production. According to BRRI (1991), Aus rice requires supplementary irrigation during the initial stage of its growing season; in contrast, Aman is almost completely rain-fed rice that grows in the months of monsoons, although it requires supplementary irrigation during planting and sometimes in the flowering stage depending on the availability of rainfall. In contrast, Boro rice grows in the dry winter and the hot summer; thus, it is completely irrigated (Mahmood, 1997). Only 5% of Aman rice and 8% of Aus rice are irrigated (Ahmed, 2001).

4. Methodology

4.1. Empirical model selection

The objective of this analysis is 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. This objective can be accomplished by

using either ordinary least squares (OLS) or quantile regression (QR) depending on the distribution of the dependent variable. The OLS approach is applied when the dependent variable is normally distributed, whereas QR is employed when the variable is not normally distributed. The QR (median) regression is more robust to outliers than mean regression (OLS). Furthermore, QR provides a clearer understanding of the data by assessing the effects of explanatory variables on the location and the scale parameters of the model. More importantly, median regression does not require classical assumptions regarding the distribution of the regression error terms (Cameron and Trivedi, 2009). Consequently, quantile or median regression is suitable for heteroscedastic data and can thus correct the model for the problem of heteroscedasticity (Koenker and Bassett, 1978; Benhin, 2008; Cameron and Trivedi, 2009).

Following Ozkan and Akcaoz (2002), Lobell et al. (2007) and Almaraz et al. (2008), we used three climate variables as independent variables: maximum temperature, minimum temperature and rainfall. Previous studies used different units of time, such as months, phonological periods and growing seasons, for climate variables. However, this study has used an average growing season temperature variable with the total growing season rainfall variable because the average growing season climate is able to capture the net effect of the entire range of the development process by which yields are affected by climate (Lobell and Field, 2007). Moreover, the average growing season temperature is a key determinant of average yield (Cabas et al., 2010). The monthly average growing season maximum and minimum temperature and the total growing season rainfall have been used in previous studies (Granger, 1980; Chang, 2002; Lobell and Field, 2007; Lobell et al., 2008). In this study, the rice yield data for all three crops are regressed on the climate variables to estimate their effects on the rice yield. We checked the distribution of each rice crop yield against time by drawing histograms before we selected the OLS or QR regression type. An inspection of the histograms revealed that the Aman and Aus rice yields did not follow a normal distribution, but the Boro rice yield appeared to have a normal distribution. Therefore, mean regression (OLS) was selected for the Boro rice estimation, whereas median regression (QR) was selected for the Aman and Aus rice. These methods are best suited to estimate the central tendency of our 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:

$$Y_{Aus_t} = \beta_1 max\,t_t + \beta_2 min\,t_t + \beta_3 train_t + \varepsilon_t$$

where Y_{Aus} is the yield for Aus rice (in kg per acre), $max\,t$ is the average maximum temperature (°C) from March to August, $min\,t$ is the average minimum temperature (°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).

Median regression (at the 0.5 quantile) is employed for the estimation of the Aus model. Thus, the objective is to estimate the median of the dependent variable, conditional on the values of the independent variables. The median regression minimises the sum of the absolute residuals.

Aman model:

$$Y_{Aman_t} = \beta_1 max\,t_t + \beta_2 min\,t_t + \beta_3 train_t + \varepsilon_t$$

where Y_{Aman} is the yield of Aman rice (in kg per acre), $max\,t$ is the average maximum temperature (°C) from June to November, $min\,t$ is the average minimum temperature (°C) from June to November, $train$ 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:

$$Y_{Boro_t} = \alpha + \beta_1 max\,t_t + \beta_2 min\,t_t + \beta_3 train_t + \varepsilon_t$$

where Y_{Boro} is the yield of Boro rice (in kg per acre), $max\,t$ is the average maximum temperature (°C) from December to May, $min\,t$ is the average minimum temperature (°C) from December to May, $train$ 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 minimises the sum of the squares of the residuals. All variables under each model are log transformed before estimation.

4.2. Data sources and properties

Monthly data on maximum temperature, minimum temperature and total rainfall were obtained from the Bangladesh Meteorological Department (BMD) (2010) for all 33 weather stations, which cover all of Bangladesh for the 1972–2009 period. These monthly data were then converted as the average of the growing periods for three rice crops: Aus, Aman and Boro. Therefore, 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 1972–2009 period.

Aggregate rice yield data by variety for the same time period (1972–2009) were obtained from various issues of the Bangladesh Economic Review (GOB, 1991, 2001, 2010). The summary statistics for all of the data are presented in Table 1. This table also illustrates the fundamental climatic characteristics during three rice growing seasons in Bangladesh.

The mean value for the Boro rice yield is the highest and more than twice as high as that of the Aus rice. The highest mean maximum and minimum temperatures are observed for the Aus rice, and the lowest temperatures were observed for the Boro rice. In contrast, total rainfall in the Aus and Aman periods is approximately four and three times higher, respectively, than the total rainfall in the Boro period. However, these descriptive statistics do not provide any evidence of changing climate. To build the quantitative justification for climate change during the growing seasons for Aus, Aman and Boro rice crops separately, we estimate a linear trend model for three major climate variables with time (t) as an explanatory variable over the entire period. The results are illustrated in Table 2.

The coefficients of the time trend variable for the monthly average growing season maximum temperature ($max\,t$) and minimum temperature ($min\,t$) are statistically significant with considerable explanatory power for all three rice crops, whereas those for the total average growing season rainfall ($train$) are significant for the Aus and Aman rice. However, the explanatory power of the time trend for maximum temperature is the highest for the Aman rice and the lowest for the Boro rice. With regard to the minimum temperature, the explanatory power is maximal for the Aus rice and minimal for the Boro rice. Therefore, most of the climate variables appear to show an upward trend over the 1972–2009 period; thus, these results provide clear evidence of changing climate across the three rice growing periods in Bangladesh. We will determine whether this significant climate change affected rice yield below.

Nevertheless, our data set encompasses more than 20 years of observations that require testing for stationarity (Chen et al., 2004). Therefore, this requirement warrants further investigation of the data series to ensure that it is stationary before we estimate the regression. Accordingly, we performed an augmented Dickey–Fuller (ADF) test (i.e., the presence of unit roots for each variable) (Dickey and Fuller, 1979) and the results are reported in Table 3.

The table shows that the yields for all three rice crops are integrated of order one, I(1), which implies the non-stationary of the

Table 1
Descriptive statistics for the data for the 1972–2009 period.

Statistics	Variables											
	Yield (kg per acre)			Maximum temperature (°C)			Minimum temperature (°C)			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
Std. dev.	105	126	220	0.43	0.35	0.49	0.31	0.30	0.37	8511	8528	4493
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
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

Source: Authors' own estimation based on GOB (2010) and BMD (2010).

Table 2
The results of the linear trend model of changes in climate variables for the 1972–2009 period.

Rice crops	Climate variables	Intercept	Coefficient for time (trend) variable	*t*-Value	*p*-Value	R^2
Aus	*maxt*	31.69	0.03***	5.10	0.000	0.42
	mint	24.63	0.02***	4.59	0.000	0.37
	train	48448	339.36**	2.96	0.005	0.20
Aman	*maxt*	29.88	0.03***	6.65	0.000	0.55
	mint	22.08	0.01***	3.37	0.000	0.24
	train	36921	468.42***	4.62	0.000	0.37
Boro	*maxt*	29.32	2.23**	2.23	0.031	0.12
	mint	15.31	0.02***	4.12	0.000	0.32
	train	13837	44.40	0.66	0.510	0.01

** Represents the 5% level of significance.
*** Represents the 1% level of significance.

series. However, all of the climate variables are integrated of order zero for the Aus and Boro rice varieties; thus, these data series are stationary in their level form. However, the maximum temperature is of I(1), which indicates a unit root in the level data for the Aman rice variety. The variables with I(1) must first be differenced before estimation (Gujrati, 2004; McCarl et al., 2008). Because all or most of the variables are not integrated at the same order under each model, we did not perform a co-integration test; rather, a regression analysis using either an OLS with the differenced variables or a QR (quantile at 0.5) is performed. For the same reason, a causality analysis was not performed. Rather, yield changes are assumed to be caused by climate variations rather than the reverse, as proposed by Lobell and Field (2007).

5. Results and discussion

5.1. The results for the Aus model

The effects of the climate variables on the Aus rice yield is shown in Table 4, which indicates that 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 R^2 value indicates that 37% of the variation in the Aus rice yield is explained by climate variability. The *t*-values for average maximum temperature and total rainfall associated with their *p*-values reveal that these two climate variables are highly significant. Both *maxt* and *train* are statistically significant at the 1%

level; thus, this result implies a highly significant contribution of these variables to the Aus rice yield. Although *mint* does not appear to be statistically significant, it is negatively associated with the Aus rice yield.

5.2. The results for the Aman model

The contribution of the climate variables to the Aman rice is presented in Table 5. The probability of the Quasi-LR statistic ensures the significance of the overall model.

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

5.3. 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 6.

This model has an *F*-value of 4.59 with a *p*-value of 0.008. This result implies that the overall model is statistically significant at the 1% level. The R^2 value indicates that 29% 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

Table 3
Augmented Dickey–Fuller (ADF) test for determining the stationarity of the data series.

Variables	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)

Table 4
The results for the Aus model.

Independent variables	Coefficient	t-Value	p-Value
maxt	12.39***	3.40	0.001
mint	−2.03	−0.50	0.617
train	0.90***	4.53	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

*** Represents the 1% level of significance.

Table 5
The results for the Aman model.

Independent variables	Coefficient	t-Value	p-Value
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 = 0.29
Adjusted R^2 = 0.25
Sparsity = 0.327
Quasi-LR statistic = 43.08
Prob (Quasi-LR stat) = 0.000

* Represents the 10% level of significance.
** Represents the 5% level of significance.
*** Represents the 1% level of significance.

Table 6
The results for 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 = 23
Durbin–Watson = 1.98
F-statistic = 4.59
p-Value of F-statistic = 0.008
Breusch–Pagan chi-square = 1.05
Prob > chi-square = 0.30

** Represents the 5% level of significance.
*** Represents the 1% level of significance.

the problem of serial correlation. This value is an improvement over that achieved in the study by Ozkan and Akcaoz (2002) with their D–W statistic of 1.09, which indicated the problem of positive 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 −2.49, and that for the average minimum temperature is 3.12, which indicate that both *maxt and mint* are statistically significant. However, the relationship between yield and *maxt* is negative, whereas *mint* has a positive effect on yield. This result suggests that both climate variables affect Boro rice yields considerably. Total rainfall during the Boro rice period is insignificant because this rice crop grows under completely irrigated conditions. This finding of an insignificant effect of total rainfall on Boro rice production is consistent with the results obtained for Bangladesh by Rimi et al. (2009), who applied a simulation model. However, the results of the current study are more

robust than the past studies in terms of both methods and diagnostic tests.

6. Conclusions

The objective of this study was to estimate the relationship between rice yields and climate variables using aggregate-level time series data. To this end, both OLS and QR models were used. The overall findings reveal that three climate variables have substantial effects 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 adversely affect the Aus rice, although this effect is not significant. The overall Aus model is also found to be significant. For the Aman rice model, all three climate variables were statistically significant. However, the direction of the effects is not identical. Maximum temperatures and rainfall have positive effects on yields, whereas minimum temperatures affect yields negatively. Finally, both maximum and minimum temperatures have substantial effects on yields in the Boro rice model. However, the maximum temperature is found to be negatively related to Boro rice yields. One interesting finding is that rainfall is significant for the Aus and Aman rice; this result supports the fact that these varieties grow in rain-fed conditions: Aus partially and Aman entirely. In terms of the *F* and R^2 values, the three models obtain statistical significance, and the results for overall goodness for fit are consistent with those of Lobell (2010). Therefore, two climate variables (namely, maximum and minimum temperatures) are found to adversely affect Boro and Aman rice yields, respectively. Given this severe sensitivity of rice yields to climate factors, variety-specific adaptation strategies must be adopted to mute the adverse effects of climate change. 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 spillover effects of crop research (McCunn and Huffman, 2000). Finally, a caveat must be noted here: the aggregate-level data are unable to produce any regional variations of climate change and effects on rice yield (Chen et al., 2004; Lobell et al., 2007). Therefore, future research should focus on analysing data at the disaggregated district level to capture regional variations and to obtain a more comprehensive picture of the issue of climate change and rice yield in Bangladesh.

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