International Journal of Geology, Agriculture and Environmental Sciences
Volume – 3 Issue – 1 February 2015
Website: www.woarjournals.org/IJGAES *ISSN: 2348-0254*

Empirical Evidence of Climate Change: Effects on Rice Production in Bangladesh

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Abstract: ***Bangladesh is frequently cited as one of the country's most vulnerable to climate change, despite the country's insignificant contribution to climate change. Any changes in climate will, thus, increase uncertainty regarding rice production as climate is major cause of year-to-year variability in rice productivity. This study analyzed the empirical evidence of climate change and its effect on rice production in Bangladesh. The study used paired t-test to establish that climate change in evident in Bangladesh. Yield response regression model used to determine the effects of temperature and rainfall on rice yield indicated that if an average annual temperature increases by 1^0C, rice yield will decrease by 0.68 mt/ha. The study recommends that Bangladesh Rich Research Institute (BRRI) and NGOs should introduce water conserving measures to farmers. Farmers should be encouraged to plant trees or integrates trees in their rice farms to serve as canopies to reduce the amount of temperature reaching rice plants.***

Keywords: Climate Change, Bangladesh, Paired t-test, Rice and rice yield response.

1. Introduction

In recent times, climate change (CC) and its effects on key crops, such as, rice, wheat and maize, have drawn significant research interest alongside population increase, economic growth and changing diet patterns, also described as the driving forces influencing earth's food and water ecosystems (Liu, et al., 2013). Despite the recent advances, e.g. from improved crop varieties to better management practices that have contributed significantly towards improving various staple crop yields (Papademetriou, 2000), climate still remains the key factor in agricultural productivity (Rosenzweig, et al., 1993). On the other hand, potential climate change effects are predicted to have far-reaching implications on humanity if proper measures are not adapted to counterbalance the change effects more specifically, in regions that are most vulnerable to drastic climate change effects and food deficits (Fraser, 2013).

Bangladesh is extremely vulnerable to the impact of climate change in part because it is a low lying and very flat country, subject to reverie flooding and vulnerable to sea level rise. The influence of three great rivers such as the Ganges, the Brahmaputra and the Meghna makes the country a great deltaic plain. The extensive floodplains are the main physiographic features of the country. Both reverine flooding and sea level rise can result in inundation of crops; sea water in particular can result in salinization, causing permanent loss of currently productive agricultural land. The climate of Bangladesh is characterized by high temperature and rainfall patterns. Since agriculture is dependent on weather and crops are known to suffer yield losses when temperatures, heavy rainfall, high humidity and fairly marked seasonal variations. More than 80 percent of the annual precipitation of the country occurs during the southwestern summer monsoons, from June through September. In recent years the weather pattern has been erratic, with the cool, dry season having considerably decreased a change probably attributable to climate change. Climate change in Bangladesh is an especially serious concern since agriculture is such an important sector in the country. It contributes roughly 20 percent to gross domestic product (GDP), with crops representing 11.2 percent, livestock 2.7 percent, fisheries 4.5 percent and forestry 1.8 percent (Bangladesh, Ministry of Finance 2011). Furthermore, the sector provides employment and income to some of the poorest and most vulnerable members of society. Between 2000 and 2003, agriculture provided work to about 52 percent of the labor force (BBS 2004).

In view of the current situation, to overcome the threats to world food security, many institutions both academic and research, have embarked on modelling the climate change effects on the key crops at various spatiotemporal scales. Rice is one of the major crops to feed the world's growing population (Shimono et al. 2010). About 3 billion people consume rice daily. As one of the most common staple foods for humans, it feeds more people than any other crop

(Maclean et al. 2002). In Bangladesh, rice production is very important because it is the staple diet of the Bangladeshi people and about half of the rural population is involved in its farming. Rice production needs to increase to meet future population growth. Any decline in rice production through climate change would thus critically impair food security in the country. Therefore, quantifying the effects of climate change on rice farming and assessing the potential of rice farmers to adapt to climate change are urgent research topics.

2. Materials and Methods

2.1 Paired t- test for comparing decades means of climate variables

Intergovernmental Panel on climate change, IPCC (climate change, 2007) defined climate change as "change in the state of the average weather conditions which can be identified (e. g. using statistical tests) by changes in the mean and /or the variability of its properties which persists for an extended period, typically decades or longer". Testing the differences between two means of climate variables (temperature, amount of rainfall, relative humidity, wind speed and sunshine duration) this study used paired t- test so as to establish whether the difference is significant or not. The hypotheses tested are

$H_0: \bar{\chi}_{2i} = \bar{\chi}_{1i}$

$H_A: \bar{\chi}_{2i} > \bar{\chi}_{1i}$ for temperature and bright sunshine duration.

$H_A: \bar{\chi}_{2i} < \bar{\chi}_{1i}$ for rainfall and relative humidity.

The t-calculated is given as

$$t - calculated = \frac{\bar{\chi}_{2i} - \bar{\chi}_{1i}}{SE_i} \quad (1)$$

Where $\bar{\chi}_{2i}$ and $\bar{\chi}_{1i}$ the means for the current and the previous decades are are compared for i th climate variable respectively and SE_i is the standard error for i th climate variable. If t-calculated is greater than the critical t^* value from the conventional student t- statistical distribution at a determined significant level, the null hypothesis is rejected in favor of the altered. If the null hypothesis is rejected, it implies there is significant difference between the two decades means compared. Therefore, climate has change with respect to that particular variable. The reverse is true if t-calculated is less than the critical t^* value.

2.2 Effects of Climate Change Indicators on Rice Yield

2.2.1 Empirical framework

Chen and Chang (2005), Lobell et al. (2007) and Chang (2001) have estimated crop yield response functions by using field data on crop yields, climate and non-climate related variables. According to these researches, the yearly impact of climate change can be linked to the respective year's crop yield. Crop yield response model in this study uses a production function approach which was adopted by Chang (2001) to quantify the effects of climate change indicators on rice yield for the past 40 years (1971-2010). The basic concept of this model is that the trend of rice yield is affected by climatic variables especially changes in temperature and rainfall and non-climatic variables such as socioeconomic factors, technology and soil conditions (Daze, 2007). According to Chang (2001), rice yield response (production) function is given as:

Yield=f (Climate, Technology, Management, Land) (2)

The yield is the output in metric tons per hectare; climate and land denote climate factors and soil conditions respectively. The climate variables (rainfall, temperature, relative humidity and sunshine duration) are not controlled by farmers and hence are exogenous factors. At individual level , each farmer tries to maximize yields by choosing endogenous variable inputs such that the resulting yields becomes a function of exogenous variables such as rainfall, temperature, relative humidity and sunshine duration, price of output, price of inputs and soil conditions (Mendelsohn et al., 1994). Chen and Chang (2005) indicated that temperature and rainfall are the major climate variables that affect crop yield even though other climatic factors may have significant effects.

2.2.2 Rice Yield Response to Climate Variables

According to Lobell et al. (2007), the contribution of climate to crop yield trends can be estimated by modeling the crop yield data without removing trend as a function of both time and climatic variables. Mainardi (2010) assumed that the effects of the previous year's crop yield on the current year's crop yield measure the technological changes. Soil condition can be proxied by the slope of the land in the study area. The slope of the land depends on the area that each farmer cultivates rice. Following Chang (2001) management of farms can be measured as the ratio of full time farm households to total farm households in the area. Since rice yield data is not taken at the farmer level but at the regional level, the soil condition and the management variables are excluded in the model used in this study.
The corresponding differences in annual minimum and maximum temperature and rainfall are included in the model in order to measure the influence of departure from normal climatic conditions on rice yield (Chang, 2001). These variables also capture the extreme event on rice yield. According to Mendelsohn et al. (1994), when one omits the variation term of temperature or rainfall, the estimation of the effects of global warming on crop yield will be bias. Temperature and rainfall have a non-linear effect on rice yield. The actual yield response model is given as:

$$Y_t^R = \delta_o + \delta_t Y_{t-1}^R + \delta_1 T_t + \delta_2 T_t^2 + \delta_3 R_t + \delta_4 R_t^2 + \delta_5 VarT_t + \delta_6 VarR_t + \xi_t \quad (3)$$

where $\delta_{t-1}, \delta_1, \delta_2, \delta_3, \delta_4, \delta_5 and\ \delta_6$ are the slope coefficients of the explanatory variables $Y_{t-1}^R, T_t, T_t^2, R_t, R_t^2, VarT_t\ and\ VarR_t$ respectively. $Y_t^R, Y_{t-1}^R, T_t\ and\ R_t$ are denote rice yield (metric tons per hectare) in year *t*, previous years rice yield (metric tons per hectare), average annual temperature $(℃)$ in year *t*, annual rainfall amount *(mm)* in year *t* respectively. $VarT_t\ and\ VarR_t$ are represent differences between monthly minimum and maximum average temperatures $(℃)$ and total rainfall amount *(mm)* in year *t* respectively. The non-linear temperature and rainfall amount variables are shown by T_t^2 *and* R_t^2 respectively. Lastly, ξ_t is the stochastic error term which satisfies the classical normal regression assumptions.

Chang (2001) used linear-log functional form to estimate crop yield response model based on the fact that temperature and rainfall have non-linear relationship with crop yield. The same functional form was used in this research because it addresses the issue of non linear relationship between rice yield and climatic values. The a priori expectations for the explanatory variables used in equation (4) are summarized in table 1 below.

$$Y_t^R = \delta_o + \delta_t Y_{t-1}^R + \delta_1 \ln(T_t) + \delta_2 \ln(T_t^2) + \delta_3 \ln(R_t) + \delta_4 \ln(R_t^2) + \delta_5 \ln(VarT_t) + \delta_6 \ln(VarR_t) + \xi_t \quad (4)$$

Table 1: A priori Expectations of Rice Yields Response Model

Variables	Parameters	A priori expectations
Previous years rice yield (Y_{t-1}^R)	δ_t	Positive
Temperature (T_t)	δ_1	Negative
Extremely high temperature (T_t^2)	δ_2	Negative
Rainfall (R_t)	δ_3	Positive
Rainfall Square / extremely high rainfall (R_t^2)	δ_4	Negative
Maximum-minimum temperature; extreme ($VarT_t$)	δ_5	Negative
Maximum-minimum rainfall; extreme ($VarR_t$)	δ_6	Negative

2.2.3 Statement of Hypothesis

A. H_0: Extreme variations in temperature $(VarT_t)$ have no effect on rice yield.

H_1: Extreme variations in temperature $(VarT_t)$ have negative effect on rice yield.

Extreme variations in annual rainfall amounts $VarR_t)$, normal level of temperature (T_t), extreme level of temperature (T_t^2) and extreme level of rainfall amount (R_t^2) follows similar hypothesis states above.

B. H_0: Normal rainfall amounts (R_t) have no effect on rice yield.

H_1: Normal rainfall amounts (R_t) have positive effect on rice yield.

C. H_0: Advanced in technology (Y_{t-1}^R) have no effect on rice yield.

H_1: Advanced in technology (Y_{t-1}^R) increases rice yield.

2.2.4 Validation of Hypothesis

The student t-statistic test is used to test the null hypotheses stated above. It is used to determine whether the estimated parameters are significantly different from zero.

2.3 Data

For this study time series data is used to estimate the effects of climate change on rice yield in Bangladesh. The years considered in the current study are from 1971 to 2010. Data of rice yield in metric tons per hectare were obtained from the Ministry of Agriculture, Bangladesh and date of temperature, rainfall amounts, relative humidity, wind speed and sunshine duration were obtained from Department of Meteorology, Government of People‘s Republic of Bangladesh. The average annual data for selected variables were used for this study.

3. Result and Discussion

3.1. Variability of Climatic Variables

Figure 1 shows line graphs that describe the coefficient of variation for each of the climatic variables over the past four decades. The graphs indicate the variability of rainfall, temperature, relative humidity and bright sunshine duration. From the figure, the dispersion or variability of rainfall amount relative to the mean is highest (14.33%) during the first decade (1971-80). The second decade (1981-90) recorded the lowest coefficient of variation in rainfall amount (9.46%) and this is followed by the fourth decade (2001-10). The coefficient of variation for temperature has been the lowest among the other climatic variables for the past four decades. The variability in temperature fluctuates slightly over the decades. The graph for bright sunshine duration indicates that there is a general rise in the dispersion of bright sunshine duration from 26.62% in the first decade to 28.23% in the second decade and this declined thereafter to 2.71% in the fourth decade.

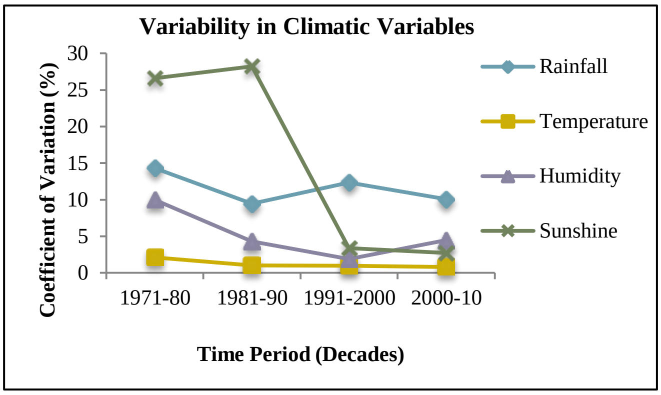

Figure 1: Variability in Climatic Variables

3.2 Empirical Evidence of Climate Change

This section tests the evidence of climate change by comparing means of two decades rainfall amount, temperature, relative humidity and bright sunshine duration.

3.2.1 Empirical evidence of changes in annual rainfall:

The paired t- test results in table 2 show the empirical evidence of changes in decades mean of annual rainfall to establish whether there is significant change in the mean. The t-statistics and the p-values shown in the table indicated that none of the two decades means of total annual rainfall values compared is statistically significant. The difference between 1971-80 and 1981-90; 1971-80 and 1991-2000; 1971-80 and 2001-2010 decades means of average annual rainfall are highly statistically significant at 1% and consistent with the priori expectation and there is no significant difference in the decade's means of total annual rainfall between 1981-90 and 1991-2000; 1981-90 and 2001-2010; 1991-2000 and 2001-2010. Therefore, climate has changed in terms of rainfall amount.

Table 2: Paired t-test for Comparing Decades Means of Average Total Annual Rainfall

Decades	Mean Rainfall	n	df	t-Statistics	t-Critical (one tail)	p-Value (one tail)
1971-1980	157.95	10				0.0000*
1981-1990	199.71	10	9	-10.261	1.8331	
1971-1980	157.95	10				0.0001*
1991-2000	206.46	10	9	-5.648	1.8331	
1971-1980	157.95	10				0.0007*
2001-2010	201.37	10	9	-4.455	1.8331	
1981-1990	199.71	10				0.2302
1991-2000	206.46	10	9	-0.771	1.8331	
1981-1990	199.75	10				0.4275
2001-2010	201.37	10	9	-0.188	1.8331	
1991-2000	206.46	10				0.3492
2001-2010	201.37	10	9	0.400	1.8331	

Source: Author's own Calculation
N. B. n and df represent the number of year and degree of freedom
** represent 1% level of significance*

3.2.2 Empirical evidence of global warming

The paired t-test results in table-3 show the empirical evidence of changes in decade's means of annual temperature. The difference between 1971-80 and 1981-90 decades means of average annual temperature is highly significant at 1% consistent with the a priori expectation. The difference in the decade's means of average annual temperature between 1971-80 and 1991-2000 is highly significant at 1% and consistent with the priori expectation. This means there is significant difference between decade's means of average annual temperature values of 24.66^{0}C and 25.25^0 C. The t- test value of -2.925 implies that the difference between 1971-80 and 2001-10 means of average annual temperature is statistically significant at 1%. Therefore there is a significant difference between 1971-80 mean value of 24.66^{0}C and 2001-10 mean value of 25.23^{0}C. It also supports the a priori expectation that climate is becoming warmer.

Table 3: Paired t-test for Comparing Decades Means of Average Annual Temperature

Decades	Mean temperature	n	df	t-Statistics	t-Critical (one tail)	p-Value (one tail)
1971-1980	24.656	10				0.0092*
1981-1990	25.131	10	9	-2.874	1.8331	
1971-1980	24.656	10				0.0042*
1991-2000	25.246	10	9	-3.363	1.8331	
1971-1980	24.656	10				0.0084*
2001-2010	25.234	10	9	-2.925	1.8331	
1981-1990	25.131	10				0.1835
1991-2000	25.246	10	9	-0.950	1.8331	
1981-1990	25.131	10				0.1298
2001-2010	25.234	10	9	-1.203	1.8331	
1991-2000	25.246	10				0.4539
2001-2010	25.234	10	9	0.119	1.8331	

Source: Author's own Calculation
N. B. n and df represent the number of year and degree of freedom
** represent 1% level of significance*

Finally there is no significant difference between the mean decade temperatures of 1981-90 and 1991-2000; 1981-90 and 2001-10 and 1991-2000 and 2001-2010. So in terms of temperature, climate change is evident in case of Bangladesh.

3.2.3 Empirical evidence of changes in relative humidity

Table 4 below depicts paired t- test for comparing decade's means of annual average relative humidity. The difference between 1971-80 and 1981-90;1971-80 and 1991-2000; 1971-80 and 2001-10; 1981-90 and 1991-2000 decades means of average annual relative humidity is highly statistically significant at 1% and consistent with the a priori expectation. The t- test value of -2.169 implies that the difference between 1981-90 and 2001-10 means of average annual relative humidity is statistically significant at 5%. Therefore there is a significant difference between 1981-90 mean value of 75.36 and 2001-10 mean value of 79.86. The t-test results show that there is no significant difference between 1991-2000 and 2001-10 means of average annual relative humidity. Therefore climate has changed in terms of relative humidity.

Table 4: Paired t- test for Comparing Decades Means of Average Annual Relative Humidity

Decades	Mean Relative Humidity	n	df	t-Statistics	t-Critical (one tail)	p-Value (one tail)
1971-1980	64.46	10				0.000004*
1981-1990	75.36	10	9	-8.878	1.8331	
1971-1980	64.46	10				0.0000073*
1991-2000	80.64	10	9	-8.464	1.8331	
1971-1980	64.46	10				0.00021*
2001-2010	79.86	10	9	-5.415	1.8331	
1981-1990	75.36	10				0.00010*
1991-2000	80.64	10	9	-5.941	1.8331	
1981-1990	75.36	10				0.0291**
2001-2010	79.86	10	9	-2.169	1.8331	
1991-2000	80.64	10				0.2932
2001-2010	79.86	10	9	0.564	1.8331	

Source: Author's own Calculation
N. B. n and df represent the number of year and degree of freedom
**, ** represent 1% and 5% levels of significance respectively*

3.2.4 Empirical evidence of changes in bright sunshine duration

The empirical evidence of climate change shown by changes in decades means of bright sunshine duration is illustrate in table 5. The Paired t-test values are -8.933, -25.545, -23.256, -3.460 and -3.509 for the differences in bright sunshine duration between 1971-80 and 1981-90; 1971-80 and 1991-2000; 1971-80 and 2001-10; 1981-90 and 1991-2000; 1981-90 and 2001-10 are highly statistically significant at 1% whose decades means of average annual bright sunshine duration values are 1.98 hours and 4.68 hours; 1.98 hours and 6.05 hours; 1.98 hours and 6.24 hours; 4.68 hours and 6.05; 4.68 hours and 6.24hours. The difference between the means is consistent with the a priori expectation meaning the test supported that bright sunshine duration is increasing. Hence bright sunshine duration had increased from 1.98 hours (1971-80) and 4.68 hours (1981-90) etc. Also, there is a significant difference between the decade's means of average annual bright sunshine duration of 1991-2000 and 2001-10. The p- value of 0.408 indicates that the test is significant is 5%.

Table 5: Paired t- test for Comparing Decades Means of Average Annual Bright Sunshine Duration

Decades	Mean Sunshine Duration	n	df	t-Statistics	t-Critical (one tail)	p-Value (one tail)
1971-1980	1.98	10				0.000005*
1981-1990	4.68	10	9	-8.933	1.8331	
1971-1980	1.98	10				0.0000*
1991-2000	6.05	10	9	-25.545	1.8331	
1971-1980	1.98	10				0.0000*
2001-2010	6.24	10	9	-23.256	1.8331	
1981-1990	4.68	10				0.00358*
1991-2000	6.05	10	9	-3.460	1.8331	
1981-1990	4.68	10				0.00331*
2001-2010	6.24	10	9	-3.509	1.8331	
1991-2000	6.05	10				0.0408**
2001-2010	6.24	10	9	-1.960	1.8331	

Source: Author's own Calculation
N. B. n and df represent the number of year and degree of freedom
**, ** represents 1% and 5% levels of significance respectively*

The difference in the mean value is consistent with the a priori expectation. This means the decade's means of average annual bright sunshine duration value of 6.05 hours (1991-2000) is significantly different from that of 6.24 hours (2001-10).

3.3 Effect of Climate Change Indicators on Rice Yield

Table 6 presents regression results on the effects of climate change indicators on rice yield in the study area. Linear-log model was used because it gives better estimators and goodness of fit than other models. The coefficient of determination (R^2) shown in the table indicates that 62% of the variations in rice yield is explained by the variations in the previous year's rice yield(Y_{t-1}^{R}), temperature (T_t), rainfall (R_t), variations between maximum and minimum temperature $(VarT_t)$ and rainfall($VarR_t$). The F-statistics also shows that the explanatory variables jointly and significantly affect rice yield. The Durbin-Watson value of 1.85 implies that there is no linear relationship between any of the explanatory variables (no multicolinearity). Additionally, the White test with p-value of 0.042 of the computed chi-square indicates that Heteroskedasticity is absent. This implies that the variance of the error term is constant.

Table 6: Yield Response to Climate Change variables

Variable	Coefficients	Std. Error	t-Statistic	Prob.
Y_{t-1}^{R}	0.687	0.082	8.399	0.000*
$\ln(T_t)$	-1.627	1.342	-3.333	0.003*
$\ln(R_t)$	-0.302	0.297	-1.017	0.319
$\ln(VarT_t)$	1.622	0.656	-2.473	0.021
$\ln(VarR_t)$	0.239	0.301	0.792	0.436
C	12.009	13.857	0.867	0.394
R-squared	0.953	Mean dependent var		4.935
Adjusted R-squared	0.945	S.D. dependent var		0.719
S.E. of regression	0.168	Akaike info criterion		-0.581
Sum squared resid	0.704	Schwarz criterion		-0.347
Log likelihood	13.715	F-statistic		126.951
Durbin-Watson stat	1.850	Prob(F-statistic)		0.000

Dependent Variable : Rice Yield (Y_t^R)
Method : Least Squares
Sample : 1981-2010
White Heteroskedasticity-Consistent Standard Error & Covariance

Source: Author's own Calculation
** represent 1% level of significance*

From table 6, the coefficient of previous year's rice yield (Y_{t-1}^{R}) which measures the effects of technological changes on rice yield is consistent with the a priori expectation. It is also significant at 1 % indicating that technological changes significantly affects rice yield. More importantly, average annual temperature (T_t) is consistent with the a priori expectation. It is significant at 1% meaning that average annual temperature has significant effects on rice yield in the study area. Therefore, an extreme increase in temperature reduces rice yield. In the other words, the warmer the climatic conditions, the lesser the rice yield, in this study, the variations between minimum and maximum temperatures do not have significant effects on rice yield.

4. Conclusions and Policy Recommendations

This study determined the empirical evidence of climate change using paired t-test. It also quantified the effects of climate change indicators (rainfall and temperature) on rice yield in Bangladesh. The paired t-test revealed that climate has changed over the past 40 years in terms of significant changes in decade's rainfall, temperatures, relative humidity and bright sunshine duration. The results from the rice yield response regression model indicated that an increase in average annual temperature by 1^0C will decrease rice yield by 0.68 mt/ha.

It is recommended that Bangladesh Rich Research Institute (BRRI) and Non-Governmental Organizations (NGOs) should introduce water conserving measure to farmers to help them keep water for usage during rice production. Farmers should be encouraged to adopt mulching as water conserving measure to reduce the detrimental effects of high temperature on rice in the field. Finally, farmers should be encouraged to plant trees or integrated trees in their rice fields to serve as canopies to reduce the amount of temperature reaching rice plants.

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