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Historical Weather Impacts on *boro* Rice Cultivation in Bangladesh

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Abstract This study examines the past weather impacts on *boro* rice cultivation in Bangladesh including physical input variables to explore the impacts of weather. A cross-sectional time series dataset over 44 years consisting climate variables, non-climatic factors, and *boro* rice yield across seven climatic zones of the country is used for the present study. Employing a panel data regression model, findings reveal that average temperature reduces *boro* yield growth whereas seasonal rainfall improves it. All the physical input variables have positive and significant impacts on *boro* cultivation. However, the contribution of non-climatic factors is much higher than that of climate variables. Finally, physical inputs should get emphasized to include crop-climate model to estimate the exact impact of climate change on *boro* yield growth.

Keywords: *climate change, physical inputs, boro rice yield, Bangladesh*

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1. Introduction

According to the Economic Review of Bangladesh, the volume of production different food grains was much lower than that of present days, even though Bangladesh is predominantly and agriculture-based country. With the adoption of green revolution, the production of food grain has increased dramatically over time [1]. Agriculture sector contributes about 17 percent to the country's GDP and employs more than 45 percent of total labor force [2,3]. Of all agricultural crops, rice is placed in the leading order by contributing 74.85 percent of total crop agriculture subsector [2]. Moreover, among three rice (*aus, aman, boro*), only *boro* is responsible for 41.94 percent production of the country [2]. However, this quantity is not sufficient to feed the country's population that continues to grow whereas the arable land is declining due to urbanization and increasing industrialization. Thus, food security in Bangladesh is still a challenge. Furthermore, the impacts of climate change added a greater magnitude to this challenge of the country. Anthropogenic warming and greenhouse gas concentrations are main felons for increasing the temperature with declining precipitation of world's climate [4]. In addition, rice production is one of the most susceptible sectors to climate change in Bangladesh [5].

A number of researcheshave been conducted to examine the impacts of climate change on crop production in globally and locally. Most of them are based on indirect crop simulation models [6-11]. Few are found on direct assessment using regression models [5,12-19]. These studies did not consider the factors including modern varieties, use of fertilizer and chemicals, irrigation, better farm management, and so on, which have substantial role in crop yield growth. Thus, the net impacts of climate change still remain uncertain. A study conducted by You et al., [20] emphasized to find the impact of growing season temperature considering non-climatic factors on China's wheat productivity. They found that the impact of temperature is negatively significant to wheat yield but it is insignificant when omitting physical inputs from the model. The contribution of temperature is relatively low compared to the use of physical inputs. Another study of Barnwal and Kotani [21] characterized the climate change impacts on rice yield distributions in Andhra Pradesh, India. They also consider physical inputs: fertilizer, and irrigation. By conducting quantile regression, they showed fertilizer is positively significant for *rabi* rice crop and irrigation is for *kharif* rice crop.

Although some empirical investigations such as Sarker et al. [18,19] found in Bangladesh, they just have explored the relationship between climate change and rice yields, ignoring the importance of physical inputs. Considering the above mentioned factors, this is the first study of its kind in Bangladesh. The ultimate objective of this study is to find out the relative importance of non-climatic factors over climate variables on *boro* rice cultivation. At first, a regression model is employed to assess the impact of climate change and physical inputs on *boro* yield. Then, it investigates the impact of climate variables ignoring physical inputs. Finally, this study compares the impacts between them with summary conclusions and some policy implications.

2. Methodological Framework

Bangladesh can be categorized into seven climatic zones: south-eastern zone, north-eastern zone, northern part of the northern zone, north-western zone, western zone, south-western zone, and south-central zone [22]. Each zone consists of several districts of the country which clarifies in Table 1. In addition, Figure 1 represents the study locations.

Table 1. Climate zones of Bangladesh along with districts

Regions	Covering districts	% of *boro*rice area of Bangladesh
South-eastern	Chittagong, Bandarban, Khagrachhari, Cox's Bazaar, Patuakhali	4.34
North-eastern	Sylhet; Moulvi Bazar; Sunamganj; Habiganj	8.12
Northern part of the north	Rangpur, Nilphamari, Lalmonirhat, Kurigram, Gaibandha, Thakurgaon, Panchagarh	11.24
North-western	Dinajpur; Bogra; Joypurhat; Sirajganj; Natore; Pabna; and Kushtia	19.33
Western	Rajshahi; Naogaon; and Nawabganj	8.46
South-western	Khulna; Jessore; Faridpur; Rajbari; and Narail	15.85
South-central	Dhaka, Mymensingh, Barisal, Commilla, Tangail, Gazipur, Narayanganj, Narsindi, Gopalganj	24.57

Source: Rashid [22].

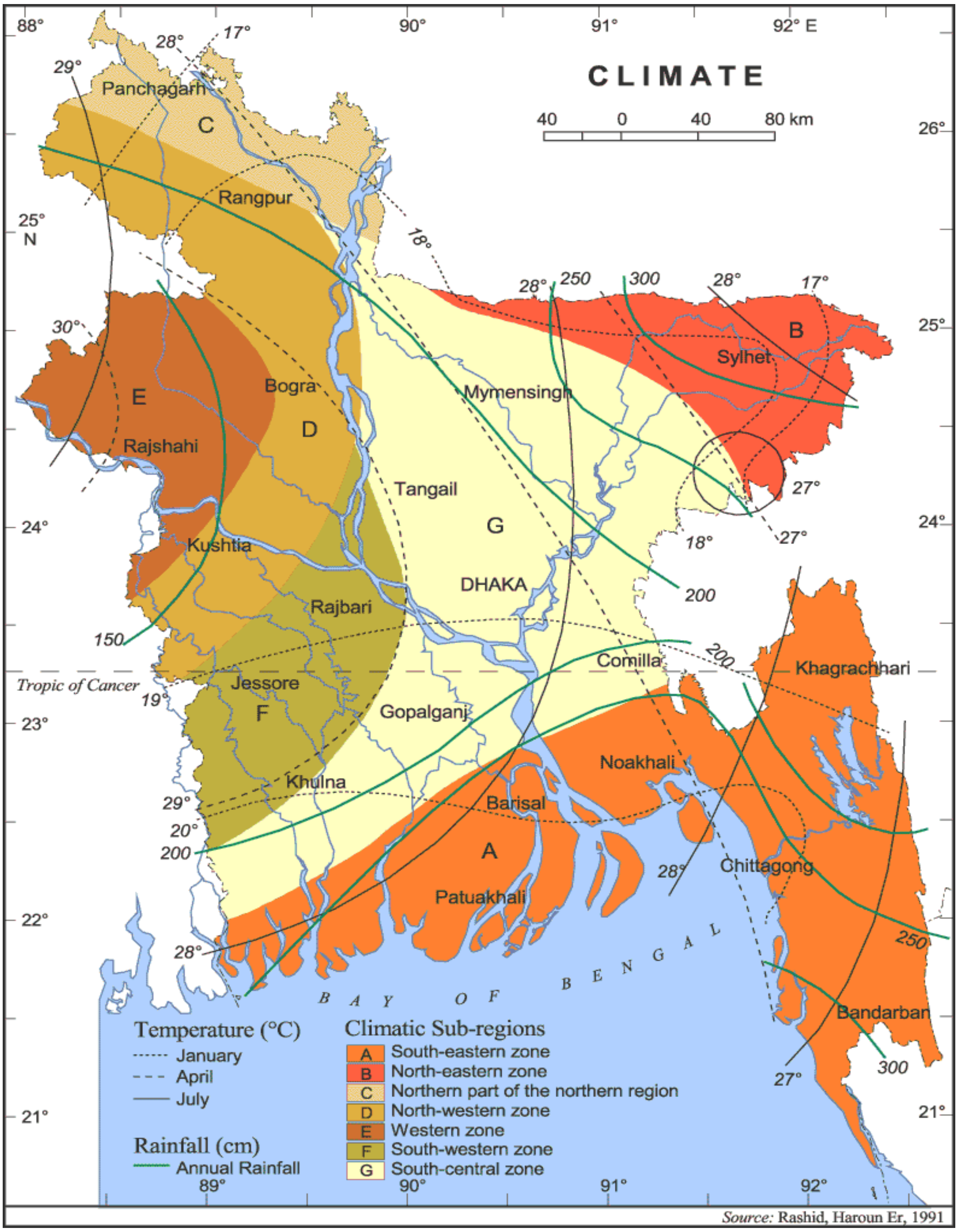

Figure 1. Climate zone map of Bangladesh (*Source*: Rashid [22])

The study is based on cross-sectional time series data of all the climate variables, non-climate factors, and *boro* rice yield from 1972 to 2016 for these seven different climatic zones. Daily records of weather data: maximum temperature (°C), minimum temperature (°C) and rainfall (millimeter) are from the Bangladesh Meteorological Department. Maximum and Minimum temperatures are taken as daily average temperature and diurnal temperature range (daily maximum temperature – daily minimum temperature). Then all climate parameters of daily average temperature, diurnal temperature range and daily rainfall are converted to monthly figure. Finally, two temperature variables are calculated as seasonal averages with seasonal total rainfall according to the growing (sowing – harvesting) period of *boro* rice. The sowing time of *boro* starts in December and the harvesting time ends in June of next calendar year [2]. *Boro* rice yield and non-climatic factors: fertilizer, seeds, pesticide, machinery, and irrigation are collected from the various issues of Yearbook of Agricultural Statistics of Bangladesh. The yield is measured in the unit of ton per hectare (ton/ha) whereas the non-climatic factors (physical inputs) are measured in costs per harvested area. The selection of physical inputs is based on the level of statistical significance. Moreover, to remove dummy variable trap six regional dummies are added for seven climatic zones. These are used to capture the social, economic, and natural differences across the zones. Finally, a time trend variable is also taken to represent technological advancement.

A Cobb-Douglas functional form of the regression model is specified for *boro* rice yield, as follows:

$$\begin{aligned}&\text{boro yield}_{it}\\&=\alpha_0+\alpha_1\text{average temperature}_{it}\\&+\alpha_2\text{diurnaltemperature range}_{it}\\&+\alpha_3\text{seasonal rainfall}_{it}+\alpha_4\text{fertilizer}_{it}\\&+\alpha_5\text{seeds}_{it}+\alpha_6\text{pesticide}_{it}+\alpha_7\text{machinery}_{it}\\&+\alpha_8\text{irrigation}_{it}+\alpha_9\text{trend}_{it}\\&+\alpha_{10}\text{south eastern}_i+\alpha_{11}\text{north eastern}_i\\&+\alpha_{12}\text{northern part of the north}_i\\&+\alpha_{13}\text{north western}_i+\alpha_{14}\text{western}_i\\&+\alpha_{15}\text{south western}_i+\varepsilon_{it},\end{aligned}$$

Where,
i = climatic zones
t = 1972 – 2016
α = intercept
ε = disturbance term.

Every variable is log transformed before employing feasible generalized least squares (FGLS) estimation method. The FGLS give the best results for big dataset, as is the condition here [19].

3. Results and Discussions

Dataset with 20 years' time span or more should probably be tested for stationary checking [14]. As our dataset is of more than 20 years, therefore, Augmented Dickey-Fuller (ADF) test is employed here to test whether there is presence of unit roots for each variable. The estimated results in Table 2 propose that all variables are stationary at levels.

Table 2. Unit root test results

Variables	ADF test statistic (*p*-value)
boro yield	68.37(0.000)
average temperature	25.18(0.000)
diurnal temperature range	23.12(0.000)
seasonal rainfall	32.41(0.000)
fertilizer	34.96(0.000)
seeds	46.13(0.000)
pesticide	32.29(0.000)
machinery	63.27(0.000)
irrigation	76.82(0.000)

Hypothesis under ADF test: H_0: All panels contain unit roots; H_1: At least one panel is stationary.

Now, both fixed – effects and random – effects estimations are applied in linear Cobb – Douglas functional form, and found very little variation. Nonetheless, Table 3 reports only fixed – effects model estimation results which are more reliable by rejecting any possibilities of correlation between regressors and time invariant distinctiveness.

Table 3. Estimated model coefficients of *boro* rice yield

Explanatory variables	Coefficients	*p*-value
average temperature	-0.807***	0.009
diurnal temperature range	0.026	0.124
seasonal rainfall	0.077**	0.027
fertilizer	0.046**	0.023
seeds	0.085*	0.076
pesticide	0.061*	0.057
machinery	0.032**	0.044
irrigation	2.443***	0.001
trend	0.184***	0.000
south-eastern	0.047	0.618
north-eastern	0.012	0.325
northern part of the north	0.058*	0.099
north-western	0.031*	0.072
western	-0.022***	0.006
south-western	0.019*	0.064
south-central	Omitted to avoid dummy variable trap	
constant	8.207***	0.000
Model statistics		
adjusted r^2	0.59	

Significance levels for coefficients are represented as *$p< 0.10$; **$p< 0.05$; and ***$p< 0.01$.

The higher adjusted r^2 denotes fitness of the model. All the non-climatic factors positively statistically significant to the *boro* rice yield. That means physical inputs (fertilizer, seeds, pesticide, machinery, and irrigation) improve *boro* rice growth. The coefficient of irrigation has the highest magnitude in increasing boro rice yield. It is expected because *boro* rice in Bangladesh is completely dependent on irrigation. The time trend which stands for technological progress is also positively associated with *boro* cultivation at 1% level of significance. Significant regional dummies in the result demonstrate different management practices and soil quality by zones. However, average temperature has a significant negative impact while seasonal rainfall has a significant positive impact on *boro* rice yield. Since our major focus is to eliminate the role of non-climatic factors from genuine climatic impacts on *boro* rice yield, defining *boro* yield^{CC} as

$$\begin{aligned}
&\text{boro yield}^{CC} \\
&= \text{boro yield}_{it} - \alpha_0 - \alpha_4\text{fertilizer}_{it} \\
&-\alpha_5\text{seeds}_{it} - \alpha_6\text{pesticide}_{it} - \alpha_7\text{machinery}_{it} \\
&-\alpha_8\text{irrigation}_{it} - \alpha_9\text{trend}_{it} \\
&-\alpha_{10}\text{south eastern}_i - \alpha_{11}\text{north eastern}_i \\
&-\alpha_{12}\text{northern part of the north}_i \\
&-\alpha_{13}\text{north western}_i - \alpha_{14}\text{western}_i \\
&-\alpha_{15}\text{south western}_i,
\end{aligned}$$

Where, CC = *boro* yield change due to climate change (average temperature, diurnal temperature range, and seasonal rainfall).

Therefore, no significant effect of climate variables is found to *boro* yield while excluding non-climatic factors in the regression model. Moreover, the calculated picture of actual contribution for climate variables and non-climatic factors to *boro* yield growth is depicted in Table 4.

Here, the percentage growth for each variable is calculated from 1972 to 2016. Then, contribution to growth is calculated by multiplying percentage growth to coefficient (from Table 3) for every variable, and the values in parentheses represent the percentage shares of contribution to total *boro* yield growth. The growth is 43.01% of total *boro* yield. It shows that better use of non-climatic factors contribute 115.49% share of total growth while climate variables account for 15.49% yield decline (Table 4). Figure 2 portrays the share of climate variables and physical inputs to *boro* rice cultivation, at a glance.

The positive contribution of non-climatic factors is comparatively higher than the negative role of climate variables. Finally, these findings warrant considering input adequate non-climatic beneficial factors to crop yield growth with climate risk mitigation.

Table 4. Parameters' contribution to *boro* yield growth.

Explanatory variables	Coefficients	% growth (1972 to 2016)	Contribution to growth
average temperature	-0.807	7.89	-6.37 (-14.80)
diurnal temperature range	0.026	1.42	0.04 (0.09)
seasonal rainfall	0.077	-4.34	-0.33 (-0.78)
total climate			-6.66 (-15.49)
fertilizer	0.046	413.33	19.02 (44.20)
seeds	0.085	171.02	14.54 (33.80)
pesticide	0.061	285.46	17.42 (40.48)
machinery	0.032	132.37	4.23 (9.85)
irrigation	2.443	-2.26	-5.52 (-12.84)
total non-climate			49.68 (115.49)
total growth		43.01	43.01 (100)

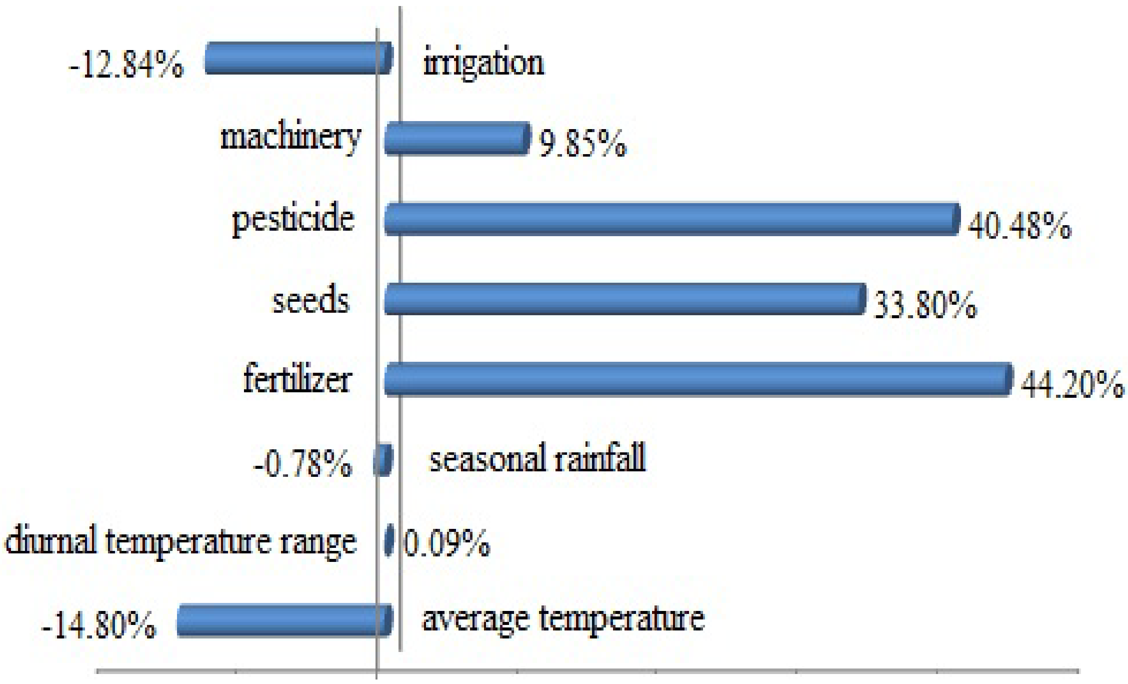

Figure 2. Percentage contributions of related parameters to *boro* rice cultivation

4. Conclusions

This research highlights the significance of inclusion of physical inputs with climate variables to disclose the accurate phenomena of rice-climate dealings. For this purpose, this study uses 44 years of climate variables, physical input variables, and *boro* rice yield data. Employed panel data regression model presents that average temperature significantly declines yield growth while seasonal rainfall improves it. All the non-climatic factors dramatically increase *boro* rice cultivation. However, the model shows that the contribution of physical inputs is larger in amount than that of climate variables. Furthermore, the model does not fit when the analysis is conducted ignoring physical inputs, screening lower adjusted r^2. This study also finds the higher share of non-climatic factors relative to climate variables to the total growth of *boro* rice.

Since *boro* is an intensely irrigated crop, the percentage of irrigation to growth shows downward trend, because western Bangladesh is becoming drought-prone and groundwater-depleted area [23]. Emphasis should be given to improve irrigation in Bangladesh for *boro* cultivation. Uses of surface water for irrigation are the best option in Bangladesh when the country is suffering from ground water depletion. Alternating Wetting and Drying (AWD) technology could be the congenial option for this regard. As Bangladesh's crop productions vary across region, research should get emphasized on region-specific. This will help to the progress of local level adaptation strategies to climate change. Finally, strengthening government support is required through various educational and training programs for local poor farmers to enhance agronomic and crop management practices.

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