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Identifying the Threshold Level of Flooding for Rice Production in Bangladesh: An Empirical Analysis

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Abstract

Flood is responsible for the agricultural production scheme and livelihood well-being in Bangladesh. It is the most frequent catastrophe that affects crop production in terms of area coverage and yield. However, a normal flood is beneficial for the ecology and environment. As rice is the most important crop for sustaining the food security of the country, this study identified the threshold level of flooding for rice area coverage and production. The study used the time series data of annual rice area coverage, production, and flooding area in a well-established threshold regression model. The empirical results expose that flooding 22 percent of the geographical area is the threshold value for rice area coverage and production in Bangladesh. Up to the threshold level (22 percent), a one square kilometer increase in flooding would increase the rice area coverage by 31 hectares, as flooding would bring more land under cultivation. Beyond the threshold limit, a one square kilometer increase in flooding would reduce the rice area coverage by 2 hectares. On the other hand, the production of rice would increase by 492 tons with a one square kilometer increase in flooding up to the threshold limit. However, the rice production would reduce by 70 tons if a one square kilometer increase flooding above the threshold limit. On top of that, both the rice area coverage and production showed increasing trends with the increase in flooding level in the last few years. The reasons behind this are- government supports, subsidies, incentives, and stress coping strategies towards accelerating national production to overcome the effects of the flood to sustain national food security; development of stress-tolerant and high yielding modern rice varieties by the research organizations; and replacing the local varieties with these modern varieties by the farmers and extension workers in Bangladesh.

Introduction

Geographically, Bangladesh exists between 20°30′ and 26°40′ north latitude, and 88°03′ and 92°40′ east longitude of the globe. It is one of the world's largest functional deltas with an area of about 1,47,570 square kilometers (FFWC, 2019). Indian boundary surrounds the west, north, and part of the east, and some of the southeastern borders is Myanmar, and the Bay of Bengal is to the south. The country is in a subtropical monsoon climate; the annual usual rainfall is approximately 2,300 mm, ranging from 1,200 mm in the northwest to above 5,000 mm in the northeast (FFWC, 2019). It has 405 rivers, 57 of which are trans-boundary, 54 of which originated in India including three main rivers - the Ganges, the Meghna, and the Brahmaputra. The other three rivers have been originated from Myanmar (FFWC, 2019). Climate change is the actual fact and Bangladesh is one of the world's most vulnerable nations. The intensity and frequency of extreme events, related to climate change, are rising day by day. Amongst the natural hazards, flood is the most frequent one in the country. Bangladesh is certainly a low-lying country that stands at the foot of the Himalayan Mountains. The main causes of flooding in Bangladesh mentioned in Choudhury and Chairman (2001) are- i) access rainfall, ii) Himalayan snow melting, iii) Brahmaputra basin's hydrographic changes, iv) every year, 2.4 billion tons of sediments transported by Bangladesh's river flow, decreases the water carrying ability of rivers, which aggravates flooding, v) deforestation in catchment areas tends to worsen flooding, and vi) construction of unplanned roads, highways, dams, embankments, etc. often build barriers to water flow and aggravate flooding.

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On top of that, heavy rainfall and flooding in nearby northern countries of Bangladesh trigger a flash flood. The country has different flood-prone areas, such as flash flood-prone areas, river flood-prone areas, and tidal surge prone areas. The flood-prone areas are also categorized as low, moderate, and severe according to the intensity of flooding (Figure 1).

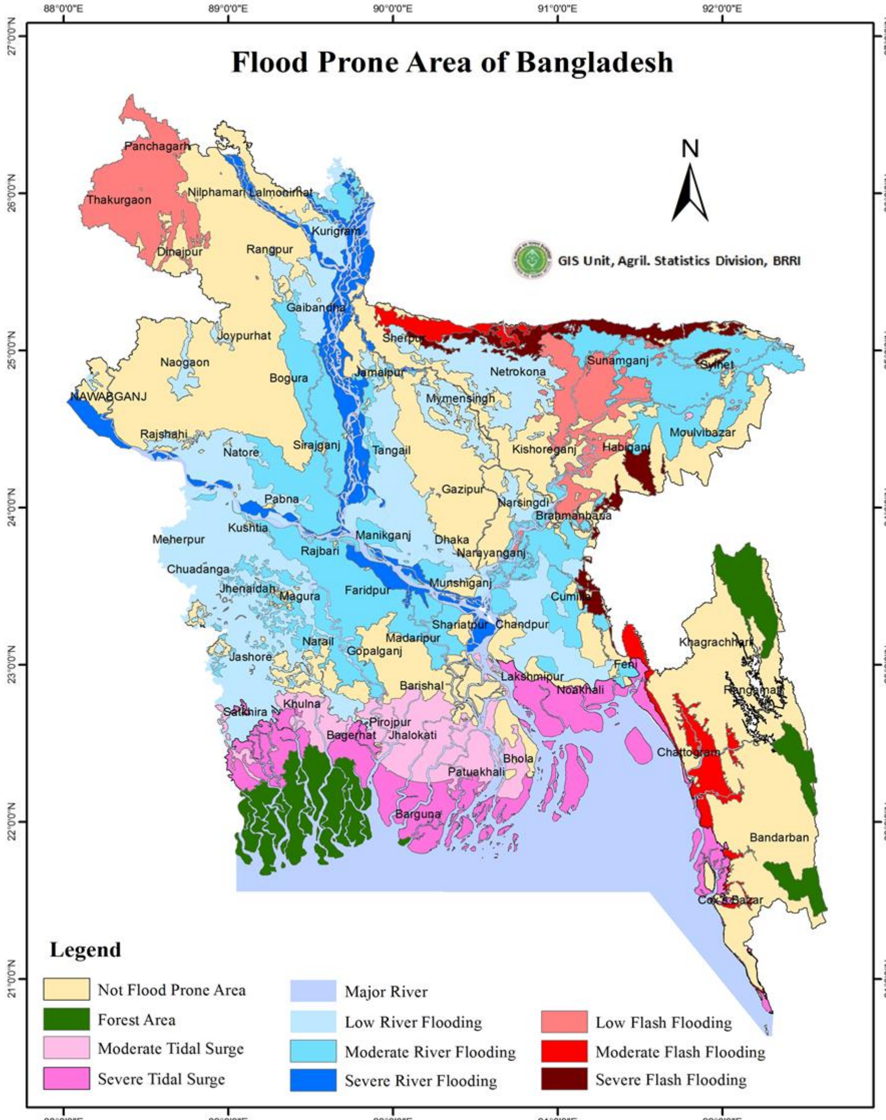

Figure 1. Flood-prone areas in Bangladesh. The map has been developed in the GIS lab of the Agricultural Statistics Division of Bangladesh Rice Research Institute based on the information from the Bangladesh Agricultural Research Council. Low flood = flooding below the danger level within 50 centimeters; Moderate flood = flooding at and above the danger level up to 1 meter; Sever flood = flooding more than 1 meter above the danger level; the danger level varies according to the rivers and infrastructure (www.ffwc.gov.bd).

In addition to the dwellings flood mainly affect the country's crop field. Bangladesh stands third in terms of rice production among the rice producing countries of the world (The daily sun, 2020; IndexMundi, 2020). Rice is Bangladesh's most dominant crop, which covers a crop area of about 75 percent (Rahaman *et al*., 2020; Islam *et al*., 2019). It is the staple food of about 165 million people in the country (Siddique *et al*., 2017; BER, 2019). Rice production is therefore of great importance to Bangladesh's political and agricultural economy, and rice price is a critical factor for GDP growth rate, inflation, wages, employment, food security, and poverty (Rahman *et al*., 2020). At various climatic conditions, rice production is affected by different biotic and abiotic stresses (Rahman *et al*., 2015a; Rahman *et al*., 2013; Rahman and Rashid, 2013). The abiotic stresses, mostly rice faces in a crop cycle are submergence (flood), drought, salinity, and cold (Jena *et al*., 2015; Rahman *et* *al*., 2015b). As already stated, the flood is the most prevalent catastrophe in Bangladesh, the government takes certain steps to sustain agricultural production and maintain the fair farm-gate price to ensure the income of the producer and national food security. Ministry of Agriculture and its organizations, therefore, stand with the farmers with all the appropriate technologies to mitigate the impact of the flood and hold farm production up.

The Ministry of Food also performs in the market by procuring food grains at pre-declared farm-gate prices. Although the amount of rice procurement is very low (5-7 percent of national production), its successful implication has a small influence on the rice marketing, stocking, and pricing system in Bangladesh (Rahman *et al*., 2020). Bangladesh produces several flood reports so far. Hossain *et al*. (2017) conducted a satellite image-based survey of the affected region and crop damage due to the flash flood in the *haor* basin in Bangladesh. Mahtab *et al*. (2018) simulated the rainfall in the *haor* area during the 2017 flash flood to predict the possible inundated location in the near future. A hydro-meteorological analysis of the 2015 flash flood in the eastern hill basin of Bangladesh found the cause of the flash flood as the excess rainfall in the consecutive days of the last week of June of that year (Hossain *et al*., 2016). These studies focused on specific events to assess the cause and effect of the flood in a specific location. However, a countrywide historical assessment of the impact of the flood on the main staple (rice) is necessary to plan for ensuring food security for the nation. For this, a question arises, until what level of flooding is not harmful for rice production? The flood is not always harmful, even it has some useful effects on agricultural production (Hassan, 2019). In normal flooding, farmers' cropping practices become well adapted, and in a damaging flood, the water rises earlier, higher, more rapidly, or later than farmers expect when they decide which crops to grow on their different types of land (Brammer, 1990). Monsoon flood inundation of about 20-25 percent area of the country is assumed beneficial for crops, ecology, and environment (FFWC, 2019; Islam *et al*., 2017). Because floods provide water for crop cultivation, restore the groundwater level, restock soil quality, and provide water for the fisheries. However, the saturation of well over that triggers devastating effects, i.e. significant property damage; large loss of land area coverage, crops, livestock, poultry, etc.; human misery; and the grinding poverty of the poor (FFWC, 2019). A normal flood usually inundates 10-20 percent of areas of the country for three weeks or less, depth of the standing water is one to two meters in most areas of the floodplain, and it is three meters in the low-lying areas. Whereas an abnormal flood inundates at least 35 percent of areas of the country for a period of at least one month, the depth of the standing water is more than two meters in most areas of floodplain, and it is more than three meters in the low-lying areas (Banerjee, 2010). The aforementioned studies mentioned the range of flooding levels to be beneficial for crops, livestock, fisheries, and forestry. However, empirical identification of specific crop-wise threshold levels is absent in the literature. Therefore, it is important to identify the threshold level of flooding for the most important and most flood prone crop of Bangladesh (such as rice). Aiming out this, we have designed this study to investigate the year-wise flooding level and the effect of the flood on rice area and production in Bangladesh using an econometric method.

Methodology

Concept of flood and production nexus

Flood impacts rice production in two sequential ways. It affects the rice area coverage and yield, both of these have a direct impact on rice production (Hassan, 2019). On the other way, it can be stated that rice production is the function of area coverage and yield. Flood has a direct effect on crop area coverage. A massive inundation can reduce the crop area significantly which would affect the total production. Inundation for a longer period also affects the area coverage of a crop. However, the stress of massive flood and inundation for a longer period has a direct impact on the yield of the specific crop that has a consequence on the production of the crop (Figure 2).

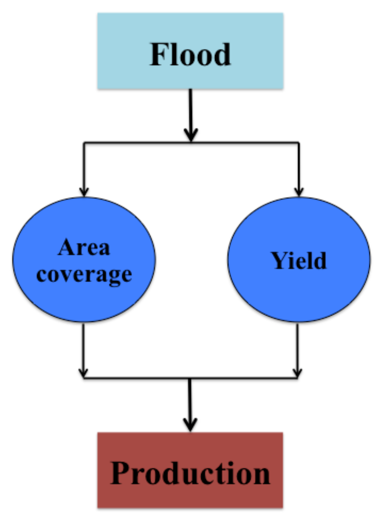

Figure 2. Concept of the effect of flood on crop production

Data source

The data on the annual flood-affected area of Bangladesh has been collected from the annual flood report of the Bangladesh Water Development Board (BWDB). The year-wise rice area and production data are available in the ministry of agriculture, Department of

Agricultural Extension (DAE), and Bangladesh Rice Research Institute's (BRRI) websites.

Empirical model

As already stated, each year flood affects Bangladesh, a threshold-flooding limit is important to figure out so that we can easily recognize the devastating flood-affected years. For this, the well-known threshold regression model on time series data has been implemented in this study. Recognizing Hansen (2011) for a review of threshold regression models in economics, we consider a threshold regression with two regions outlined by a threshold $\mathfrak{T}$ that can be written as:

$$y_t = x_t\beta + z_t\delta_1 + \epsilon_t \quad \text{if } -\infty < w_t \leq \mathfrak{T}$$
$$y_t = x_t\beta + z_t\delta_2 + \epsilon_t \quad \text{if } \mathfrak{T} < w_t < \infty$$

Where, y_t is the dependent variable, x_t is a $1 \times k$ vector of covariates feasibly including lagged values of y_t or another explanatory variable, β is a $k \times 1$ vector of region-invariant parameter, z_t is a vector of exogenous variables with region-specific coefficient vectors δ_1 and δ_2, w_t is a threshold variable that can also be one of the variables in x_t or z_t, and ϵ_t is an IID (Independently and Identically Distributed) error with mean 0 and variance σ^2.

The parameters of concern are β, δ_1, and δ_2. Region 1 is defined as the subsection of observations in which the value of w_t is less than or equal to the threshold $\mathfrak{T}$. Similarly, Region 2 is defined as the subsection of observations in which the value of w_t is beyond the threshold $\mathfrak{T}$. Inference on the threshold parameter $\mathfrak{T}$ is problematic due to its inferior asymptotic distribution (Hansen, 2000). The estimated threshold ($\hat{\mathfrak{T}}$) is one of the values in the threshold variable w_t. In order to estimate the threshold, we minimize the least squares of the following regression of T observations and two regions,

$$y_t = x_t\beta + z_t\delta_1 I(-\infty < w_t \leq \mathfrak{T}) + z_t\delta_2 I(\mathfrak{T} < w_t < \infty) + \epsilon_t \text{ .... (1)}$$

for a sequence of T_1 values in w_t, where $T_1 < T$. The default trimming percentage is set to 10%, which implies that T_1 corresponds to the number of observations between the 10th and the 90th percentile of w_t. The estimator for the threshold is

$$\hat{\mathfrak{T}} = \arg min_{\mathfrak{T}\in\Gamma} S_{T_1}(\mathfrak{T})$$

where $\Gamma = (-\infty, \infty)$,

$$S_{T_1}(\mathfrak{T}) = \sum_{t=1}^{T}\{y_t - x_t\beta - z_t\delta_1 I(-\infty < w_t \leq \mathfrak{T}) - z_t\delta_2 I(\mathfrak{T} < w_t < \infty)\}^2$$

is a $T_1 \times 1$ vector of SSR (sum of squared residual), and $\mathfrak{T}$ is a $T_1 \times 1$ vector of tentative thresholds.

In our analyses, we estimated two regressions with equation (1). In one regression, the dependent variable is the 'rice area' and the region-specific variable is the 'flooded area', where the threshold variable is the 'percent of the total area flooded'. In the other regression, the dependent variable is the 'rice production' and the region-specific variable is the 'flooded area', where the threshold variable is the 'percent of the total area flooded'.

Results

Threshold regression: identifying threshold flooding level and the consequences of flood on rice area and production

The estimated threshold regressions results reveal that the threshold flooding level of Bangladesh for rice production is 22 percent of the total geographical area. The value of the coefficient of the flooded area as region 1 variable of the regression 1 is 0.031. This means that up to 22 percent of the total area, every one square kilometer increase in flooding area would lead to an increase in the rice area by 31 hectares.

Table 1. Results of the threshold regressions

Threshold value: 22%		**Threshold variable: Percent of the total area flooded**				
Regression 1	Dependent variable: Rice area (000 ha)					
		Variables	Coefficient	Standard Error	z-value	p-value
	Region 1	Flooded area (Sq. km.)	0.031**	0.015	2.080	0.037
		Constant	10155.94	223.846	45.370	0.000
	Region 2	Flooded area (Sq. km.)	-0.002*	0.001	-2.00	0.069
		Constant	10564.83	254.615	41.49	0.000
Regression 2	Dependent variable: Rice production (000 ton)					
		Variables	Coefficient	Standard Error	z-value	p-value
	Region 1	Flooded area (Sq. km.)	0.492**	0.235	2.094	0.043
		Constant	20193.77	4444.870	4.540	0.000
	Region 2	Flooded area (Sq. km.)	-0.070*	0.039	-1.795	0.053
		Constant	22660.53	2826.282	8.020	0.000

Notes: Sq. km.= Square kilometer, 000 ha= thousand hectares, and 000 ton= thousand tons. Superscript '**' and '*' represent significant at 5 percent and 10 percent level, respectively. Prepared by the authors based on the threshold regression results generated by STATA14 software. The instruction of estimating the threshold regression model is available in the STATA library.

The coefficient of the region 2 variable reveals that beyond the threshold level (22 percent), a one square kilometer increase in flooding area would reduce the rice area by 2 hectares. The value of the coefficient of the region 1 variable in regression 2 is 0.492. This means that up to the threshold level, a one square kilometer increase in flooding area would lead to a 492 tons increase in rice production. In contrast, the coefficient of the region 2 variable represents that above the threshold level, a one square kilometer increase in flooding area would reduce rice production by 70 tons (Table 1).

Discussion

The finding of this study is very relevant to the existing literature. According to Islam *et al*. (2017) and FFWC (2019), inundation of about 20-25 percent area of the country by monsoon flood is assumed beneficial for crops, ecology, and environment, inundation of more than that may cause direct and indirect harms and significant problems to the socio-economic status of the population. As already mentioned, floods are affecting Bangladesh almost every year. The level of flooding is increasing from the recent (2014-2020) years (Figure 3).

Along with the increasing trend (overall at the rate of 1.63 percent per year) of flooding level, the rice area coverage and production are in increasing trends (Figure 4). Overall rice area coverage and production increased at the rate of 0.32 percent and 2.84 percent per year, respectively during 1971-2019. The increasing rate of rice production was 2.56 percent during 1971-1995, whereas it became 3.13 percent during 1996-2019 due to the adoption of high yielding modern rice varieties. The country is producing around 38 million tons of rice annually, whereas it was around 10 million tons during 1971-72 (Figure 4). The reason behind this is the government's strategy to accelerate rice production by addressing natural hazards and productivity towards ensuring food security in terms of availability. The scientists have developed potential stress tolerant rice varieties addressing the specific stress prone areas of the country. The Bangladesh Rice Research Institute (BRRI), a pioneer rice research institute of the ministry of agriculture, Bangladesh has released modern and tress tolerant varieties for increasing the rice area and production. The agricultural universities and Bangladesh Institute of Nuclear Agriculture (BINA) also have contributed to boosting the rice production of the country. BRRI along with the Department of Agricultural Extension (DAE) played important role in disseminating the modern rice varieties in the country. The ministry of agriculture has special incentive programs in terms of seed, fertilizer, irrigation, and mechanization to boost rice productivity up and cope with the region specific natural stresses.

The yield of local rice varieties is much lower than that of modern varieties. During 1971-2019, the local rice varieties have been replaced by the modern rice varieties significantly (Figure 5). The adoption of modern rice varieties shows an increasing trend (at the rate of 4.92 percent per year) and that of local rice varieties shows a decreasing trend (at the rate of 4.50 percent per year). It influenced the boosting of national production up. The production from the modern rice varieties increased by 5.83 percent annually, on the other hand, the contribution of local rice varieties in the national production has decreased by 4.5 percent annually (Figure 6).

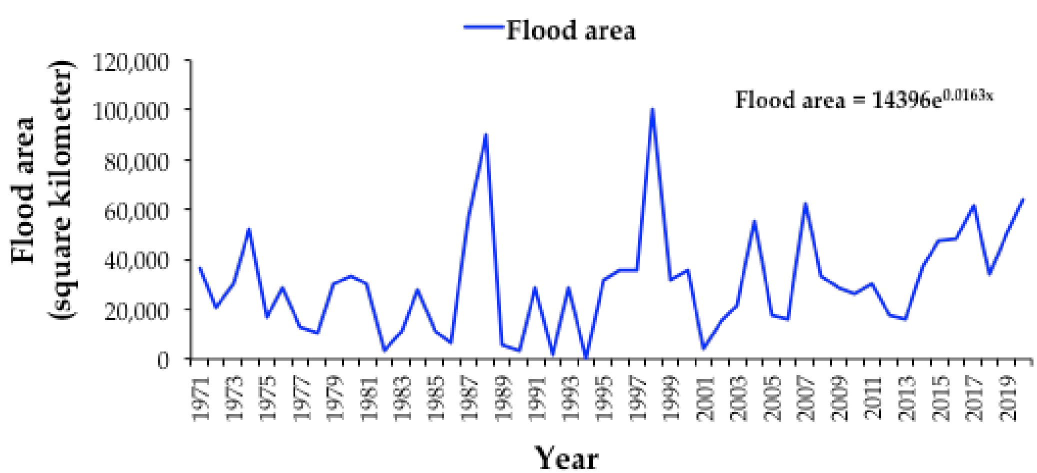

Figure 3. Historical inundated area by flood in Bangladesh (Prepared by the authors, based on the information from BWDB)

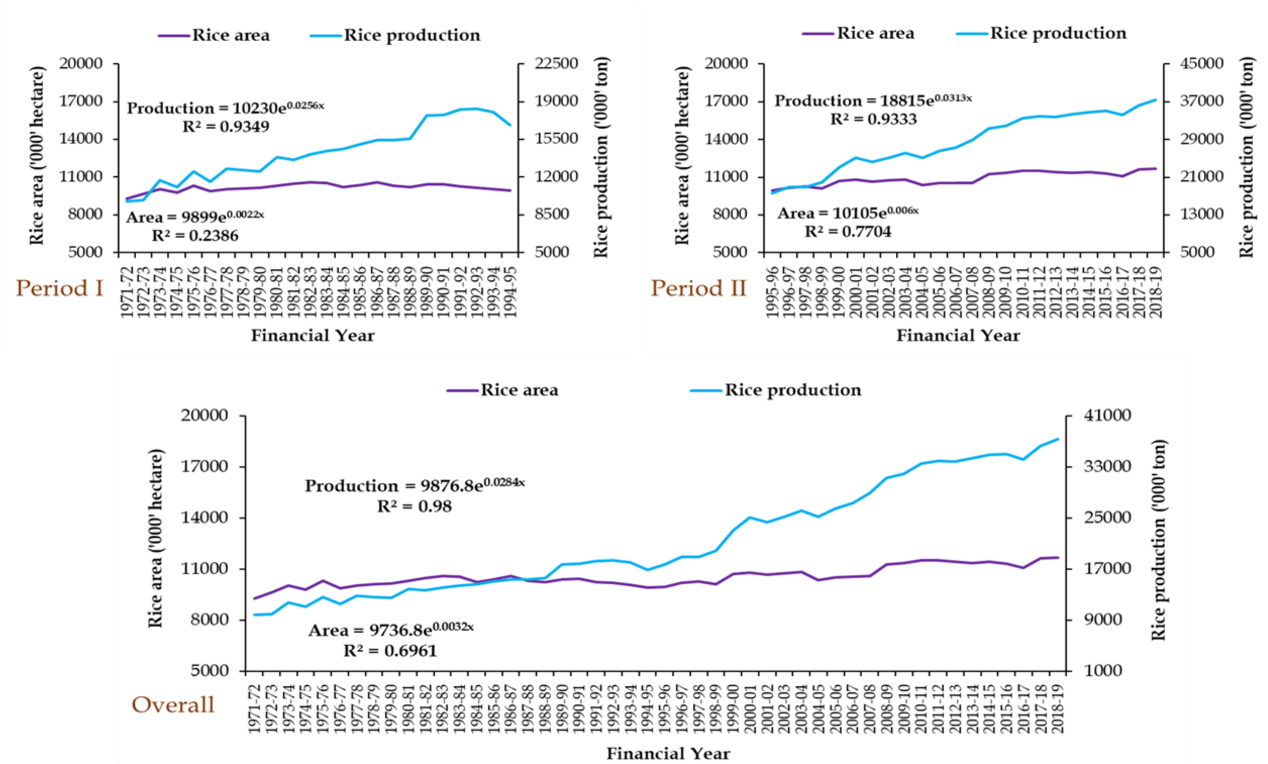

Figure 4. Periodic growth of area and production of rice in Bangladesh (Analyzed and prepared by the authors based on the data from BBS and DAE)

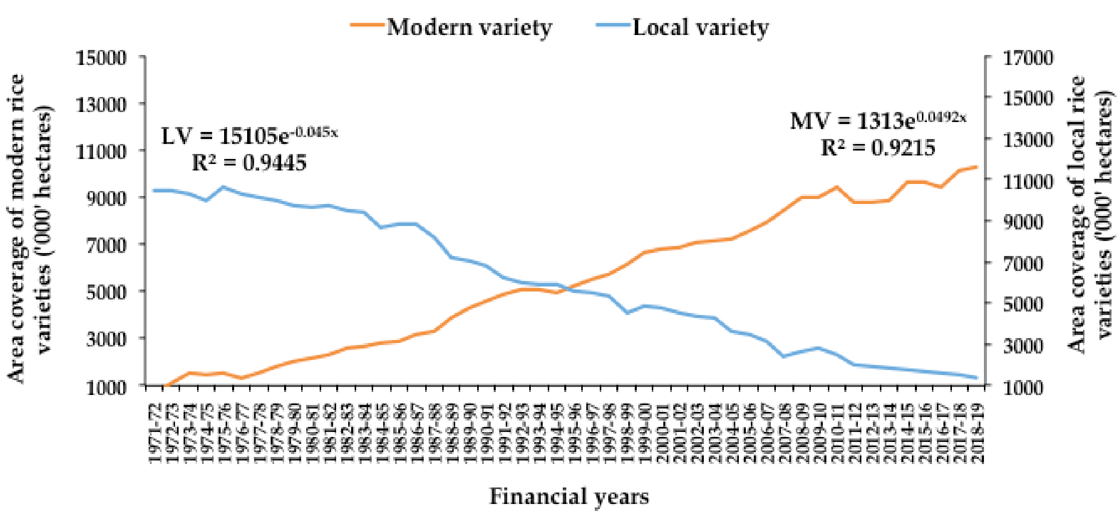

Figure 5. Area coverage of modern and local rice varieties in Bangladesh. Note: Prepared by the authors, based on the data from BBS and DAE. LV and MV represent the local variety and modern variety, respectively.

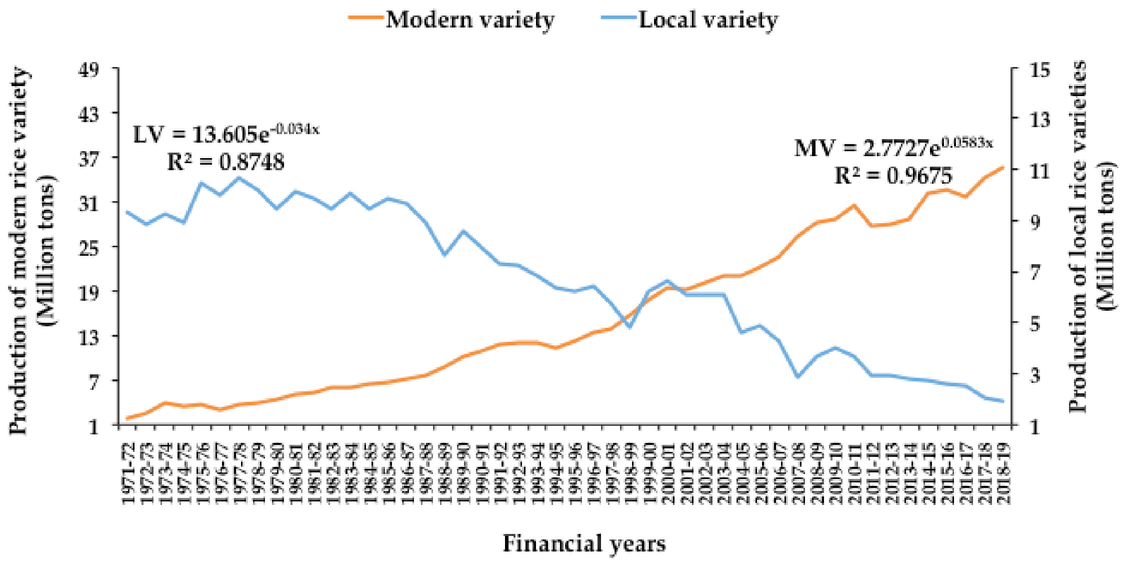

Figure 6. Production from the modern and local rice varieties in Bangladesh. Note: Prepared by the authors, based on the data from BBS and DAE. LV and MV represent the local variety and modern variety, respectively.

Conclusion

This study employed the threshold regression model to do this and found that flooding 22 percent of the geographical area in Bangladesh is not harmful; even beneficial for rice production and area coverage. Flooding beyond this threshold limit (22 percent) would affect the rice area coverage and overall national production. However, the flooding level is increasing day by day in recent years. The area coverage and production of rice are also increasing coping with this common hazard. The reasons behind this are the government strategy and support to sustain rice productivity towards ensuring food security, development and dissemination of stress tolerant and high yielding modern rice varieties, and the adaptation strategies of the farmers, agricultural scientists, and extension workers. The findings of this study would help the policymakers, researchers, extension workers, and farmers to decide whether the flood in a certain year is devastating for rice production or not. It also will direct the policymakers to make a decision about the agricultural subsidy (especially for rice), incentives, and supports to sustain food self-sufficiency in Bangladesh.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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