THESIS

IMPACTS OF FLOODING ON THE RICE PRODUCTION OF BANGLADESH: A PANEL DATA STUDY

Submitted by

S M Kamrul Hassan

Department of Economics

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Master's Committee:

Advisor: Robert Kling

Sammy Zahran
Jude Bayham

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ABSTRACT

IMPACTS OF FLOODING ON THE RICE PRODUCTION OF BANGLADESH: A PANEL DATA STUDY

This paper attempts to measure the impact of flooding on rice production in Bangladesh by using two versions of econometric model, namely a total production model and a yield model. The production model uses tons of production as the dependent variable while the yield model uses the log of yield which has been defined as tons per acre. The findings from the production model suggest the vulnerability of the boro variety of rice, as it appears to have meaningful coefficients with flood damage indicator variables. The spatial dimensions of vulnerability become apparent as some districts appear to have more damaging impacts on several varieties of rice even while the national level estimates do not reveal the fact. But with both negative and positive flooding effects, the overall trend of rice production signifies the resilience and development achieved in this sector. The yield model uses similar variables to the production model but normalizes them and drops some control due to the presence of multi-collinearity. But while this second model has theoretically appealing attributes, the findings are not meaningful or significant as only one of the concerned variables gives the expected effects signs. This puts a caution in the transformation of the variables used in panel data regression.

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1. Introduction

Bangladesh is considered as one of the most natural disaster-prone countries of the world. World Risk Index- 2018 has categorized the country as ‘very high risk’ in terms of exposure, vulnerability and susceptibility to disasters. There are several subtypes of disasters that affect this country but flood is the most common as it overruns other extreme events by the number of affected people and amount of economic damage (EM-DAT, 2019). Flood is defined as the unusual or above surface-water flows that move over the riverbank and inundate the nearby highlands. But flood has also been the part of life of the people because of its intimate connection with agricultural production system. There are two major flood types in Bangladesh. Annual flood or the “*borsha”* is considered as normal incident which is associated with monsoon rainfall and works as blessings for agriculture. On the other, the low frequency floods of high magnitude, the “*bonna”* is considered to be abnormal flood and it is devastating due to its unpredictability, inundation and the losses of life and property (Khalequzzaman, 1993; Paul & Rasid, 1993). Bangladesh has experienced the low frequency high magnitude floods in 1974, 1984, 1987, 1988, 1998, 2004, 2007 and 2017 since its independence. Recently many scientific literatures have been simulating the agricultural losses from the increased frequency of climate change induced hazards. Because of the climatic instability, flooding patterns and frequency will change, and the results can be disastrous for the agricultural sector.

Rice is the staple of nearly 160 million people of this country. The annual population growth rate in Bangladesh is 2 million per year and if this rate persists, total population will become 238 million by 2050. Flood hazard induced vulnerabilities can also create threats on the food security of the people of Bangladesh. On the other hand, the amount of total cultivable land is decreasing by more than 1% per annum due to the construction of industries, housing, and different types of infrastructure. There is no alternative to increase the efficiency of rice production for feeding the overgrowing number of populations in the country. But the incidence of different types of hazards, namely flooding, has become a consistent threat towards achieving food security and sustainable livelihood. Hence, it is important to exactly quantify the impacts of flooding on the rice production in Bangladesh.

This paper attempts to measure the impact of flooding on the rice production by using panel data of rice production, surface water level and several other meteorological variables. One of the major distinctions of the paper is the construction and use of panel data set from 1970-2015. Few of the early studies have tried this method. The Bangladesh Water Development Board (BWDB) observes the daily surface water level across different water stations of the country to predict the flood threats. In this study, we have thoroughly used the danger level and daily surface water level data for the abovementioned time to measure flood conditions. The viability of these kinds of indicators has never been rigorously tested in any study so far. Secondly, most of the previous studies investigated the effects of flooding on the rice production in total or seasonal basis. In this study, we attempt to analyze the impacts based on the seasonality as well as variety. Thirdly, the findings from the study will be helpful for the government to adopt necessary policy initiatives for reducing the vulnerability of the food security of people and increase resilience at the same time.

2. Flood in Bangladesh

2.1 Flood geography of Bangladesh

Flood is the most frequent natural disaster of Bangladesh. The geographical and geological characteristics of the country are primarily considered as the major reasons behind this flood risk and vulnerability. Large scale floods in Bangladesh are caused by a complex combination of large river flows entering the country from upstream catchments, high extreme rainfall over the country and a few other factors (Yang, Ray, Brown, Khalil, & Yu, 2015). Bangladesh is located at the foot of the Himalayan mountain range which is the highest precipitation zone in the world. The country is an active delta and floodplains[1] of the Ganges, Brahmaputra, Meghna (GMB) and smaller rivers occupy about 80 percent of the country (Brammer, 1990). Although the runoff from GMB catchment of 1.76 million square km passes through Bangladesh, only 7.5% of the total catchment area of these three major rivers and their distributaries lies in Bangladesh while the rest of 92.5% lies outside the country.

Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. Regional climatic differences in this country are minor. Four meteorological seasons are recognized as- pre-monsoon (March, April and May), monsoon (June to September), post-monsoon (October and November) and winter (December, January and February). Generally, Pre-monsoon months are hot and humid; monsoon months are humid and rainy, post-monsoon months are quite hot and dry but the winter

[1] A floodplain is made up of flat or nearly flat land that is adjacent to a stream or river and experiences occasional or periodic flooding.(Sultana & Thompson, 2017)

months are cool and dry (Khatun, Rashid, & Hygen, 2016). The monsoon precipitation in the upstream catchment areas also create huge amount of river flows that passes through the narrow

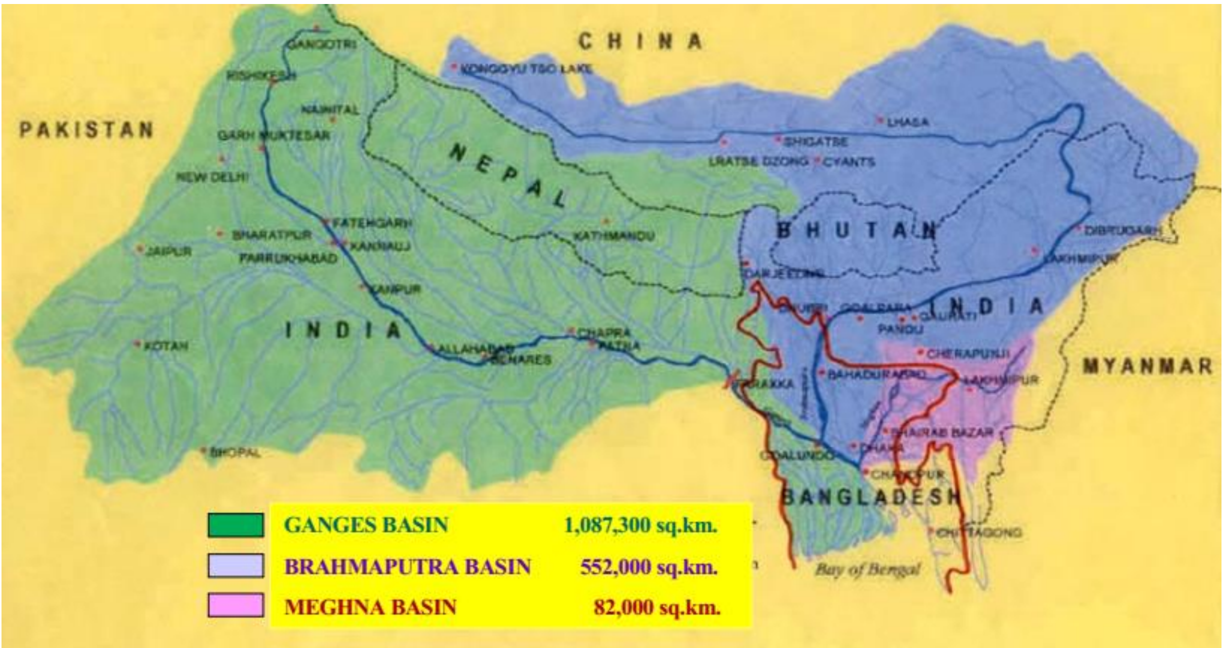

Figure 1: The GMB basin, source: M. M. Hossain (2008)

passages of the country and drains into the Bay of Bengal. At the same time, local precipitation aggravates the condition. Bangladesh experiences about 2300 mm of average rainfall which ranges from 1500 in the western part of the country to about 5000 mm in the north eastern regions. This vast runoff often spills over the riverbank and inundates nearby farmlands as well as localities sometimes. There are also some anthropogenic factors behind flooding. Unplanned construction of embankments in the upstream catchments reduces the capacity in the downstream to store water. Unregulated infrastructures in the floodplain without adequate opening can create obstructions in the natural flows of water. Hence, flood visits Bangladesh on a yearly basis while the devastating floods occur in every 5 to 10 years. The Flood Forecasting and Warning Center

(FFWC) of the Bangladesh Water Development Board (BWDB) is the government mandated organization to monitor the flood situation.

2.2 History of flood in Bangladesh

The literature on the flood history in Bangladesh is not very enriched for the periods before the 1950s. Most of the research have used data about flood incidents after the 1950s. The official documents and statistical information were also being regularly produced from this time. Although some flood research has relied on geological evidence from straight-graphs to trace the patterns of flooding from ancient period. Hofer & Messerli (2006) analyzed the flood history of Bangladesh by classifying it into four phases, namely longer-term geological evolution, the last 20,000 years, the 18th & 19th century, and the 20th century. They have identified the changing patterns of vulnerability and risk during this period frame. The configuration of the Bengal basin has attracted investment from international hydrocarbon exploration agencies, and they have accumulated huge amount of subsurface data. But the access to this data is restricted for most of the researcher. On the other hand, last 20,000 years have experienced interaction between global climate and sea-level, regional tectonic movement and local topographic changes which have dominated the pattern of sediment accumulation in the Bangladesh floodplain over time. Hence the flood dynamics have changed during this long period. Massive flooding happened in some clusters of years, 1770–1790 and 1860–1890, during the 17th and 18th centuries. Scientific analysis reveals that these decades were preceded by phases of low flood occurrence. The district gazettes and different historic descriptions are available on flooding during period. It has been found that flooding in 1769, 1787, 1871, 1885 had created famines, food shortages and chaos in the market price in the country. This clustering of large flood events is supposed to be linked with the changes in monsoon rainfall over the subcontinent and long-term climatic variability on the global scale.

In 1927, Professor Mahalanabis prepared a list of the floods which occurred in between 1870 and 1922 (Younus, 2014). There are no authentic records of floods for the period of 1923–1953. Since 1954, flood events in this region have been relatively well recorded. It is possible, therefore, to be more specific about interpretation and to take a closer look at the trend. Severe and catastrophic floods affecting this region during the period 1954–2017 and the percentage of area inundated by each flood event are shown in the following table.

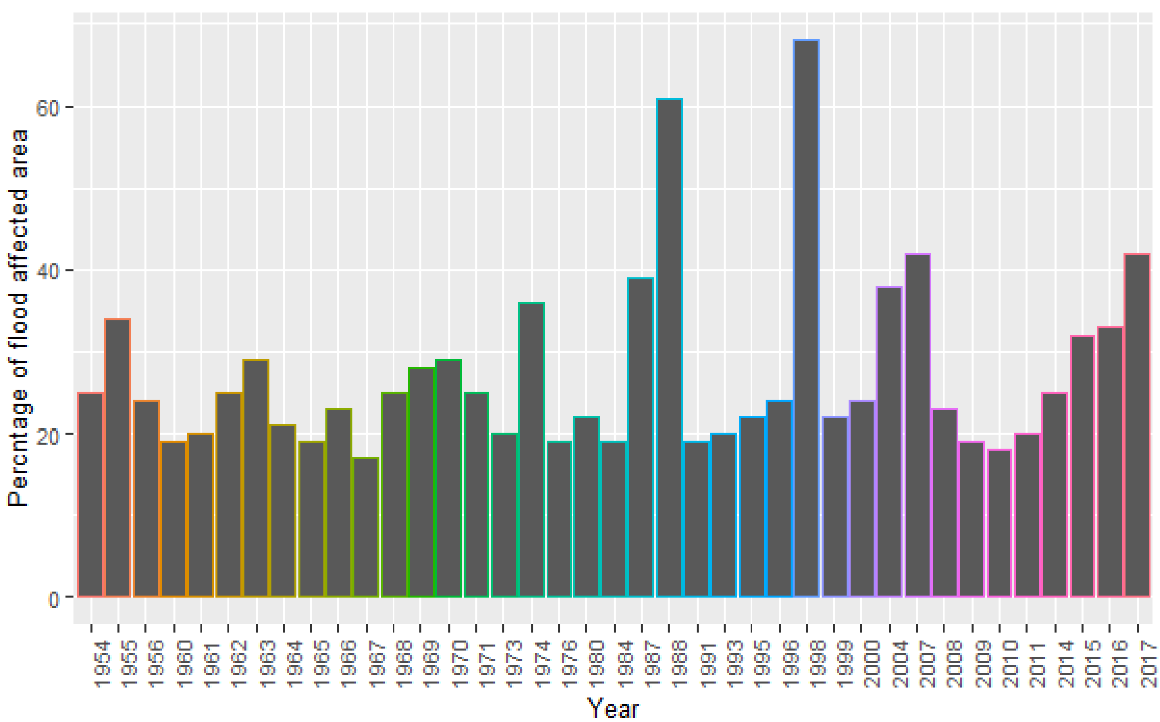

Figure 2: Flood affected areas over the years, source: author

2.3 Types of flooding in Bangladesh

There are four major flood types in Bangladesh. They are:

- Riverine flood
- Rainfall induced flood
- Flash flood
- Storm surges

2.3.1 Riverine flood

Riverine floods happen from the spilling of the major rivers and their tributaries and distributaries which is most extensive when the three major rivers are in peak stage at the same time. The morphological characteristics of land shows that Bangladesh's floodplains are neither uniform or flat (Brammer, 1990). Almost all the floodplains of the country are prone to riverine flood during the monsoon. Mainly the embanked areas of the country are characterized by this kind of flooding. As the river flood usually affects large flood plain areas, it causes significant damage to crop, homesteads, livestock, plants, and infrastructure. It also causes extensive riverbank erosion.

2.3.2 Rainfall induced flood

This kind of flood is most common in low-lying areas of Bangladesh where the drainage facilities are not very organized. Often the heavy rainfall occurring over the flood plains within Bangladesh during the monsoon period generates water volumes that exceed the drainage capacity. The amount and intensity of local rainfall and the water level of major rivers determines the extent, depth and duration of rainwater flooding. Damage from this kind of flooding is particularly severe when rainwater floods coincide with high river floods

2.3.3 Flash flood

Northern and eastern parts of Bangladesh have specific vulnerability to flash flood which results from heavy rainfall occurring in the neighboring hills and mountains (Dewan, Nishigaki, & Komatsu, 2003). Flash flood is characterized by a very sharp rise of water level in the rivers that causes sudden overbank spillages. The short durations and supercritical velocities often cause high degrading effects. People do not get enough time for evacuation during the flash flood while they lose their lives and valuables within a very short period.

2.3.4 Storm surges

This category of flood is also known as “coastal flooding” as storm surges are caused by tropical cyclone and leads towards massive damage of the lives and properties in the coastal areas of Bangladesh. The primary reason behind the surge is the pressure differential in cyclonic storm and the high winds. This results in huge waves of mass of water which moves at the same speed as the cyclone(Khalil, 1990). It is notable that Bangladesh suffers the most from cyclones and tidal surges from any other parts of the world.

2.4 Beneficial and damaging impact of flood

It is well known that the agricultural production system as well as the livelihood of people is intimately related with flooding in Bangladesh. Flood is not bad at all and it has some beneficial impacts on the agricultural production. Brammer (1990) has differentiated between the 'normal flooding', to which farmer's cropping practices are well adapted, and 'damaging flood' which occur when water rises earlier, higher, more rapidly or later than farmers expect when they decide which crops to grow on their different kinds of land. Monsoon flood inundation of about 20% to 25% area of the country is assumed beneficial for crops, ecology and environment. Because floods supply water for crop production, recharge the groundwater table, replenish soil fertility and support fish production. But the inundation of more than that causes disastrous consequences, i.e. major damage to infrastructure, great loss of property, crops, cattle, poultry etc., human suffering and impoverishment of the poor (BWDB, 2016).

Table 1: Normal vs. abnormal flooding in Bangladesh, source: Banerjee (2010)

Normal flood	Abnormal flood
• Affects 10-20% areas of the country • Inundation period is 3 weeks or less • Depth of standing water is 1–2 m in most areas of floodplain, and 3 m in the low-lying areas	• affects 35% or more of the country • Period of continuous inundation is one month or more • Depth of standing water is 2 m or more in most areas of floodplain, and 3 m or more in the low-lying areas.

Table 1 shows the differences of normal flood and abnormal flood as classified by Banerjee (2010). Normal flood is supposed to have beneficial impacts while the abnormal flood causes more harm than the benefits.

2.5 Flood management in Bangladesh

Flooding is a natural phenomenon and complete flood control in the country is neither possible nor is it expected by the farmers. The flood management related activities in Bangladesh can be mainly divided into two major types, namely structural and non-structural. The structural measures attempt to control the physical process of flooding while the non-structural measures attempt to reduce the damage and loss by administrative measures (Nishat, 2004). Structural measures of flood management include the construction of embankments and dams, improvements of drainage channels, building drainage structures, installing pumping system etc. They can protect the vulnerable people from a certain level of inundation. Non-structural measures of flood management include the forecasting and warning, community involvement in the flood management etc. During 60s the focus of flood management in Bangladesh was the structural measures by implementing some large-scale Flood Control, Drainage and Irrigation (FCDI) projects. But this type of measure required huge amount of investment, longer time period for completion and was preferred by the engineers. However, the subsequent policy development had been marked by the shift towards small scale projects in the 1980s and in the 1990s to sustainability, maintenance, stakeholder participation and increased attention to the effects of these initiatives on nonagricultural land and water use. The Flood Forecasting and Warning Center (FFWC) was established in 1972 as an initiative of non-structural measure of flood management. FFWC collects the daily rainfall & water level data from different stations across the country, issues flood bulletin for two times on a day from May to October, gives deterministic flood forecast with a lead time of 24, 48 & 72 hours as well as probabilistic flood forecast with 10 days lead time, and provides other warning information to enhance the disaster management capacity of different agencies and communities as a whole.

The Government of Bangladesh (GoB) has formulated several policies addressing the flood problem in this country. Some of the major policies are: National Water Plan, Flood Action Plan (FAP), National Flood and Water Management Strategy, National Water Policy, National Water Management Plan, National Disaster Management Policy etc. Different government bodies are actively involved in the flood management activities of the country. Some mentionable government agencies in this regard are: Water Resources Planning Organization, Bangladesh Water Development Board, Joint River Commission, Bangladesh Meteorological Department, Local Government Engineering Department, Department of Disaster Management etc.

3 Rice Production in Bangladesh

Bangladesh is a predominantly agricultural country from ancient time periods. Agriculture plays a crucial role in the overall socio-economic development of this country by contributing 14.23 percent of the annual GDP and employing 40.62 percent of the labor force. There are three major sectors of agricultural production, namely food grain, fisheries and livestock. Food grain production is the major part of the agricultural system which is mainly dominated by rice. Almost 13 million farm families of the country cultivate rice on about 10.5 million hectares of land.

3.1 Production seasons and varieties of rice

Rice is cultivated in 78.16% of the cropped area of the country and there are three growing seasons: aus, aman and boro (BBS, 2018). The growing periods of rice correspond well with the climatic patterns. Aus and aman are grown during the monsoon and boro is grown during the dry season. The rice ecosystems of the country consist of the following patterns: irrigated, upland (direct-seeded), rain-fed lowland (mostly monsoon-season, 0–50 cm), medium-deep stagnant water (50–100 cm), deep-water (>100 cm), tidal saline, and tidal nonsaline. Aman rice is grown in the July/August to November/December period and it is partly rain-fed in the early periods of growth, partly dry seasonal crop in the flowering and harvesting periods. Boro rice is produced from December/January to April/May after the aman. Boro rice is an entirely dry season crop as the precipitation remains very scarce in the early times of its growth. It is grown under abundant sunshine and moderate temperature conditions. This is followed by aus rice which is grown in the rain-fed conditions. Aus is produced from March/April to July/August, in between boro and aman seasons, and it overlaps both seasons. This means that the longer-duration varieties of rice do not allow for more than two rice crops per season on the same land, although other crops may be grown, depending on duration of the crop and other agronomic factors (D. M. Hossain, Bayes, & Islam, 2014).

The farmers of Bangladesh have been growing different types of local varieties of rice from ancient times. Local varieties are well adapted to the climatic and natural conditions of this land, can grow in less suitable lands such as coastal zones or non-irrigated places but the yield rate is low. Bangladesh is famous for its extensive rice biodiversity. It has been reported that the gene bank of International Rice Research Institute (IRRI) contains more than 8,000 traditional rice varieties collected from Bangladesh. These different types of local seeds have been grown in the land before the 1970s when green revolution induced High Yielding Variety (HYV) rice came in with modern cropping practices. In 1973, Bangladesh Rice Research Institute (BRRI) started an adaptive research in partnership with International Rice Research Institute (IRRI) and released varieties under the brand name BR and later Brridhan. Most of the HYVs were suitable for aus and boro seasons as aman season was being subject to different monsoon related stresses like flooding, temporary submergence and prolonged waterlogging. Later, BRRI scientists moved on to develop suitable varieties with Bangladeshi land races.

The High Yielding Varieties (HYVs) could produce 2.5 times higher than local varieties. However, it requires adequate water supply, fertilizer and enough care, as it is vulnerable to drought or harmful insects. This variety costs more than local variety, but its benefits are much higher (Asada, Matsumoto, & Rahman, 2005).

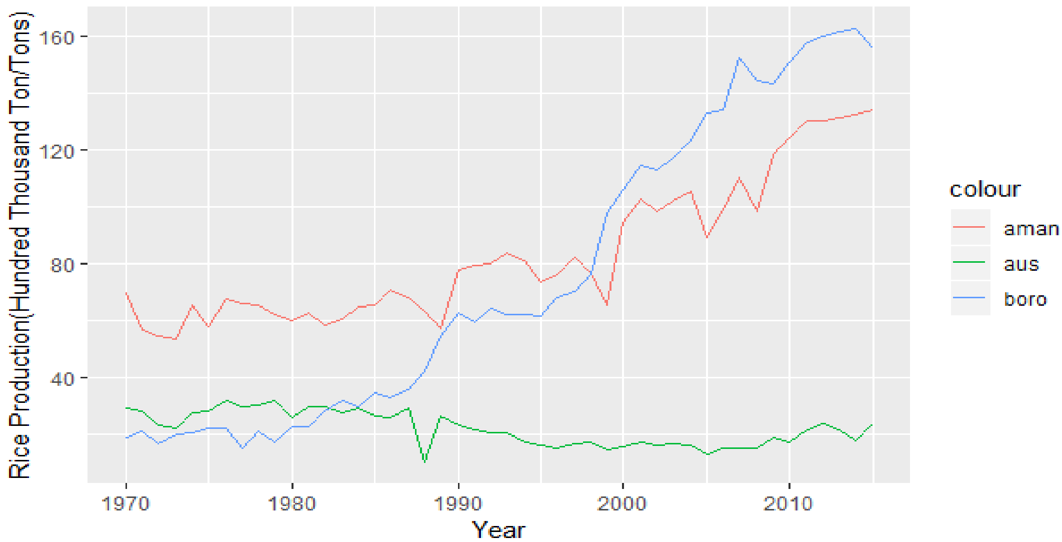

Figure 3: Trend of production of aus, aman and boro rice, source: author

The graph above explains the trend of trends of different seasonal rice production in Bangladesh from 1970 to 2015. There are three seasons of rice production but at present most of the farmers of Bangladesh choose to produce rice in the two seasons and vegetables in another season. It can be observed from the following graph that aman and boro rice production have been increasing over the years while the trend of aus rice is going downwards over the years. The area expansion under boro has come increasingly at the expense of aus, and, more recently, of aman as well, although aman acreage has generally remained static. There are several reasons behind this trend change. Production in the aus season is limited because of several environmental constraints, mainly rainfall. Over time, due to the expansion of irrigation facilities, the aus varieties have given way to boro varieties, because the latter gives two to three times higher yield than the former. At present aus contributes 7 percent of the total rice production. On the other hand the

HYV rice has also dominated over the local variety over the years. The figure 4 clearly shows that HYV share in total rice production is on the rise.

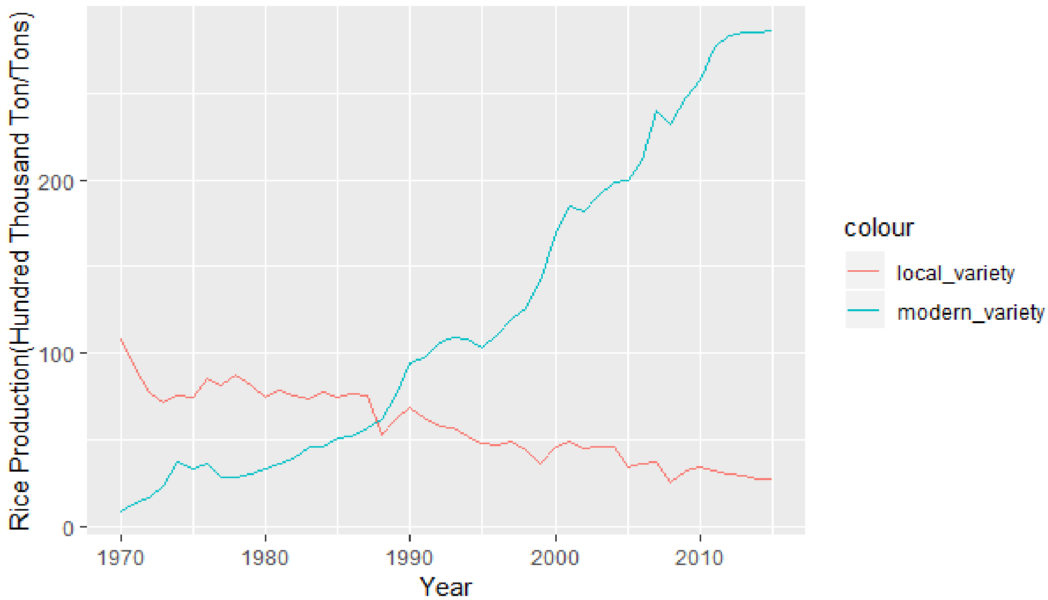

Figure 4 : Use of local vs. high yielding variety over the years, source: author

3.2 Agro-ecological zones in Bangladesh

Agro-ecological zones refer to the land areas which are characterized by almost similar agricultural practices as well as ecological characteristics. Bangladesh has been divided into 30 agro-ecological zones mainly based on four elements, namely physiography, soils, inundation land types and agro-climatology. The 30 agro-ecological zones have been sub-divided 88 more agro-ecological sub regions and which have also been sub-divided into 535 units. The following figure describes the agro-ecological zones of the country. The third factor considered in the agro-ecological zoning is the land types in relation to flooding. Bangladesh Bureau of Statistics (BBS) has categorized six distinct levels of lands in relation to flooding.

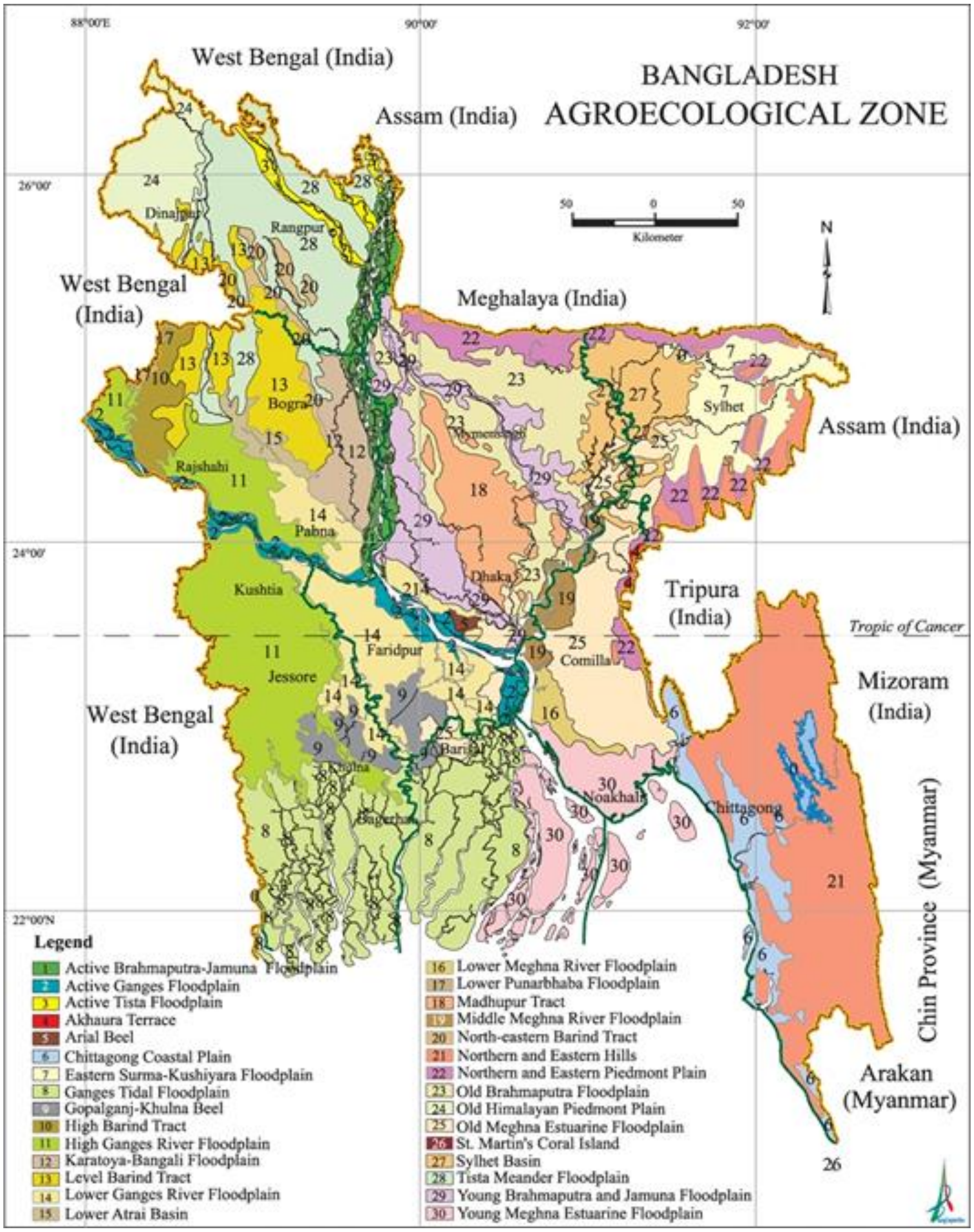

Figure 5: Bangladesh agro-ecological zones, source: (Banglapedia, 2012)

3.2.1 Land levels in relation to flooding

There are six distinct types of land levels across Bangladesh. The following table explains the names of different such levels as well as their characteristics.

Table 2: Land levels

Land type	Inundation characteristics
Highland	Stays above normal flood level
Medium highland	Flooded up to about 90 cm deep in the flood season
Medium lowland	Flooded in between 90 cm to 180 cm deep during the flood season
Lowland	Flooded in between 180 cm to 300 cm deep during the flood season
Very lowland	Flooded deeper than 300 cm during the flood season
Bottomland	Depression sites in any land levels that remain wet throughout the year

The depth limits might vary from year to year across the flooding classes. These levels of flooding indicate the expectation of farmers before they decide to produce some crops in the land. This categorization reflects the fact that almost all types of land in Bangladesh is affected by inundation and cropping practices have been adapted into this way. Rice is produced in almost all levels of land but the highland has an impermeable soil type and can be prepared for rice cultivation by puddling. Local aus, transplanted aman can grow on the medium highlands. The medium lowland is safe for transplanted aman and local aus. Lowland is flooded too deeply but can be used for boro cultivation during the dry season. Very lowland is also used for cultivating the boro paddy during the dry season. Bottomland is too wet and the boro paddy, irrigated or non-irrigated, can be produced in this kind of land. If the flood water does not exceed over 1.5 meter, then transplanted aman can be grown in this land.

3.3 Crop calendar of Bangladesh

Table 3 displays the rice cropping calendar of Bangladesh. Different varieties of rice are seeded, transplanted and harvested in different periods of time. The local cropping season of Bangladesh is divided into two categories based on the monsoon, namely *Kharif (*Spring and summer season*) & Rabi* (winter*)*. It appears that some types of flooding always threated the rice production throughout the whole country.

Table 3: Calendar of rice cropping

Name of season	Sowing/Transpla n-tation period	Harvesting period	characteristics	Risk of flood
Aus	Mid-March - Mid April	Mid July- Early August	Kharif—I / Summer/ pre-monsoon	flooding during the harvesting period
Aman (Local Transplant)	End June - Early September	November	Kharif-II / Monsoon and post monsoon	late flood in harvesting period
Aman (Local Broadcast)	Mid-March - Mid April	Mid November - Mid December	Kharif—II / Monsoon and post monsoon	late flood in harvesting period
Aman (HYV)	Late June - Mid August	December - Early January	Kharif—II / Monsoon and post monsoon	late flood in harvesting period
Boro (Local)	Mid November - Mid January	April - May	Rabi / winter (dry season)	Flash flood in April
Boro (HYV)	December - Mid February	Mid-April - June	Rabi / winter (dry season)	Flash flood in April

4 Literature Review: The Impact of Flooding on Rice Production of Bangladesh

There are numerous studies which have attempted to measure the impact of flooding on the agricultural sector as well as rice production of Bangladesh. Different types of studies have attempted to use different methods for the impact analysis from multiple perspectives. Bangladesh Bureau of Statistics (BBS) is one of the oldest institutions of the Government of Bangladesh (GoB) and BBS annually publishes the yearbook of agricultural statistics where the data on crop damage from different types of disasters are provided. BBS collects the data through its regional offices but do not provide detailed information about the calculation of crop damage from flooding and other types of natural disasters, like drought or cyclone. There are no other agencies which have historically reported the crop damage data from flooding which leaves few chances for checking the authenticity of the BBS data through comparative analysis.

Different researchers have used the BBS data to estimate the impact of flooding on the rice production of Bangladesh. Murshid (1987) conducted an analysis by using the secondary database on crop damage to estimate the relative role of technology and weather in affecting the instability of rice production in Bangladesh. The period of analysis was 1969-70 to 1979-80. Cross section regression, by districts, was used to interpret the variation of production instability happening due to the spread of technology. The regression included weather related variables, namely levels and variation of rainfall but it did not intend to directly assess the impact of flood in explaining the instability. But the author made a primary analysis of the crop damage estimates during the 10 years period by fitting a trend line and explaining the deviations from the trend in terms of different technology variables and natural disasters. Flood appeared to disturb the aman production only in 1974-75. Aus and boro production deviations were not caused by flood but other factors. However, the study did not analyze the impact of flooding by including the flood related variables in the regression and hence, was limited in this regard.

Ahmed & Bernard (1989) analyzed the rice price fluctuation in Bangladesh and emphasized the necessity of accurately estimating crop damage from natural disasters to combat the erratic movement of rice price in the market. They used the BBS data from 1969-1984 period and fitted a semi-log trend line to estimate the deviations from trend. The data reveals that aus and aman varieties of rice are more vulnerable to flood than boro rice. The analysis also found that location specific crop losses from flood does not affect the annual loss of production, instead it can increase the aggregate supply by boosting prices. Additionally, rainfall induced flood can increase the soil moisture and crop yield in highlands. That is why the average annual yield in flood years appeared positively deviated from the trend. Overall, it could not find out a perpetual impact of flood on all varieties of rice crops during the study period. But M. Hossain (1990) questioned this method and identified the estimated trend to be less reliable on the basis that it was being affected by the lower amount of production in the disaster years. Instead, he estimated the trend by dropping some of the years which were affected by natural disasters. The author also conducted the trend analysis on a seasonal basis. He classified the rice production into two seasons, namely, wet season (aus rice and aman rice) and dry season (boro rice) and study used the BBS crop damage data for 1973-1990. The national level analysis revealed that there were seven negative deviations in those 17 years of which four deviations happened during four flood years. But the effect at the national level was not so severe and the author shifted analysis to regional level perspectives. The regional level analysis showed that production fell short in some selected regions, but the national effect was not so severe as some other regions experienced above normal production during the same year. Although some of the regions were experiencing losses of aman production but it was subsequently being recovered by the boro rice production in the dry season. But both Ahmed & Bernard (1989) and M. Hossain (1990) questioned the reliability of the BBS estimations on crop damage.

Paul & Rasid (1993) used the country wide BBS data from 1962 to 1987 and district wise crop loss data from 1967 to 1988. BBS reports crop damage data on yearly basis (January - December) but the crop production data in fiscal years (July-June). They rearranged the data and expressed the average losses as percentages of total rice production. The amount of average annual loss was four percent of total production of rice. Although the annual loss from flooding at the national level had seldom been very severe, the spatial variation among districts was noticeable in the study. Some districts had an annual loss of 11 percent while some had less than 1 percent of loss every year. The author then classified the districts into four categories by nested means procedures. It was concluded that flood vulnerabilities depend on the spatial patterns of the districts.

Banerjee (2010) attempted to look at the impact of flooding on rice production from regional level perspectives. The researcher examined district-level rice and jute productivity data from BBS for the time of 1978–2000 to investigate the long-term and short-term impacts of floods. Twenty districts of Bangladesh were selected due to the availability of consistent data and they were classified into two groups namely, More Flood-prone (MF) and Less Flood-prone (LF) due to the regional variation of flood impacts. A district was considered as “more” flood-prone if 50% or more of its total area remains susceptible to flooding of a depth of 90 cm or more in a “normal” flood year. 11 districts were classified as LF and 9 others were designated as MF in the study. The effect of flooding was analyzed from short- and long-term perspectives. Long term effects were calculated by comparing the area under cultivation and agricultural productivity in more and less flood prone districts. Short term effects were calculated in two stages. Average annual yield rates in regular years are compared with “extreme” floods years and the drought years. Bangladesh experienced extreme flooding in 1974, 1987, 1988, 1998 and 2004. Next, the yield rates of the aus, aman and boro were examined to determine the impact of flooding on crops grown in flood months and immediate post-flood months. Yield rates in the MF and the LF districts are studied separately and compared with the respective averages for Bangladesh. The analysis revealed that the amount of cultivated area as well as agricultural productivity is higher in the MF districts. In addition, the yield rates decline in extreme flood years, but productivity goes up in normal years as well as post flood periods.

There are several other studies on estimating the flood impacts on agricultural production in Bangladesh but few of them have analyzed the time series data from economic perspectives. On the global level, a common method is to use the flood damage functions which defines the relationship between the severity of flooding and the projections of the resultant damage (Yang et al., 2015). The severity of flooding is measured by different types of hazard parameters, i.e. water depth, flow velocity, flood duration, volume, sediment, contaminant load, salinity etc. The projections are derived by using the historical information and questionnaire survey data through regression and other data driven approaches. Monetary loss is the most common dependent variable in these types of studies. The shape of the flood damage functions varies across studies while three of the most common damage functions are logistic, exponential and linear. Most of the research papers in this arena have used sophisticated methods, i.e. satellite imagery to exactly measure the flooding characteristics while focusing on years/months of extreme flooding in a region. Flood damage functions have been extensively used by different authors, i.e.(Dutta, Herath, & Musiake, 2003; Guiteras, Jina, & Mobarak, 2015; M. M. Q. Mirza, 2003; M. Q. Mirza, 2002; Sciance & Nooner, 2018). However, as most of these studies depend on remote sensing technology or hydrodynamic modeling and it requires that kind of technical expertise which is not also the concern of this paper.

Okuyama (2009) identified four basic methodologies in the disaster impact assessment. They are: Input Output Model, Social Accounting Matrix (SAM), Computable General Equilibrium (CGE) and Econometric models. Each of the models have their distinct strengths as well as weaknesses. Most of the studies on the economic impacts of flooding on Bangladesh agriculture have used econometric models. Econometric models are statistically rigorous, provides stochastic estimates and able to forecast over time. But it requires panel cross sectional and time series data and gives the total impact instead of direct and higher-order impacts distinguished.

Some countries like UK, USA, Australia, Japan, Netherlands etc. also have their own flood damage simulation models. In such cases, those countries have developed adaptive software packages to measure the comprehensive flood damages, which are however, not the concern in this paper.

The review of literature reveals several important aspects about the impact of flooding on the rice production in Bangladesh.

- Bangladesh had been considered as an agricultural country until very recent times and the country is found to be highly vulnerable in terms of flooding as well as different other climate change induced hazards. But there is no nationally agreed framework or guideline for estimating the impacts of flood on the agricultural sector of Bangladesh. All the previous research initiatives on the question of the impact of flood on rice production have been carried out by non-governmental/individual/institutional effort.

- This is a generic notion that flood has negative effects on the rice production of Bangladesh. On the other hand, Bangladesh has been increasing the amount of rice production consecutively over last few decades. The country is self-sufficient in rice production now and does not import rice anymore. Most of the economic researchers have tried to explain this relationship in terms of the beneficial and negative impacts of flooding. A flood hazard produces positive as well as negative effects on the rice production which have been explained in detailed in the previous chapter.

- The negative consequences of flooding have different dimensions. First, the impacts of flood become severe in some years of extreme event. In the other years the overall rice production remains stable and grows up. Secondly, there are regional dimensions of the impacts of flood. The more vulnerable areas of Bangladesh experience more flood than the less vulnerable areas. That is why the national level estimates might not reflect the spatial differences of the impact. Because a flood vulnerable area might experience the high inundation during the harvesting season of a variety of rice while the less vulnerable areas might not have any such inundations. Instead, the less vulnerable areas might also experience the growth of production which can off-set the negative consequences of flooding in the vulnerable zones when the data is nationally reported.

- The beneficial impacts of flooding have also some specific dimensions. Firstly, most of the previous economic researchers did not take any attempt to measure the beneficial impacts of flood. But they have explained the dichotomy between the increased flooding as well as the growth of rice production in terms of the beneficial impacts of flood. Secondly, there are also spatial dimensions of the beneficial impacts of flood. More vulnerable areas experience more of the beneficial impacts of flood than the less vulnerable areas. Because the areas which suffer the high and longer periods of inundations will also reap the natural benefits of this incident than the areas which do not experience the inundation.

- Mainly the wet season rice varieties, i.e. aus and aman, have experienced both negative and positive consequences of flood. The boro rice is not supposed to experience any kind of beneficial impact of flood as it is grown during the dry season. However, boro variety experience the negative impacts of flooding as it is harvested during the pre-monsoon period.

- Bangladesh Bureau of Statistics (BBS) is the major source of crop production related information. Although BBS estimates on crop damage are not equally accepted by the statisticians but the crop production data looks accurate. Most of the economic researchers who have attempted to assess the impact of flooding have looked into the crop damage estimates and tried to rectify the inherent limitations of the data. The rice crop production data can be a useful tool for testing the trend of the impacts of natural shocks.

- The Flood Forecasting and Warning Center (FFWC) under the Bangladesh Water Development Board (BWDB) is the mandated agency of the Government of Bangladesh (GoB) to look after the flood related incidents. Most of the hydrological/geological/and other scientific studies have highly relied on the danger level estimates of the FFWC to count the number of flood incidents. We did not focus on those studies due to the technical limitations of this research, but the danger level related information can also be a good source to identify the occurrence of flooding

- There are scopes of studying the correlation between the beneficial and negative impacts of flood by using the crop production data. Several issues appear in this context. Firstly, the positive and negative impacts of flooding have been mentioned by all the previous researchers who have attempted to analyze the impacts of flooding on agriculture. Secondly, we do not have the option to measure flood events and different characteristics of a flood event by using satellite imagery or other scientific tools. But the danger level estimates can be a good proxy to develop a scientific measure of flooding. Thirdly, BBS data on rice production data is highly reliable for its authenticity. BBS reports the detailed procedures of the calculation methods. Hence, we can explore this option of using the rice production data instead of using the crop damage data. Fourthly, few researchers have tried to apply this novel strategy of testing the correlation of beneficial impacts and negative impacts with the rice production. We can test the new method for analyzing the impacts of flood on the rice production in Bangladesh.

- The findings by applying this new method will be useful several reasons. First, it will contribute the development of a simple but new approach in studying the correlation of the impact of flooding and rice production. Secondly, a panel dataset will be prepared for the analysis of this correlation. No such panel data has been studied previously from the perspective of the flood impact on rice production in Bangladesh. It is a challenging and new venture in the domain of agricultural economic research in Bangladesh. Thirdly, the findings will be helpful for revisiting the findings from the previous research. We will be able to either support the findings from the previous researchers or add new dimensions to their analysis. Fourthly, this paper will be a motivational force for the young researchers in the field of agricultural economics of Bangladesh. There has been a dearth of quality research papers which have used panel data for estimating this kind of correlation. This paper will be a starting point for the new research and in future, newer perspectives may come out of this same dataset by using different approaches of impact analysis.

5 Research Methodology and Data Analysis

5.1 Types of data used in the research

This research will try to study the correlation of the two major impacts of flooding and the rice production of Bangladesh. Flooding has positive as well as negative impacts. To capture both impacts of flood, we will construct two new variables by using the danger level data collected from BWDB. The rice production data of BBS will be directly used here without further modifications. The analysis in the previous chapters has also revealed the correlation of rice production with different other climatic variables, i.e. temperature, rainfall. Hence, we will collect the temperature data from Bangladesh Meteorological Department (BMD) and the rainfall data from BWDB. After cleaning the different formats of data, a panel dataset will be developed. Then we will try to find out the expected correlations by regression analysis.

5.2 Rice production data

Bangladesh Bureau of Statistics regularly collects data on agricultural productions around the country and publishes the "Yearbook of Agricultural Statistics". In 2018, BBS published the "45 Years Agricultural Statistics of Major Crops" where the time series data on rice production across the districts have been provided. "District" is the second highest administrative tier in the local government of Bangladesh. A "division" stays in the top of the tier. At present there are 8 divisions and 64 districts in Bangladesh. There are three more tiers below the "district" in the local government hierarchy of this country. But the rice production for 19 districts is consecutively available from 1970 to 2006 time period. From 2007, BBS started reporting the data for 64 districts. However, it appears that the production data for the whole country had been represented under 19 districts for all those years. For that reason, the data from 2007 for the 64 districts have been rearranged under the 19 districts based on the physical proximity of the districts. The original 19 districts have been considered as the base and the nearby districts of the base districts have been renamed as the base district. Afterwards the rice production data of the similar named base districts have been added together.

The data is reported on a seasonal basis every year. There are three main seasonal varieties: aus, aman and boro. The rice production data is reported in tons until 2006 and after that year, it has been reported in metric tons. However, this data has been adjusted in tons in this research. Also, rice production data is reported as per the fiscal year of the country (July-Jun). For the purpose of data cleaning and estimation, we have converted the fiscal year (July-Jun) into the single year (January-December), i.e. 1969-70 has been considered as 1970. Finally, we keep the data of 18 districts based on the availability of other variables considered in the regression analysis.

5.3 Yield data

BBS does not report the yield data in the reports. We constructed the rice yield (tons per acreage) data by summing up the total rice production (tons) and dividing it by the area under cultivation (acreage). Yield gives better information on the productivity of the land than the total amount of rice production.

5.4 Meteorological data

Bangladesh Meteorological Department (BMD) has different 38 stations around the country which regularly monitors the weather conditions and forecasts weather on a daily basis. This research has used the daily minimum as well as maximum temperature data from the weather stations for the 18 districts for which the rice production data is also available for the similar time period. BMD uses some codes to denote weather stations in a district. BMD codes have been used to denote a district in the dataset. Two districts in the rice production dataset, namely "Kishoregonj" and "Bandarban", did not have any weather stations. In such case, the daily maximum and minimum temperature data from "Srimangal" and "Rangamati" districts have been used as a proxy for "Kishoregonj" and "Bandarban" districts respectively. The proxy districts are located closer to those two districts for which the data is missing.

The dataset was as vast as every district has 365 days of temperature data in a year and 16425 days for 45 years (1970-2015). After collecting the daily minimum and maximum temperature data for 18 districts for 45 years, two indicator variables, i.e. warm days and cold days, were created.

5.4.1 Warm day

If the daily maximum temperature went above 35-degree Celsius then it had been identified as a warm day and a value of 1 was created for it. Otherwise it stayed as 0. The purpose of creating this new variable is to control the correlation of rice production with extreme temperature. Because rice trees cannot tolerate extremely high temperatures over the limit of 35-degree

Celsius. Afterwards, we add the number of warm days in every district for every production season in a year. We get this data for every district for 45 years consecutively.

5.4.2 Cold day

On the other hand, if the minimum temperature went under 20-degree Celsius, then it was classified as cold day with a value of 1. Otherwise, it stayed as 0. Rice trees cannot also tolerate the low temperature below 20-degree Celsius. As we want to control the impact of extreme meteorological conditions, we also calculate the number of cold days in every district for every production season in a year. So, we get this data for every district for the 45 years consecutively.

5.4.3 Daily rainfall

Bangladesh Water Development Board (BWDB) collects the daily rainfall data, in millimeters, for several districts for historical time periods. This research has collected and cleaned the data of daily rainfall for the 18 districts of Bangladesh from 1970 to 2015 time. Later, the data of daily rainfall was summarized and split across the three seasons every year for all the districts. Hence the total rainfall data during aus, aman and boro seasons in a year in a district was prepared.

5.5 Water level data

The most important data to measure flooding in a district is the water level of the water stations in a district. Bangladesh is a riverine country and every district has several river stations managed by the BWDB. The river stations collect daily average water level data in non-tidal district and while for the tidal districts, the daily average water level during the high tides and low tides is reported. Every station has a danger level and if the water level moves over the danger level, then it is considered as a potential threat of flood. The water level data from 85 stations from the 18 districts have been collected from BWDB. The non-tidal water stations have daily mean water level data. But for the tidal stations, daily mean water level data has been calculated by taking average of the daily high tide and low tide data. Then, we create two indicator variables, namely danger days and benefit days.

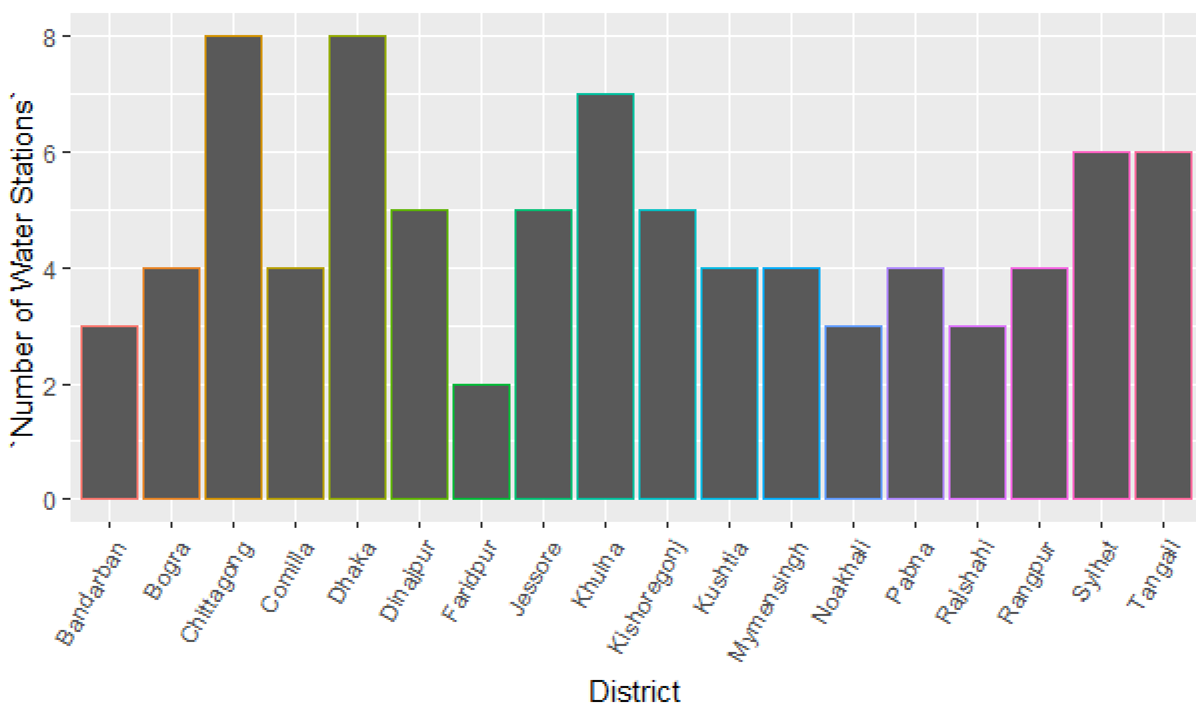

Figure 6: Number of water stations across districts, source: author

5.5.1 Danger day

If the mean daily water level in any station exceeds the danger level of the station, then we name it as a "danger day" and give a value of 1. But if the water level stays below the danger level, then we put zero. Afterwards, we count the number of days the water level exceeded the danger level in a station during the harvesting period of different varieties of rice. Then we calculate the danger days for a district in terms of the three seasons for the time period of 45 years. There are variations in the number of water stations across the districts. Some districts have eight water stations while some have only two water stations with the available data. But in the case of the water level exceeding the danger level in more than one station in a day in a particular district, we do not add all the “ones” but consider it as a single “one”. Otherwise the number of danger days will be overestimated.

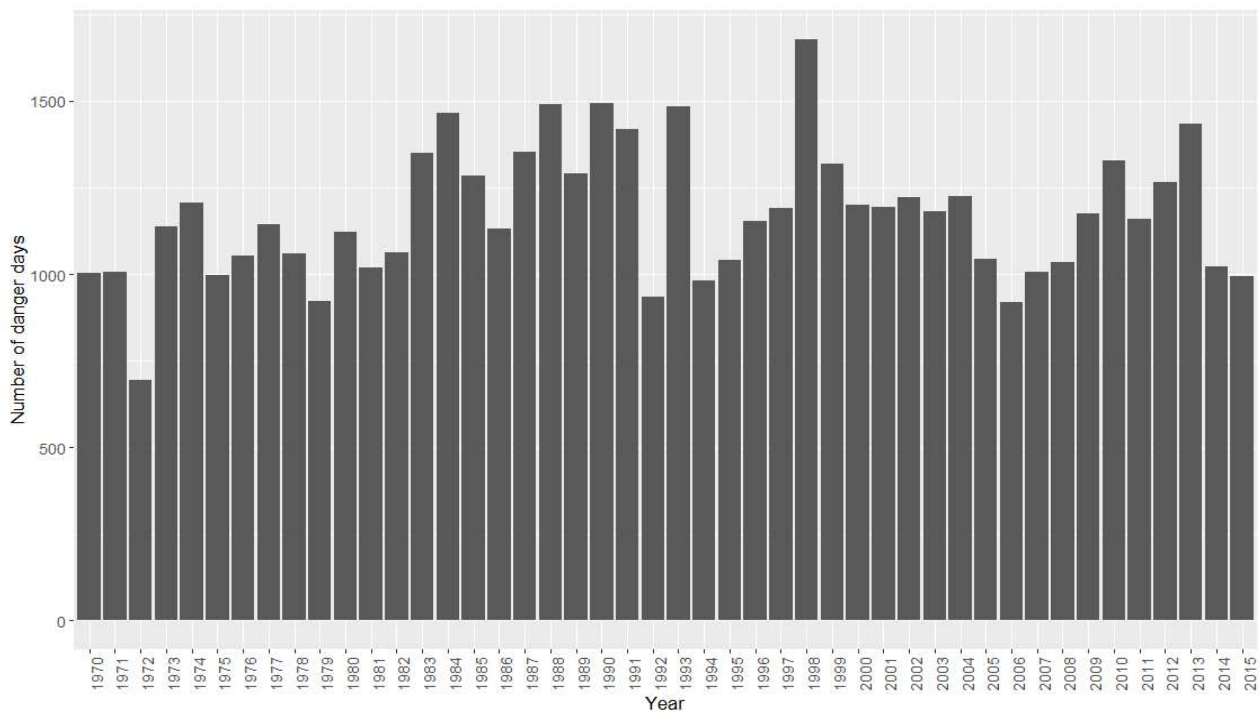

Figure 7: Total number of danger days over the years, source: author

5.5.1.1 Normalized danger days

For detailed analysis of the impact of flooding on rice production of Bangladesh, we have also created another variable from this already created variable called “Danger Days”. The normalized danger days have a value in between 0 to 1. Then we multiply it with 100. We normalize the danger days by using the following formula:

$$Normalized\ Danger\ Days = \left(\frac{Total\ number\ of\ danger\ days\ in\ a\ season}{Total\ number\ of\ days\ in\ the\ season}\right) * 100$$

5.5.2 Benefit day

Flooding has a lot of positive impacts on agriculture. Rice production in Bangladesh is highly dependent on irrigation system as huge amount of water is required in the initial period of seeding and transplantation. To capture the beneficial effects of flood we create a new variable and name it as "benefit days" which take the value of one if the mean water level in a water station crosses the danger level during the seeding and transplantation period of every rice variety. Otherwise it stays as zero.

Floodwater during the beneficial period is valuable for preparing the land to cultivate rice and other plants. To skip the risk of over-counting the benefit days in the districts with greater number of water stations, we do not consider all ones for a day in a district, but a single "one".

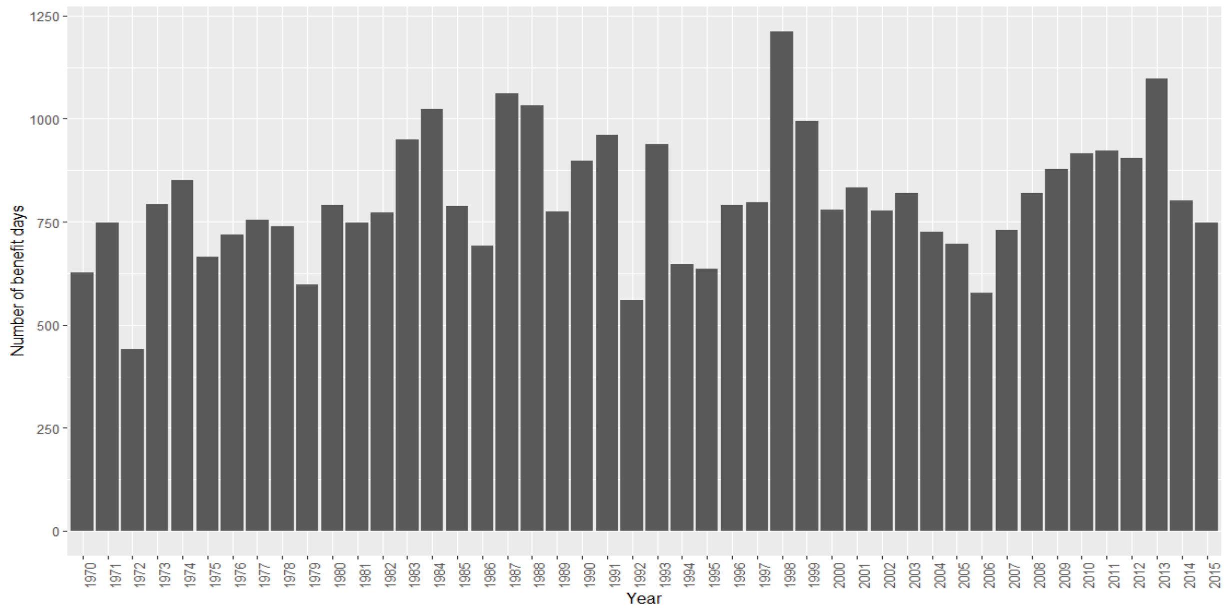

Figure 8: Total number of benefit days over the years, source: author

5.5.2.1 Normalized benefit days

Like the normalized danger days, we also create another variable called normalized benefit days by using the following formula. The normalized benefit day also has a value in between 0 and 1. Later we multiply this value with 100.

$$Normalized\ Benefit\ Days = \left(\frac{Total\ number\ of\ benefit\ days\ in\ a\ season}{Total\ number\ of\ days\ in\ the\ season}\right) * 100$$

The table 4 represents information of the 18 districts, the mean number of danger days as well as the mean number of benefit days across different seasons of rice production.

Table 4:Mean number of danger and benefit days across districts

	Danger days			Benefit days		
District	**Aus**	**Aman**	**Boro**	**Aus**	**Aman**	**Boro**
bandarban	0.98	0.00	0.00	0.00	0.91	0.00
bogra	0.87	2.02	0.00	0.00	1.70	0.00
chittagong	42.50	30.85	16.09	8.78	39.72	9.72
comilla	55.48	50.67	15.37	5.46	54.02	4.39
dhaka	56.67	60.80	3.80	0.04	61.98	0.63
dinajpur	4.57	3.24	0.18	0.02	5.78	0.00
faridpur	1.46	10.22	0.50	0.91	11.33	0.41
jessore	47.13	70.91	23.98	24.33	53.50	37.50
khulna	56.52	52.07	30.74	21.00	48.37	20.96
kishoregonj	59.57	64.73	5.65	0.00	61.78	0.00
kushtia	1.02	7.17	0.00	0.00	8.57	0.00
mymensingh	10.50	3.22	8.11	10.02	11.87	3.35
noakhali	90.00	90.11	81.63	78.07	61.98	82.78
pabna	4.17	6.13	0.00	0.00	11.46	0.00
rajshahi	2.15	10.96	0.00	0.00	8.17	0.00
rangpur	23.54	13.57	2.29	1.98	29.59	0.02
sylhet	36.41	15.54	4.11	0.57	40.35	0.00
tangail	5.02	7.02	2.00	2.17	8.57	3.57

It is evident from the table that most of the districts have high number of danger days during the aus and aman season, which is consistent with the theoretical propositions of flooding in Bangladesh. Aus and aman seasons are affected by flooding annually and the intensity is different among the districts based on the geographical and geological conditions. Boro rice is harvested during the pre-monsoon season and it also experiences the dangerous effects of flooding as it is evident that some district has high number of danger days during the boro season. Overall, the mean number of danger days is greater for the districts during the aus and aman season in comparison with boro season.

5.6 Categorizing districts by vulnerability

There are 18 districts in the dataset. We have learned that the impacts of flood vary across the districts based on the vulnerability conditions of different areas. Hence the districts are categorized into two types, namely More Flood Prone (MF) and Less Flood Prone (LF) by following the approach of (Banerjee, 2010). The following table contains the name of the more flood prone as well as less flood prone districts.

Table 5: District classification based on vulnerability

More Flood Prone (MF)	*Bogra, Mymensingh, Sylhet, Kishoregonj, Pabna, Dhaka, Comilla, Jessore, Faridpur, Tangail*
Less Flood Prone (LF)	*Dinajpur, Rangpur, Rajshahi, Khulna, Noakhali, Chittagong, Bandarban, Kushtia*

5.7 Production model

We will estimate two econometric models for finding out the impact of flooding in the rice production in Bangladesh. The first set of models is called the production model because it considers the total rice production (in tons) as the dependent variable in the regression. The details of the first set of following econometric model are provided below.

$$\boldsymbol{Production_{it} = \alpha + \beta_1\ Danger\ Days_{it} + \beta_2\ Benefit\ Days_{it} + \gamma X_{it} + \delta_i + \theta_t + \epsilon_{it}}$$

The dependent variable in the model is the rice production (tons) of a district in a season. The explanatory variables of interest are danger days and benefit days. Flooding is considered as dangerous during the harvesting period but beneficial during the seeding and transplantation period. The hypothesis is that rice production would be positively related with β_2 but negatively related with β_1. δ_i and θ_t the district/area fixed effect and time fixed effect respectively. There are certain characteristics of district-based vulnerability, i.e. elevation, in the data and they vary from district to district but remain constant over the years. Also, there are some issues, i.e. government policies, subsidies, donor funding, which change over the years but remain constant across the districts.

Rice production is also affected by the other meteorological conditions like temperature and rainfall. Because extremely high or low temperatures can be detrimental during the harvesting period. Excessive rainfall can also cause flooding while a limited amount of rainfall can be beneficial for rice production as it helps to soften the soil during the transplantation time. Bangladesh has a tropical climate with considerable variations in the climatic parameters like temperature and rainfall. The research intends to control these factors, i.e. temperature and rainfall under the X_{it}. We have created several variables like warm days to denote high temperature and cold days to denote low temperature. Also, we have calculated the total amount of daily rainfall to measure the total rainfall in a season. These variables are controlled in this regression. ϵ_{it} contains the errors of the regression.

5.7.1 Regression estimates for all varieties of rice

We run a common regression for all the district and across different varieties in different seasons of rice. Aus season has two types of varieties: Local and High Yielding Variety (HYV). Aman rice has three varieties: Local Transplant, Broadcast and HYV. Local Transplant and Broadcast, both are local varieties. Boro season has also two varieties like Aus season: Local and HYV. The dependent variable of the following regressions is different varieties of rice production(tons). The left column shows the name of explanatory variables. All the estimates have robust standard errors (SE).

It is expected that the production of rice will be positively correlated with the benefit days but negatively correlated with the danger days. A significant coefficient would be helpful to reject the null hypothesis in this aspect. The table 6 in the next page shows the regression estimates for all of the varieties of rice for all of the districts. We are mainly interested in the signs and significance of the danger days and benefit days. The signs of the coefficients of local variety of aus rice is against the expectation for danger days as well as benefit days.

Table 6: Regression estimates for all districts and all varieties of rice
***, **, * corresponds to 1, 5 and 10 percent level of significance

variable	Aus (Robust SE)		Aman (Robust SE)			Boro (Robust SE)	
	Local	HYV	Local Transplant	Broadcast	HYV	Local	HYV
Danger days	190.228 (185.871)	-9.618 (91.265)	-123.851 (233.803)	-36.114 (122.367)	210.696 (342.790)	75.196 (66.000)	**-1271.022 *** (480.140)**
Benefit days	-50.922 (100.791)	-159.4081* (92.724)	225.704 (326.504)	172.505 (107.732)	-266.832 (715.057)	59.589 (78.540)	-1506.873 (1845.942)
Warm days	8.266 (80.653)	26.598 (73.952)	-678.642 (541.038)	-82.420 (201.593)	1801.714* (957.912)	-9.977 (101.407)	-2964.291 (1879.346)
Cold days	-382.336 (272.276)	-8.511 (230.255)	-194.165 (630.064)	-221.787 (182.405)	181.844 (1586.936)	-26.690 (44.956)	460.983 (833.244)
Rainfall	13.612 (13.449)	9.863 (11.366)	-8.281 (16.216)	-5.924 (7.168)	-37.904 (33.102)	-2.454 (3.481)	-13.046 (37.907)

HYV aus rice has negative correlation with danger days. But the estimated coefficient is not significant enough to reject the null hypothesis. However, the coefficient of the benefit displays negative and significant correlation with the HYV aus rice. But it was expected to have a positive correlation between the flooding in benefit days and rice production. Over the years, there has been a deteriorating trend of aus rice production for several reasons. The most important factor behind this is the tendency of farmers to switch towards boro production due to its higher yields (Uddin & Dhar, 2018).

Local transplant aman is negatively correlated with the danger days and positively correlated with benefit days. One additional flood day during the harvesting period can cause a loss of

123.851 tons of rice. On the other hand, one additional days of flooding in the seeding and transplantation period can increase the local transplant aman production by 225.704 tons. But none of the estimates have lower p values and both are insignificant. The estimates for broadcast aman have meaningful signs. One additional flood day during the harvesting period can cause a loss of 36.114 tons of rice and one additional days of flooding during the beneficial period can cause an increase of 172.505 tons of rice. But both estimates are insignificant. The estimates of HYV aman rice have unexpected signs. They are positively correlated with danger days and negatively correlated with benefit days. Most of the farmers in Bangladesh have used the local varieties of aman rice and there have been less innovations of HYV for aman season. The HYV cannot tolerate flooding and wet climate during the monsoon season.

Boro season is the less vulnerable season to flooding while in recent years, the flash flooding or early flooding in March-April has been posing threats for boro production. Most of the farmers in Bangladesh use the HYV seeds in the boro season and it has been found that HYV boro rice is negatively and significantly correlated with danger days. For one additional days of flooding during the dangerous period, 1271.022 tons of HYV boro rice is being lost. However, the correlation with benefit days does not have expected signs. Local boro rice has a positive correlation with benefit days but it is insignificant. It has already been mentioned that we do not expect any significant and beneficial impact of flood on boro rice production as it is produced entirely based on the irrigation during the dry season. The results are generalized for all the regions of Bangladesh. Now, we split the regression for different varieties of different seasons based on the vulnerability of the regions. The following tables lay out the different regression estimates for MF and LF districts of the country.

5.7.2 Regression on aus rice

The table 7 shows the regression results of the impact of flooding on local and HYV aus rice in LF and MF districts. As we did not find any significantly negative or positive impact of flooding on aus rice production in the first set of regressions, now we look at the differences among districts of certain patterns.

Table 7: Regression estimates for LF and MF districts during the aus season
***, **, * corresponds to 1, 5 and 10 percent level of significance

Variable	Local Aus (Robust SE)		HYV Aus (Robust SE)	
	MF	LF	MF	LF
Danger days	-92.792 (76.969)	514.564 (334.019)	-62.112 (161.637)	3.326 (93.277)
Benefit days	-204.783* (90.645)	50.871 (163.082)	-250.772 (141.739)	-49.446 (168.455)
Warm days	-122.349 (92.113)	223.039* (121.960)	-19.875 (98.665)	140.377 (114.863)
Cold days	-0.981 (149.682)	-851.793* (454.582)	332.658 (327.503)	-425.267 (293.736)
Rainfall	15.642* (6.558)	8.764 (26.649)	12.680 (12.614)	3.297 (25.358)

The local and HYV variety of aus rice is negatively correlated with danger days in the MF districts only. In the less vulnerable districts the negative impacts of flooding are not so apparent in the estimates. It has been found in the earlier literature that most of the vulnerable districts are negatively affected by the danger days of flooding while the less vulnerable areas might not be affected by flood.

However, none of the estimates for MF districts are statistically significant here. Estimates on the benefit days are also negatively correlated with the more flood prone districts and it is significant for local aus production. But this is an unexpected sign as opposed to the positive relationship. In recent years, the production of aus rice is shrinking as most of the farmers are choosing to produce aman and boro rice. The deteriorating amount of production of aus rice might be a barrier for finding out the true correlation between the different impacts of flooding and aus rice production. Farmers often produce aus if they do not cultivate boro rice and produce different types of vegetables during the dry season.

5.7.3 Regression on aman rice

Literature suggests that aman rice is more vulnerable to flood as it is mainly produced during the monsoon period. The rainfed aman required certain amount of flood water but exceeding the limit can bring chaos in production. The table 8 displays the regression estimates for aman rice production for different categories of districts. The local transplant aman rice is meaningfully correlated with danger days in more flood prone districts. More vulnerable areas of Bangladesh experience 264.719 tons of loss in local transplant aman rice production due to the negative effects of flood. Production of broadcast aman rice in MF districts is also negatively correlated with danger days. One additional flood day can cause a loss of 152.143 tons of rice, but the estimates are not significant. The negative effects of flooding are not visible on the HYV aman production in any categories of the districts. Also, the local transplant aman and broadcast aman production in the less vulnerable areas does not get affected negatively by the flooding.

Table 8: Regression estimates for LF and MF districts during the aman season
***, **, * corresponds to 1, 5 and 10 percent level of significance

Variable	Local Transplant Aman (Robust SE)		Broadcast Aman (Robust SE)		HYV Aman (Robust SE)	
	MF	LF	MF	LF	MF	LF
Danger days	-264.719* (125.606)	142.443 (478.071)	-152.143 (121.724)	103.389 (58.710)	161.756 (756.505)	366.627 (363.835)
Benefit days	-384.028* (201.667)	694.461 (529.403)	285.081* (138.940)	109.932* (59.402)	-71.864 (955.771)	-511.861 (1050.250)
Warm days	-246.097 (601.576)	-1362.468 (1207.048)	125.559 (303.689)	17.371 (137.011)	1599.847 (1272.386)	2047.341 (1734.630)
Cold days	-410.945 (757.252)	260.475 (999.605)	-296.625 (303.943)	-328.711 (467.256)	-1808.847 (1901.392)	2111.620 (2237.566)
Rainfall	-12.552 (10.287)	-16.288 (31.688)	-10.356 (9.415)	-2.339 (6.528)	-16.815 (29.215)	-57.863 (72.857)

On the other hand, the broadcast aman production in both categories of districts enjoys the beneficial impacts of flooding. One additional flood day during the beneficial period can increase the broadcast aman production by 285.081 tons in the more vulnerable areas and 109.932 tons in the less vulnerable areas. The signs of the coefficients of beneficial days are against expectation for HYV aman production in both categories of districts. Local transplant aman production in less vulnerable areas has positive but insignificant correlation while the more vulnerable areas have unexpected but significant correlation with benefit days.

In the first set of overall regression estimates we found that local transplant and broadcast variety of aman rice had expected but insignificant correlation with danger days as well as benefit days. After breaking it down based on the vulnerability index, we can find that more vulnerable areas have expected correlation with danger days for both of the varieties of rice while one of the estimates are significant. But the less vulnerable districts do not experience any negative correlation between local transplant aman and broadcast production and the danger days. For the benefit days, both of the more and less vulnerable areas have expected and meaningful correlation with broadcast aman production. But the local transplant aman production has unexpected & meaningful correlation in the vulnerable districts and expected but insignificant correlation in the less vulnerable districts. HYV aman estimates follow the similar trends both at the national level and district level analysis. The breaking down of the regression supports some of the findings from the literature analysis. The spatial dimensions of vulnerability can produce different correlations with flooding in comparison to the national level estimates. We have found some significant and expected correlation between some varieties of aman rice and the impacts of flood.

5.7.4 Regression on boro rice

The table 9 outlines the regression estimates during the boro season. Most of the farmers in Bangladesh cultivate rice during the boro season as it is less vulnerable to riverine flood or excessive rainfall. And HYV seeds are being used everywhere because of the high amount of yield. In recent years, flash flooding has become a threat for boro rice cultivation. The flood in 2017 has made devastating impact on boro rice production in the northeastern regions of Bangladesh. Regression estimates reveal that HYV boro rice production in vulnerable zones of the country has significantly negative correlation with the danger days. For one additional days of flooding during the dangerous period, 1193.531 tons of rice is being lost. The less vulnerable areas also experience a loss of 518.733 tons of HYV boro rice due to the dangerous effects of flooding, but the estimates are insignificant.

Table 9: Regression estimates for LF and MF districts during the boro season
***, **, * corresponds to 1, 5 and 10 percent level of significance

Variable	HYV Boro (Robust SE)		Local Boro (Robust SE)	
	MF	LF	MF	LF
Danger days	-1193.531** (511.499)	-518.733 (627.100)	-18.215 (31.327)	158.792 (104.876)
Benefit days	-2282.687 (1666.147)	-2130.292 (2133.937)	-21.670 (40.462)	265.416 (173.112)
Warm days	-2805.773 (3099.117)	-3032.840 (3423.719)	-98.138 (69.607)	-35.429 (187.556)
Cold days	1442.960 (1267.398)	286.139 (954.716)	-16.018 (22.314)	-126.169 (102.727)
Rainfall	-42.259 (38.011)	-11.740 (55.801)	-3.277 (1.941)	1.847 (6.559)

Local variety of boro rice also has negative correlation with danger days but they are insignificant. The estimates for benefit days have unexpected signs for HYV boro rice production across both categories of districts. The local variety of boro rice has positive signs for benefit days but they are insignificant. Boro rice production is heavily dependent on irrigation facilities as it is cultivated mostly during the dry season. Flooding has no beneficial impact on boro production, and the signs of the estimates reveal the fact.

5.8 Yield model

Based on the findings of the production, we can see that some of the estimates are significant at the national level while some others are significant at the national level. Some of them have expected signs while some others have unexpected signs or insignificant values. A few transformations in the model are being carried out at this stage.

Firstly, we tried to break away from the traditional rice cropping calendar of Bangladesh and started looking at the different sets of estimates by changing the cropping calendar for danger days and benefit days. It helps us to develop a new calendar where we consider the following times for cropping different varieties of rice. Secondly, instead of total rice production being used as the dependent variable of study, we consider the yield (tons per acreage). Then we convert the yield to log so that it can be interpreted as a sort of elasticity.

Table 10: Renewed timing for danger and benefit days

Season	Sowing/Transplantation period	Harvesting period
Aus	May – July	February - April
Aman	September- November	July- August
Boro	March-may	December-February

Thirdly, we have already created two variables called normalized danger days as well as normalized benefit days. In the yield model we will replace the danger days and benefit days by the normalized danger days and normalized benefit days. Fourthly, we carried out “VIF” analysis to check for multi-collinearity in the production model. It appeared that “VIF” values were pretty high in some cases and after dropping the "rainfall" variable, the "VIF" went down. Total rainfall in the season was found to be linearly correlated with the danger days as well as benefit days. Hence, we dropped it from the controls and run the new regressions without including the variable on the total rainfall in the season. It did not affect the signs and significance in any of those new models. The second set of regressions is run by using the following model.

$$\begin{aligned}\boldsymbol{Rice\ \ Yield_{it}} = \ & \boldsymbol{\alpha} + \ \boldsymbol{\beta_1}\ \boldsymbol{Normalized\ Danger\ Days_{it}} \\ & + \ \boldsymbol{\beta_2}\ \boldsymbol{Normalized\ Benefit\ Days_{it}} + \boldsymbol{\gamma X_{it}} + \boldsymbol{\delta_i} + \boldsymbol{\theta_t} + \boldsymbol{\epsilon_{it}}\end{aligned}$$

5.8.1 Regression estimates for all varieties of rice

We can read from the following table which displays the regression estimates for all varieties of rice across all the districts. The dependent variable in the analysis is the yield per acreage for different varieties of rice. We expect the yield to be negatively related with normalized danger days and positively with the normalized benefit days. But we can see that none of them variables of interests have the expected signs.

The table 11 shows that some of the variables have expected signs but insignificant p values. In the first set of regression for national level data we found HYV boro rice to have a significant and expected relation with danger days. Here we can see that one percent increase in the normalized values of the danger days can cause 0.005 percent decrease of HYV boro production, but the estimate is insignificant, and we cannot reject the zero null hypotheses

Table 11: Regression estimates for all districts and all varieties of rice
***, **, * corresponds to 1, 5 and 10 percent level of significance

	Aus		Aman			Boro	
Variable	Local	HYV	Local Transplant	Broadcast	HYV	Local	HYV
Normalized Danger Days	0.0004 (0.0005)	-0.0004 (0.0008)	-0.0003 (0.0007)	0.0007 (0.0011)	-0.0003 (0.0005)	0.0004 (0.0009)	-0.0005 (0.0006)
Normalized Benefit Days	0.0001 (0.0004)	0.0005 (0.0005)	0.0007 (0.0006)	0.0009 (0.0009)	0.0005 (0.0004)	-0.0005 (0.0008)	0.0001 (0.0006)
Warm Days	0.0044 (0.0028)	0.0045 (0.0044)	0.0020 (0.0033)	-0.0062 (0.0052)	0.0031 (0.0023)	0.0056 (0.0038)	-0.0006 (0.0028)
Cold Days	0.0001 (0.0004)	-0.0014** (0.0007)	-0.0038 (0.0048)	0.0048 (0.0071)	-0.0023 (0.0033)	0.0004 (0.0006)	-0.0005 (0.0004)

5.8.2 Regression on aus rice

In the second set of regression, we did not find any significant or expected estimates for the national level data. Then we split the districts based on their vulnerability to flooding to see if there are variations in the estimates at the regional level. However, it appears that none of the variables of interest have any significant p values. All the varieties of aus rice have expected relation with the normalized benefit days. But they lack significant p values and we cannot say anything firmly about those estimates.

However, only HYV Aus rice in the more flood prone districts have expected signs. It can be said that for a percent increase in the normalized values of the danger days, HYV aus production in more flood prone areas decrease by 0.0009 percentage points. But this estimate is insignificant, and we cannot reject the null here. The estimates for some of the controls are significant but that is not the main concern of this current analysis.

Table 12: Regression estimates for LF and MF districts during the aus season
***, **, * corresponds to 1, 5 and 10 percent level of significance

	Local Aus		HYV Aus	
Variable	LF	MF	LF	MF
Normalized Danger days	0.0005 (0.0011)	0.0005 (0.0005)	0.0006 (0.0012)	-0.0009 (0.0011)
Normalized Benefit days	0.0004 (0.0008)	0.0002 (0.0003)	0.0008 (0.0009)	0.0000 (0.0007)
Warm Days	0.0077 (0.0055)	0.0021 (0.0027)	0.0064 (0.0063)	-0.0019 (0.0062)
Cold Days	-0.0003 (0.0009)	0.0001 (0.0004)	-0.0015 (0.0010)	-0.0019** (0.0009)

5.8.3 Regression on aman rice

The regression estimates for different varieties of aman rice show that some of the estimates have expected and significant signs but most of the estimates are insignificant.

In the estimates for all the districts across all the varieties we found that none of the varieties of aman rice had significant relationship at the national level. But we can see a small change in the significance of the coefficients in this new set of regression. The local transplant aman yield in less vulnerable districts has significant and positive relation with the normalized benefit days.

For one percent increase in the normalized values of the benefit days, the local transplant yield goes up by 0.0015 percentage points. Broadcast and HYV aman yield have also positive relation with normalized benefit days but insignificant. On the other hand, the HYV aman yield for both types of districts and local transplant aman yield for less vulnerable district has negative relation with the normalized values of the danger days but they are insignificant.

Table 13: Regression estimates for LF and MF districts during the aman season
***, **, * corresponds to 1, 5 and 10 percent level of significance

Variable	Local Transplant Aman		Broadcast Aman		HYV Aman	
	LF	MF	LF	MF	LF	MF
Normalized Danger Days	-0.0007 (0.0007)	0.0003 (0.0012)	0.0003 (0.0014)	0.0003 (0.0017)	-0.0004 (0.0008)	-0.0005 (0.0006)
Normalized Benefit Days	0.0015*** (0.0006)	-0.0004 (0.0011)	0.0006 (0.0011)	0.0014 (0.0014)	0.0006 (0.0007)	0.0005 (0.0005)
Warm Days	-0.0012 (0.0031)	0.0082 (0.0066)	-0.0140*** (0.0054)	0.0051 (0.0095)	0.0028 (0.0035)	0.0053 (0.0034)
Cold Days	-0.0062 (0.0056)	-0.0055 (0.0074)	0.0027 (0.0104)	0.0040 (0.0100)	0.0006 (0.0063)	-0.0067* (0.0038)

5.8.4 Regression on boro rice

In the regression estimates for all of the districts, we did not find any of the varieties of boro rice to have significant positive or negative relationship between the yield and the normalized benefit or normalized danger days. The table 14 explains the estimates for boro yield in different types of districts.

The estimates show that boro yield has negative relation with normalized danger days in less vulnerable districts but insignificant. Also, the relationship with normalized benefit days is also unexpected for most of the varieties in different types of districts. Some of the controls have significant estimates which is not the concern of current analysis.

Table 14: Regression estimates for LF and MF districts during the boro season
***, **, * corresponds to 1, 5 and 10 percent level of significance

Variable	Local Boro		HYV Boro	
	LF	MF	LF	MF
Normalized Danger Days	-0.0004 (0.0021)	0.0005 (0.0009)	-0.0007 (0.0013)	0.0000 (0.0007)
Normalized Benefit Days	-0.0009 (0.0021)	-0.0005 (0.0007)	-0.0002 (0.0013)	0.0001 (0.0006)
Warm Days	0.0144** (0.0074)	-0.0024 (0.0040)	-0.0056 (0.0047)	0.0044 (0.0032)
Cold Days	-0.0002 (0.0011)	0.0001 (0.0006)	-0.0003 (0.0007)	0.0000 (0.0005)

The second set of regression analysis had been carried out from the concerns of the efficiency of the dependent as well as independent variables in the first set of regression. Diagnostic testing on multi-collinearity was another reason to drop some of the variables and check the new estimates. But it appears that this kind of transformation of the variables and changes in the model did not help a lot to produce better interpretations.

6 Analysis of the Findings

We have found the regression estimates for different rice varieties with the danger days and benefit days of flooding both at the national level as well as the LF and MF districts. The first set of regression reports the estimates without any transformations of the raw data units for the main variables of interest. In the second set of regression we drop one variable and make some transformations in the way the independent as well as the dependent variables are being measures.

The table 15 and 16 provide a brief overview of the estimates from the production model and the yield model consecutively. The expected sign means for the production model means that rice production is negatively correlated with danger days and positively correlated with benefit days. The yield model introduced some changes in the econometric model as well as some transformations in the variables. We normalized the danger days and benefit days while changed the dependent variable into the log of yield. The estimates here worked as elasticity. For the yield model, the expected signs mean that the rice yield is negatively correlated with normalized danger days and positively correlated with normalized benefit days.

Table 15: Overview of the correlations from production model

Variety	Level	Danger days	Benefit days
local aus	national	Unexpected and insignificant	Unexpected and insignificant
	regional	MF: **Expected** and insignificant LF: Unexpected and insignificant	MF: Unexpected and **significant** LF: **Expected** and insignificant
HYV aus	national	**Expected** and insignificant	Unexpected and **significant**
	regional	MF: **Expected** and insignificant LF: Unexpected and insignificant	MF: Unexpected and insignificant LF: Unexpected and insignificant
L.T. aman	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: **Expected** and **significant** LF: Unexpected and insignificant	MF: Unexpected and **significant** LF: **Expected** and insignificant
B. aman	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: **Expected** and insignificant LF: Unexpected and insignificant	MF: **Expected** and **significant** LF: **Expected** and **significant**
HYV aman	national	Unexpected and insignificant	Unexpected and insignificant
	regional	MF: Unexpected and insignificant LF: Unexpected and insignificant	MF: Unexpected and insignificant LF: Unexpected and insignificant
Local boro	national	Unexpected and insignificant	**Expected** and insignificant
	regional	MF: **Expected** and insignificant LF: Unexpected and insignificant	MF: Unexpected and insignificant LF: **Expected** and insignificant
HYV boro	national	**Expected** and **significant**	Unexpected and insignificant
	regional	MF: **Expected** and **significant** LF: **Expected** and insignificant	MF: Unexpected and insignificant LF: Unexpected and insignificant

Table 16: Overview of the correlations from yield model

Variety	Level	Normalized Danger days	Normalized Benefit days
local aus	national	Unexpected and insignificant	**Expected** and insignificant
	regional	MF: Unexpected and insignificant LF: Unexpected and insignificant	MF: **Expected** and insignificant LF: **Expected** and insignificant
HYV aus	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: **Expected** and insignificant LF: Unexpected and insignificant	MF: **Expected** and insignificant LF: **Expected** and insignificant
L.T. aman	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: Unexpected and insignificant LF: **Expected** and insignificant	MF: Unexpected and insignificant LF: **Expected** and **significant**
B. aman	national	Unexpected and insignificant	**Expected** and insignificant
	regional	MF: Unexpected and insignificant LF: Unexpected and insignificant	MF: **Expected** and insignificant LF: **Expected** and insignificant
HYV aman	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: **Expected** and insignificant LF: **Expected** and insignificant	MF: Unexpected and insignificant LF: Unexpected and insignificant
Local boro	national	Unexpected and insignificant	Unexpected and insignificant
	regional	MF: Unexpected and insignificant LF: **Expected** and insignificant	MF: Unexpected and insignificant LF: Unexpected and insignificant
HYV boro	national	**Expected** and insignificant	**Expected** and insignificant
	regional	MF: Unexpected and insignificant LF: **Expected** and insignificant	MF: **Expected** and insignificant LF: Unexpected and insignificant

Several aspects of the correlation estimates have become apparent to us now. Based on the findings from the regression analysis we can propose the following statements about the dataset, model and the outputs.

- The first set of regression appears to have more efficient estimates than the second set of regressions. The diagnostic testing on multi-collinearity and several other transformations of the variables did not bring any meaningful change of the estimates. Therefore, the interpretations of the findings are based on the first set of regression.

- Not all the estimates have their expected signs as well as the significant p values. This points out to some of the limitations of the model or the way dataset has been constructed. But some of the coefficients have expected signs and significant p values which testify the yet limited merits of the model used for the analysis in this paper. Keeping in mind of the novel approach followed in this analysis, we can proceed further to discuss the findings and relate them with the existing literature, theories and the reality.

- Most of the previous literature did not find out any long-term impact of flooding on the rice production. The ongoing analysis also supports this fact for aus and aman season but not the boro rice production. One important aspect of the previous researches which have used the rice production data is that, almost all of them have been carried out before the year 2000 and the only recent paper was that of Banerjee (2010), but the author used agricultural productivity (production per hectare) as the variable of analysis. Shaw (2018) has showed that boro rice production is highly vulnerable to the flash flooding and this kind of incident started to took place from 1996. The flash flooding in March, April and May has become a constant threat for the farmers especially in the north eastern region and south eastern hilly regions of Bangladesh. Changing patterns of flooding in last few decades is often supposed to be correlated with climate change related incidents.

- The present findings highly support the common proposition about the spatial vulnerability of rice cropping with flood. The local transplant aman and HYV boro rice is negatively correlated with danger days for the flood hazard prone regions. The estimates have been significant. Aus rice is not produced in most of the areas of Bangladesh and it occupies only 9.25 percentage of total amount of rice cultivable lands in Bangladesh. Therefore, it might not be possible to get any kind of meaningful correlation of aman production with flooding as it is not produced that much. At the same time, the broadcast aman rice is also significant and positively correlated with the benefit days in both categories of districts. In the general regression for all the districts of the country, we could only find out the negative correlation of HYV boro rice with danger days and nothing else from the other estimates. After breaking it down based on hazard index, the number of expected and significant estimates has increased.

- Some of the factors considered under time fixed effects are powerful and can be a possible reason why the flood events have not been able to exert much influence on the total production of rice. Bangladesh Rice Research Institute has developed around 41 varieties of HYV aman rice over the last 40 years(BRRI, 2019). Flood resistant varieties of rice could stave off the negative impacts of flooding. The scientific innovation on flood tolerant variety over the years and government initiatives of flood management are two such important factors that have been often referred as the driving forces behind the growth of rice production. Controlling these two variables might be useful for getting more of the estimates with expected and significant signs.

- There are some inherent limitations of the model. Flooding has been defined and measured in a simplistic way where we do not have any exact information on two important aspects, namely the extent of flood, and the duration of flood. Because the rice production data covers the whole of the district. But the flooding related variables in the study can be improved which, however, also opens a new avenue of further research. But this is also challenging as the satellite imagery or any other information on flooding in the 19^{th} century is not very available.

- Finally, a careful overview of the transformed variables in the second set of regression can be a useful resource for future research and publications. Although it did not produce meaningful results, but different sets of regression equations can be applied on the existing data. Hence there are multiple scopes for finding out the true correlations between the danger levels at different periods of time and the rice production in Bangladesh.

References

Ahmed, R., & Bernard, A. (1989). *Rice price fluctuation and an approach to price stabilization in Bangladesh* (Research Reports No. 72). Retrieved from International Food Policy Research Institute (IFPRI) website: https://econpapers.repec.org/paper/fprresrep/72.htm

Asada, H., Matsumoto, J., & Rahman, R. (2005). Impact of Recent Severe Floods on Rice Production in Bangladesh. *Geographical Review of Japan*, *78*(12), 783–793. https://doi.org/10.4157/grj.78.783

Banerjee, L. (2010). Effects of Flood on Agricultural Productivity in Bangladesh. *Oxford Development Studies*, *38*(3), 339–356. https://doi.org/10.1080/13600818.2010.505681

Banglapedia. (2012). AgroecologicalZone.jpg (530×681). Retrieved June 16, 2019, from http://en.banglapedia.org/images/f/f2/AgroecologicalZone.jpg

BBS. (2018). *Yearbook of Agricultural Statistics*. Retrieved from http://203.112.218.65:8008/WebTestApplication/userfiles/Image/LatestReports/Yearbook_2014.pdf

Brammer, H. (1990). Floods in Bangladesh: II. Flood Mitigation and Environmental Aspects. *The Geographical Journal*, *156*(2), 158–165. https://doi.org/10.2307/635323

BRRI. (2019). Aman Rice Varieties | Bangladesh Rice Knowledge Bank. Retrieved June 18, 2019, from http://knowledgebank-brri.org/brri-rice-varieties/aman-rice-varieties/

BWDB. (2016). Annual Flood Report 2016. Retrieved November 9, 2018, from http://www.ffwc.gov.bd/

Dewan, A. M., Nishigaki, M., & Komatsu, M. (2003, March). Floods in Bangladesh: A Comparative Hydrological Investigation on Two Catastrophic Events. Retrieved November 8, 2018, from 岡山大学環境理工学部研究報告 website: http://ousar.lib.okayama-u.ac.jp/11503

Dutta, D., Herath, S., & Musiake, K. (2003). A mathematical model for flood loss estimation. *Journal of Hydrology*, *277*(1), 24–49. https://doi.org/10.1016/S0022-1694(03)00084-2

EM-DAT. (2019). emdat_db. Retrieved March 8, 2019, from https://www.emdat.be/emdat_db/

Guiteras, R., Jina, A., & Mobarak, A. M. (2015). Satellites, Self-reports, and Submersion: Exposure to Floods in Bangladesh. *The American Economic Review*, *105*(5), 232–236.

Hofer, T., & Messerli, B. (2006). *Floods in Bangladesh: History, dynamics and rethinking the role of the Himalayas*. Tokyo ; New York: United Nations University Press : FAO.

Hossain, D. M., Bayes, A., & Islam, D. S. F. (2014). *A Diagnostic Study on Bangladesh agriculture*. 219.

Hossain, M. (1990). Natural Calamities, Instability in Production and Food Policy in Bangladesh. *The Bangladesh Development Studies*, *18*(4), 33–54. Retrieved from JSTOR.

Hossain, M. M. (2008). *THE FLOOD PROBLEM AND MITIGATION METHODS IN BANGLADESH*. 44.

Khalequzzaman, M. (1993). *Recent floods in Bangladesh: Possible causes and solutions*. 16.

Khalil, G. Md. (1990). Floods in Bangladesh: A question of disciplining the rivers. *Natural Hazards*, *3*(4), 379–401. https://doi.org/10.1007/BF00124395

Khatun, M. A., Rashid, Md. B., & Hygen, H. O. (2016). *Climate of Bangladesh*. Retrieved from https://www.met.no/publikasjoner/met-report/met-report-2016/_/attachment/download/b50e3f06-4485-4f34-b642-0a1e86f12c7d:a483b63367b0f087f3bd9410e135a5e0837d1927/MET-report-08-2016.pdf

Mirza, M. M. Q. (2003). Three Recent Extreme Floods in Bangladesh: A Hydro-Meteorological Analysis. In M. M. Q. Mirza, A. Dixit, & A. Nishat (Eds.), *Flood Problem and Management in South Asia* (pp. 35–64). https://doi.org/10.1007/978-94-017-0137-2_2

Mirza, M. Q. (2002). Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Global Environmental Change*, *12*(2), 127–138. https://doi.org/10.1016/S0959-3780(02)00002-X

Murshid, K. A. S. (1987). Weather, New Technology and Instability in Foodgrain Production in Bangladesh. *The Bangladesh Development Studies*, *15*(1), 31–56. Retrieved from JSTOR.

Nishat, A. (2004). *A Review of Flood Management in Bangladesh:* 48.

Okuyama, Y. (2009). *CRITICAL REVIEW OF METHODOLOGIES ON DISASTER IMPACT ESTIMATION*. 27.

Paul, B. K., & Rasid, H. (1993). Flood Damage to Rice Crop in Bangladesh. *Geographical Review*, *83*(2), 150–159. https://doi.org/10.2307/215253

Sciance, M. B., & Nooner, S. L. (2018). Decadal flood trends in Bangladesh from extensive hydrographic data. *Natural Hazards*, *90*(1), 115–135. https://doi.org/10.1007/s11069-017-3036-7

Shaw, R. (2018). Flood and Sustainable Agriculture in the Haor Basin of Bangladesh: A Review Paper. *Universal Journal of Agricultural Research*, 10.

Yang, Y. C. E., Ray, P. A., Brown, C. M., Khalil, A. F., & Yu, W. H. (2015). Estimation of flood damage functions for river basin planning: A case study in Bangladesh. *Natural Hazards*, *75*(3), 2773–2791. https://doi.org/10.1007/s11069-014-1459-y

Younus, M. A. F. (2014). Floods in Bangladesh: Nature, History, Research, Causes and Types. In M. A. F. Younus (Ed.), *Vulnerability and Adaptation to Climate Change in Bangladesh: Processes, Assessment and Effects* (pp. 77–100). https://doi.org/10.1007/978-94-007-5494-2_3

Appendix

STATA codes used in production model

Setting the fixed effect parameters:

```
xtset district year
```

Regression for all varieties of rice

```
xtreg local_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year, fe vce(robust)

xtreg hyv_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year , fe vce(robust)

xtreg local_transplant_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year, fe vce(robust)

xtreg broadcast_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year, fe vce(robust)

xtreg hyv_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year, fe vce(robust)

xtreg local_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year, fe vce(robust)

xtreg hyv_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year, fe vce(robust)
```

Regression for LF and MF districts during aus season

xtreg local_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year if vulnerable == 1, fe vce(robust)

xtreg local_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year if vulnerable == 0, fe vce(robust)

xtreg hyv_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year if vulnerable == 1, fe vce(robust)

xtreg hyv_aus danger_days_aus benefit_days_aus warm_days_aus cold_days_aus rain_aus i.year if vulnerable == 0, fe vce(robust)

Regression for LF and MF districts during aman season

xtreg local_transplant_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 1, fe vce(robust)

xtreg local_transplant_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 0, fe vce(robust)

xtreg broadcast_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 1, fe vce(robust)

xtreg broadcast_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 0, fe vce(robust)

xtreg hyv_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 1, fe vce(robust)

xtreg hyv_aman danger_days_aman benefit_days_aman warm_days_aman cold_days_aman rain_aman i.year if vulnerable == 0, fe vce(robust)

Regression for LF and MF districts during boro season

```
xtreg hyv_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year if vulnerable == 1, fe vce(robust)

xtreg hyv_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year if vulnerable == 0, fe vce(robust)

xtreg local_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year if vulnerable == 0, fe vce(robust)

xtreg local_boro danger_days_boro benefit_days_boro warm_days_boro cold_days_boro rain_boro i.year if vulnerable == 1, fe vce(robust)
```

STATA codes used in yield model

Regression for all varieties of rice

```
reg n_loc_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index

reg n_hyv_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index

reg n_lt_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index
```

```
reg n_broadcast_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index
reg n_hyv_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index

reg n_local_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro i.year i.index
reg n_hyv_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro i.year i.index
```

Regression for LF and MF districts during aus season

```
reg n_loc_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index if vulnerable == 0
reg n_loc_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index if vulnerable == 1

reg n_hyv_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index if vulnerable == 0
reg n_hyv_aus_yield norm_danger_aus norm_benefit_aus warm_days_boro cold_days_boro i.year i.index if vulnerable == 1
```

Regression for LF and MF districts during aman season

reg n_lt_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 0

reg n_lt_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 1

reg n_broadcast_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 0

reg n_broadcast_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 1

reg n_hyv_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 0

reg n_hyv_aman_yield norm_danger_aman norm_benefit_aman warm_days_aman cold_days_aman i.year i.index if vulnerable == 1

Regression for LF and MF districts during boro season

reg n_local_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro i.year i.index if vulnerable == 0

reg n_local_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro i.year i.index if vulnerable == 1

```
reg n_hyv_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro
i.year i.index if vulnerable == 0
reg n_hyv_boro_yield norm_danger_boro norm_benefit_boro warm_days_boro cold_days_boro
i.year i.index if vulnerable == 1
```