ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/339310967

Climate change impacts on farmland value in Bangladesh

Article *in* Ecological Indicators · February 2020

DOI: 10.1016/j.ecolind.2020.106181

CITATIONS
17

READS
727

8 authors, including:

Mohammad Shakhawat Hossain
World Vision
10 PUBLICATIONS **76** CITATIONS

SEE PROFILE

Muhammad Arshad
Leibniz Centre for Agricultural Landscape Research
28 PUBLICATIONS **350** CITATIONS

SEE PROFILE

Harald Kaechele
Leibniz Centre for Agricultural Landscape Research
86 PUBLICATIONS **1,363** CITATIONS

SEE PROFILE

Imran Khan
Nanjing University of Information Science & Technology
49 PUBLICATIONS **1,057** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project

Agro-meteorological Information Systems Development (AMISD) (Sub-component C-2) View project

Project

Assessment of cropping patterns for sustainable intensification in drought prone ecosystem using remote sensing and geospatial modeling View project

All content following this page was uploaded by Mohammad Shakhawat Hossain on 02 April 2020.

The user has requested enhancement of the downloaded file.

Ecological Indicators 112 (2020) 106181

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Climate change impacts on farmland value in Bangladesh

Mohammad Shakhawat Hossain[a], Muhammad Arshad[b,c], Lu Qian[a,*], Harald Kächele[b,c], Imran Khan[a], Md Din Il Islam[a], M. Golam Mahboob[d]

[a] College of Economics and Management, Northwest A&F University, 3 Taicheng Road, Yangling, Shaanxi 712100, PR China
[b] Sustainable Land Use in Developing Countries, Leibniz Center for Agricultural Landscape Research (ZALF), Müncheberg, Germany
[c] Department of Landscape Management and Nature Conservation, Eberswalde University for Sustainable Development, Germany
[d] Bangladesh Agricultural Research Institute, Gazipur 1701, Bangladesh

ARTICLE INFO

Keywords:
Climate change
Ricardian model
Farmland value
Flooding
Adaptation
Bangladesh

ABSTRACT

Many studies have examined the effects of climate change on farmland value in developed countries, but our understanding of the impact of climate change on farmland value is still very limited, especially in developing countries. In this study, we aimed to assess the effects of climate change on farmland value in Bangladesh using the Ricardian model. Household-level data collected from seven selected agroecological zones in Bangladesh were used to estimate the relationships among farmland value and long-term climate, farm household, and policy variables. The results showed that the current land values of farmers are sensitive to climate. A new variable called "flooding" was added to the Ricardian model, and the results indicated that floods are responsible for reductions in farmland value, especially in lowland areas. Among the socio-economic variables, the availability of extension services and access to irrigation facilities were positively correlated with farmland value. The estimated marginal impact results suggested that increases in temperature were associated with losses in small farmland value, whereas the precipitation levels in both seasons positively influenced farmland value. Selected global climate models predicted that climate change would have a negative impact on land value depending on the climate model and source of farm income. The empirical findings obtained from this study are expected to contribute to the formulation of sustainable adaptation strategies to maintain farm productivity and farmland value in Bangladesh in the context of climate change.

1. Introduction

Climate is an important factor of agricultural productivity, and temperature and precipitation are the major drivers of farm production (Quaye et al., 2018). Therefore, climate change will have significant impacts on agricultural productivity, efficiency of crop production, farmland value, and net farm income (Kurukulasuriya and Ajwad, 2007; Massetti and Mendelsohn, 2011; Moore and Lobell, 2014; Chatzopoulos and Lippert, 2015; Arshad et al., 2017). However, the influence of climate change on farm productivity and profitability varies widely across space and time (Mahmood et al., 2019). There is a considerable geographic disparity within and across regions, particularly in tropical and non-industrialized countries. As such, there will be high spatial variability of the impact of climate change (Mendelsohn, 2008; Ruane et al., 2012). Thus, assessing the impacts of climate change on farmers profit and farmland value at the regional or local scale is very important, as a decline in farm income has been reported to influence the consumption portfolios of farm households (Amjath- Babu et al., 2016).

The traditional approaches (e.g., the production function approach) used to examine the effects of climate change describe the agronomic relationships between production and soil and climatic factors based on an empirical or experimental production function to predict environmental damage (Rosenzweig and Parry, 1994; Roco et al., 2017; Arshad et al., 2018). These approaches involve modifying one or several input variables to estimate their effects on agriculture or crop productivity, but the ability of farmers to proactively adapt their farmland is not always considered. Mendelsohn et al. (1994) noted bias in the production function approach because it fails to adequately account for crop substitution effects or the adaptive land management practices implemented by farmers. Thus, they proposed an alternative approach in which an integrated indicator is employed as a proxy for the productive value of a given plot of farmland. This approach is outlined to include potential mixtures of crops and/or livestock combinations implemented by farmers to incorporate the indirect substitution of inputs, labor, and other farm activities but not land rent.

* Corresponding author.
E-mail address: luqian@nwafu.edu.cn (L. Qian).

https://doi.org/10.1016/j.ecolind.2020.106181
Received 3 October 2018; Received in revised form 17 January 2020; Accepted 3 February 2020
1470-160X/ © 2020 Elsevier Ltd. All rights reserved.

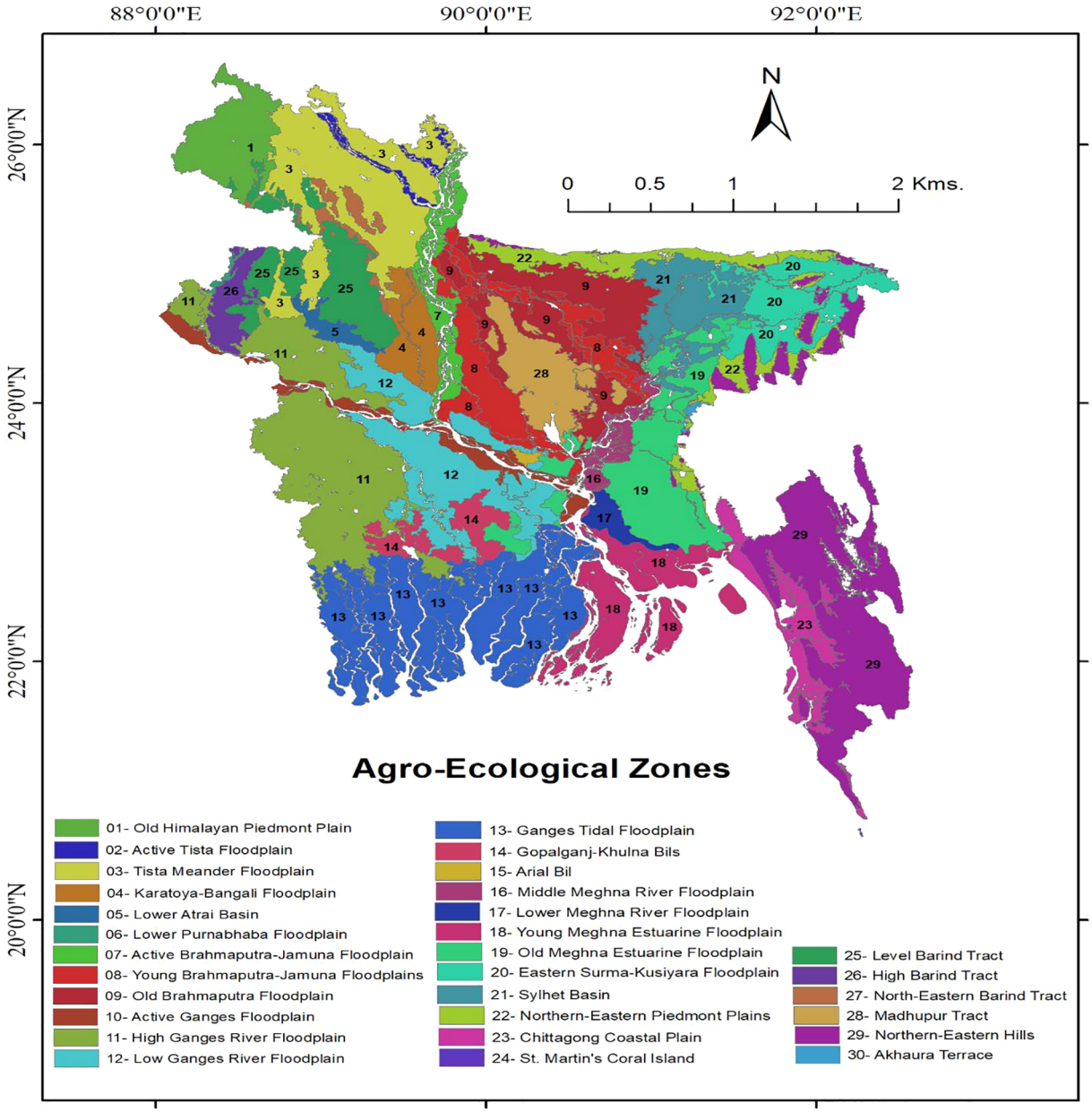

Fig. 1. Map of the AEZs in Bangladesh. Seven AEZs were surveyed (AEZ number 3, 9, 11, 18, 19, 20, 29) out of 30 (Appendix-A) in this study. Source: BARC (2005).

One of the earliest studies to examine the impact of climate change on farmland value was conducted by Mendelsohn et al. (1994), who considered a range of additional environmental variables, such as soil type and quality, which are controlled by temporal variations in climatic variables, and they showed that temperature and precipitation play vital roles in determining farmland value throughout much of the United States of America. Moreover, Bobojonov and Aw-Hassan (2014) in Central Asia and Sanghi et al. (1997) in Brazil found that both temperature and precipitation variability negatively affect farmland value when measured over medium-term time scales. The Ricardian framework has been most widely used in studies in which medium-term climatic data are employed to approximate the climate of a region and to assess its effects on farmland value. This framework was first introduced by Mendelsohn et al. (1994) to assess the impacts of climate change on land value and then employed in other studies (Seo and Mendelsohn, 2008; Moore and Lobell, 2014; Bozzola et al., 2014; Fezzi and Bateman, 2015; Chatzopoulos and Lippert, 2016; Quaye et al., 2018). Most of the previous studies were conducted in developed countries where larger and more comprehensive data sets are available. By contrast, most of the studies performed in developing countries have only analyzed the impacts of climate change on the net revenue from agricultural productivity (Seo and Mendelsohn, 2008; Mishra et al., 2015; Abidoye et al., 2017a; Abidoye et al., 2017b; Hossain et al., 2019a; Hossain et al., 2019b). Few studies have considered the impact of climate change on farmland value in developing countries (Arshad et al., 2016a; Kanwar and Bohara, 2017). However, changes in climate may have serious effects on farmland value in developing countries such as Bangladesh, where significant changes are already evident (Ruane et al., 2012; Rahman et al., 2017). Thus, given its high dependency on agriculture and vulnerability to climate change, it is very important to elucidate the possible impacts of climate change on farmland value in Bangladesh.

According to the IPCC (2014), Bangladesh is one of the most susceptible countries in the world to natural disasters and climate risks. Its geographical location, expansive delta, vast plains, and low-lying lands combined with its monsoon climate and multiple large river systems

Table 1
Current adaptation techniques undertaken by farmers across the seven AEZs.

Adaptation techniques	Percent of sampled households
Increased use of irrigation	71
Crop diversification	37
Use of different crop varieties	32
Changes of planting dates and crop types	30
Changes of cropping patterns	27
Cultivating short duration crops	24
Integrated farming systems	18
Mechanization of farms	13
Water and soil management	10
Changes in land use for nonfarm activities	8
Agroforestry techniques	7

Column sum to > 100% because sampled households reported more than one adaptation technique.

have made Bangladesh highly exposed to natural calamities (World Bank, 2010). Floods, cyclones, tidal storms, river erosion, tornados, hailstorms, and droughts are common in Bangladesh, and they affect farm productivity on a regular basis (DDM, 2017). For example, Cyclone Sidr in 2007 destroyed the entire economy of Bangladesh, and the total damages amounted to US$ 1.67 billion (IFRC, 2010). The current incidence of floods in the northern part of Bangladesh and tropical Cyclone Mora affected an estimated 3.3 million people and 562,594 ha of agricultural crops in 2017 (DDM, 2017).

Over the last four decades, the average daily temperature in Bangladesh has increased at a rate of 0.103 °C/decade (Shahid, 2010). Changes in spatial variability and a negative trend in winter season precipitation have also been reported (Shahid, 2010). According to the IPCC (2007), increases in the annual average temperatures of 1 °C by 2030, 1.4 °C by 2050, and 2.4 °C by 2100 are predicted for Bangladesh. Based on these projections, it is anticipated that the country will experience severe heat waves, more warm days, and a greater risk of droughts. These projections may have harsh impacts on an agroeconomy based country such as Bangladesh, where the agriculture sector also contributes approximately 17% to the country's gross domestic product and employs more than 45% of the total labor force (BBS, 2016). Agriculture also provides a livelihood for 70% of the rural population in Bangladesh either directly or indirectly (BBS, 2016). Given the sensitivity and vulnerability of the farming systems of Bangladesh to climate change and weather extremes, a specific investigation of its effects on Bangladesh is necessary.

The major objective of this study was to assess the impact of long-term climate change on farmland value in Bangladesh. The marginal impacts of climate and future climate projections on farmland value were also determined. We achieved these objectives by conducting a Ricardian analysis modeling country and region-specific variables based on a unique data set comprising 420 farms across seven selected agroecological zones (AEZs) in Bangladesh.

2. Materials and methods

2.1. Location of the study

Bangladesh is located in South Asia, and it has a total area of over 147,000 km^2. Bangladesh has a tropical monsoon climate with high humidity, high temperatures, and heavy seasonal rainfall. The average annual rainfall varies from 1500 mm in the west-central part to over 3500 mm in the northeast and southeastern parts of the country. Approximately 80% of the total rainfall occurs during the monsoon season (June to September). The average summer temperature ranges from 30 °C to 40 °C, whereas the average winter temperature varies from 18 °C to 22 °C. April is the hottest month and January is the coldest in Bangladesh (Banglapedia-climate, 2014). The land types in Bangladesh can be divided into 30 AEZs based on physiographic features, soils, and land levels in relation to flooding and agroclimatic characteristics (BARC, 2005) (Fig. 1). Two distinct cropping seasons are usually observed in Bangladesh: The dry season lasts from November to March and the wet season lasts from April to October. Wheat, pulses, Boro rice, oilseeds, potato, and winter vegetables are usually grown in the dry season, while jute, summer vegetables, Aus and Aman rice are grown in the wet season (Banglapedia-agriculture, 2016).

2.2. Sampling and data

2.2.1. Sampling procedure

We applied a disproportionate stratified random sampling technique to obtain a representative sample across seven selected AEZs in Bangladesh. The characteristics of the selected AEZs are shown in Appendix A. This classification provided a rigorous scientific and statistical basis for stratification. Each AEZ was considered as one stratum. One administrative district was randomly selected from each stratum (Fig. 1). Two Upazilas (lower administrative units) were randomly selected from each selected district. In addition, two villages from each Upazila and 15 respondents from each village were randomly chosen, resulting in 60 respondents from each AEZ, with a total of 420 samples across all seven AEZs.

2.2.2. Primary data

Using a structured questionnaire, primary data were collected from respondents across seven selected AEZs in Bangladesh. For this purpose, three efficient enumerators were employed to conduct the questionnaire pretests and final data collection. The questionnaire solicited detailed information regarding farm household and socioeconomic characteristics of the sampled households, including basic farm household characteristics, farm size, access to extension services and market facilities, availability of farm credit and irrigation resources, etc. Information on farmers' perception of the soil texture on their farm (loamy or clay texture), local climate dynamics over the last decade, and any perceived effects of climate variations on the productivity of their farms was also collected. We subsequently collected details of the current adaptation measures undertaken by farmers to mitigate the effects of climate change (Table 1). Table 1 shows that, among the different adaptation measures employed, increased use of irrigation was the most important adaptation measure across the seven selected AEZs in the country. We then requested detailed information regarding farmland value by eliciting the perception of farmers of the market value of their land in 2017 when the survey was conducted.

The core variable for the Ricardian analysis is the farmland value per hectare. It is generally assumed that land markets are relatively well-organized. Similar to other developing countries, the farmland markets in Bangladesh are generally operated at both formal and informal levels. Farmlands are usually priced according to tradition or on a subjective basis (Ay and Latruffe, 2013), with little consideration of modern land market systems. However, in periurban areas, markets may be more established and formal. It is assumed that some divisional land revenue departments preserve records related to value, land ownership, and transfers, but there is no systematic collection of historical data concerning farmland sales and purchases in any district. The data that are available at the district level are mostly proprietary.

It is widely assumed that the value of farmland is determined based on the biophysical attributes of the land (e.g., land productivity and water-holding capacity), which are partly affected by the estimates made by farmers of the potential productivity of a given allotment (Miranowski and Hammes, 1984; Peterson, 1986; Buck et al., 2014). Therefore, there could be potential errors in the estimated farmland value when it is compared with a fully functioning market system, in which information is widely available and shared. However, the errors in the evaluations of farmland value are not always correlated with independent climatic variables, such as temperature and precipitation, which we used in our study (Mendelsohn et al., 1994). Given these

imperfect land markets and the nonavailability of appropriate data in Bangladesh, we used the farmland prices reported by farmers. Therefore, the participants were asked to report the price of their farmland in local currency units and were also asked about the approximate selling price of their farmland on the date they were interviewed. Finally, the reported land values were converted into US dollars per hectare. We completed all of the surveys between January 2017 and April 2017.

2.2.3. Secondary data

Monthly precipitation and temperature data for the period from 1971 to 2016 (46 years) recorded at 36 meteorological stations distributed throughout Bangladesh were collected from the Meteorological Department. To estimate the climate for each surveyed district, climate data were interpolated using the inverse weighted distance method. Two different approaches were tested for modeling purposes. In the first approach, we used four 3-month seasons comprising winter (December to February), spring (March to May), summer (June to August), and fall (September to November) because this is the standard method employed for capturing seasonal effects in previous Ricardian studies (Mendelsohn and Massetti, 2017). In the second approach, we divided the whole year into two basic cropping seasons in Bangladesh: wet (April to October) and dry (November to March) seasons. The second approach was considered appropriate for Bangladesh (Abidoye et al., 2017a) and applied for the final analysis. Rainfall and temperature were both measured as the average monthly climate during each cropping season. The wet and dry cropping seasons are also known as summer and winter, respectively, in Bangladesh.

2.3. Ricardian method

The Ricardian method is named after David Ricardo (1772–1823), who proposed that farmland prices approximate the net productivity of agricultural land in the long run, where land value represents the current value of the future stream of net farm income (Ricardo, 1817). Mendelsohn et al. (1994) employed the Ricardian approach to understand the behavior of farmers when adapting to the impacts of climate change on crop and farm productivity. Thus, this approach considers the adjustments made by farmers to adapt to climatic variability, for example, such as by changing their use of crop species, inputs, or cultural management practices to optimize the whole-farm yield and revenue. This approach assumes that farmers are sufficiently economically rational to adapt to local climatic and environmental changes and that they are also able to efficiently produce outputs relative to a given set of inputs. Mendelsohn et al. (1994) argued that other models (e.g., crop growth simulation models and agroeconomic models) may overestimate the negative impact of climate change by narrowly focusing on the simulated yield responses of a single crop or cropping systems, whereas farmers actually manage whole-farm enterprises with multiple crops and other productive components. Therefore, the Ricardian approach aims to estimate the empirical relationship between climatic variables (temperature and precipitation in the present study) and the value of farmland based on cross-sectional regression analyses.

The advantages of this approach include: (i) accounting for all major enterprise activities on the sampled farms; (ii) considering the adaptations of individual farmers to perceived climatic changes; and (iii) accounting for observed farmland value as a function of the adjustments that farmers make in response to biophysical factors, including climate. The Ricardian method also assumes that farmers are sufficiently cognizant of the effects of climate on crop productivity and that they react proactively to mitigate any negative effects. However, the Ricardian method also has some limitations. For example, the method does not measure the effect of prices (Cline, 1996) and carbon dioxide (CO_2) fertilization (Mendelsohn and Nordhaus, 1996). Thus, the effects of prices and carbon fertilization need to be included in post estimation analyses (Abidoye et al., 2017a). For example, prices will depend on global demand and supply, and carbon fertilization will depend on the CO_2 concentration (Abidoye et al., 2017b). The Ricardian output in each region can be adjusted as these variables will change in the future. The Ricardian method combines farmland value and crop production value into a single composite unit (Chatzopoulos and Lippert, 2016). Furthermore, the adaptations made by farmers are considered implicitly, whereas the transactions and transition costs associated with crop management and behavioral change are ignored as is the time that may be required to fully implement such changes (Kelly, 2005). Another controversial limitation is related to the application of irrigation (Cline, 1996), which can mitigate the effects of high temperatures or droughts. Some studies have argued that irrigated and rainfed farms should be analyzed separately in Ricardian studies (Mendelsohn and Dinar, 2003), whereas others suggest that irrigation should be considered to be an endogenous variable (Kurukulasuriya et al., 2011). However, this is not an issue in Bangladesh because most farms rely on irrigation (Acharjee et al., 2017).

2.4. Empirical model specification

According to Mendelsohn et al. (1994), the Ricardian model can be expressed as follows:

$$L_v = f(C, F, H, P) \tag{1}$$

where L_v is the farmland value per hectare; C is the vector of climate variables; F is the flood classification of the land; H comprises the farm household variables, including the age and education of the respondent, household size, farming experience, farm size, and soil type (loamy or clay soil); and P is the vector of policy variables, including access to market, agricultural extension services, access to farm credit, and access to irrigation facilities.

The standard Ricardian model is based on a quadratic formulation of the climatic variables. Therefore, the empirical model can be expressed as:

$$L_v = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 F + \beta_4 H + \beta_5 P + u \tag{2}$$

where C and C^2 capture the levels and quadratic terms for the climatic variables (temperature and precipitation), respectively, and u is an error term. To capture the expected nonlinear shape of the response function between the land value and climate, linear and quadratic terms for temperature and precipitation are introduced in this study. Mendelsohn et al. (1994) showed that farmland value has a concave relationship with temperature. The farmland value function should have an inverted U-shape if the quadratic term is negative and a U-shape when the quadratic term is positive.

We included a new variable named "flooding" in our Ricardian regression analysis because flooding is a very common natural hazard compared with other hazards in Bangladesh. Every year, flooding results in a loss of human lives and affects the country's entire economy. During the monsoon season, approximately 21% of the land is flooded every year, but more than 60% of the total land can be inundated in severe cases (Dewan et al., 2003). In our analysis, the flooding variable was assigned according to five categories based on the relative frequency and depth of floods: highland, medium highland, upper lowland, medium lowland, and lower lowland (Appendix B). The probability and severity of flooding increase when moving from highland to lower lowland regions. We included these categorical variables as dummy variables to capture the effect of flooding in our analysis.

According to Eq. (2), the marginal effects of a change in temperature or precipitation on farmland value can be expressed as follows:

$$\partial L_v/\partial T = \beta_1 + 2\beta_2 T \text{ and } \partial L_v/\partial R = \beta_3 + 2\beta_4 R \tag{3}$$

where T and R denote temperature and precipitation, respectively.

The change in annual welfare, ΔW, due to the climate changing from (C_0) to (C_1) can be measured as follows:

$$\Delta W = V(C_1) - V(C_0) \tag{4}$$

Table 2
Summary statistics of the variables used in the model (Sample size n = 420).

Variables	Mean	Standard deviation
Land value (US$/hectare)	39647.32	14987.21
Temperature, wet season (in degrees Celsius)	28.10	0. 54
Temperature, dry season (in degrees Celsius)	21.15	0. 98
Precipitation, wet season (in Millimeters)	300.17	105.84
Precipitation, dry season (in Millimeters)	20.89	8.81
Highland (dummy variable) (yes = 1, no = 0)	0.81	0.39
Lowland (dummy variable) (yes = 1, no = 0)	0.25	0.44
Gender (gender of the farmer) (1 = male, 0 = female)	0.97	0.18
Farmers' age (years)	47.85	9.68
Education (years of schooling)	6.11	2.17
Farm household size (number of household members)	6.17	1.41
Farming experience (years of experience)	26.49	9.05
Loamy soil (dummy variable) (Loamy soil = 1, non-loamy soil = 0)	0.29	0.41
Clay soil (dummy variable) (Clay soil = 1, non-clay soil = 0)	0.36	0.27
Access to bank credit (yes = 1, no = 0)	0.27	0.44
Access to irrigation (yes = 1, no = 0)	0.79	0.41
Access to extension services (yes = 1, no = 0)	0.41	0.49
Access to market (yes = 1, no = 0)	0.49	0.37

The land value increases if the change is beneficial, and vice versa.

The impact of future climate change on farmland value in Bangladesh was also examined using Eq. (4) in this study. To estimate future changes in the surface temperature and precipitation in each district, two coupled atmospheric oceanic general circulation models (AOGCMs) were applied, namely, the Canadian Earth System Model (CanESM2) (Chylek et al., 2011) and the Beijing Normal University Earth System Model (BNU-ESM) (Ji et al., 2014). The data were downloaded from the Coupled Model Intercomparison Project Phase 5 (CMIP5) website (http://pcmdi9.llnl.gov). The simulated monthly mean daily surface temperatures and monthly total precipitation for each model were averaged to estimate the monthly mean climatological changes (relative percentages of precipitation change and absolute temperature change) in the periods from 2021 to 2060 and from 2061 to 2100 (relative to the historical period 1971–2005) for the Representative Concentration Pathway RCP8.5 scenarios (Van Vuuren et al., 2011).

STATA statistical software version 14.0 was used to analyze the data and run the Ricardian model. The summary statistics of the climate and other variables used in the analysis are presented in Table 2.

3. Results

Table 3 presents the results obtained by the two Ricardian models for farmland value after introducing the climate, flooding, soil, and social variables. In the first regression, only climate variables (temperature and precipitation) and their quadratic terms were included. Along with the climatic variables, flooding, soil, and other social variables were also included in the second regression. The two regressions explored whether adding country and region-specific variables changed the underlying results on climate impacts. To minimize multicollinearity among the independent variables, farming experience was excluded from the analysis because it was correlated with the age. To reduce heteroscedasticity, a robust method was applied for the estimation of t-statistics.

The results presented in Table 3 show that wet season temperature variable was significant in both models (p-value < 0.05) and had a negative coefficient, whereas their quadratic terms were significantly (p-value < 0.05) and positively associated with farmland value. The coefficients for the dry season temperature in both models were positive and statistically significant, with p-values of < 0.05 and < 0.01, respectively, but their quadratic terms were also significant (p-values < 0.05 and < 0.01) and negatively correlated with farmland value. In addition, the coefficients for wet season precipitation in models 1 and 2 were positive and statistically significant (p-value < 0.05), whereas their quadratic terms were significant (p-value < 0.05) and negatively associated with land value. Moreover, dry season precipitation in both models (1 and 2) had positive coefficients, and they were statistically significant, with p-values < 0.05 and < 0.01, respectively, whereas their quadratic terms were significant (p-values < 0.1 and < 0.01) and negatively correlated with land value. From Appendix B, it can be observed that 24.68% of the sampled farms were in highlands and another 49.84% were in medium highlands. The remaining 25.48% of farms were lowland areas. Highland had a positive coefficient whereas lowland had a negative coefficient with a p-value of < 0.01. Among the socioeconomic variables, access to irrigation, farm size, access to agricultural extension services, and loamy soil were positively correlated with farmland value with a p-value of < 0.05, < 0.01, < 0.1 and < 0.01, respectively.

The results of marginal impacts are presented in Table 4. From the Table, it can be noticed that a marginal increase in temperature in the wet season would result in a loss of land value of approximately US$ 1084 per hectare. By contrast, a marginal increase in temperature during the dry season would cause an increase in land value of approximately US$ 716 per hectare. Table 4 also shows that farmland value had a negatively elastic (–0.40) with respect to changes in temperature whereas positively elastic (0.14) to changes in precipitation.

The distribution of the marginal impacts across seven AEZs in Bangladesh were also calculated and displayed in Table 5. The results revealed that most of the zones faced losses of farmland value between US$ 368.68–1745.88 due to increased temperature in the wet season whereas maximum zones gained between US$ 120.19–547.14 due to increased precipitation in the dry season.

The impacts of future climate change on land value were also estimated and are presented in Table 6. Both CanESM2 and BNU-ESM models forecasted increases in temperatures in the ranges of 1.81–2.04 °C between 2021 and 2060 and 3.68–4.47 °C between 2061 and 2100, respectively. CanESM2 projected increases in precipitation of 3.39–19.97% during both periods. Further, BNU-ESM projected a decrease in precipitation of 4.8% between 2021 and 2060 but an increase of 5.47% between 2061 and 2100.

4. Discussion

4.1. Climate variables and farmland value

The findings obtained using both models (Table 3) appeared to be robust because the estimated models explained 9.9% to 41.6% of the observed variance in farmland value. Moreover, most of the parameter coefficients showed the expected signs. The climate variables showed nonlinear relationships with farmland value in both models, which is consistent with the results of previous Ricardian studies (Kurukulasuriya and Ajwad, 2007; Thapa and Joshi, 2011; Mishra et al., 2015; Arshad et al., 2016a; Kanwar and Bohara, 2017).

Wet season temperatures had a large negative coefficient, thereby indicating that rising temperatures will be detrimental to farm productivity and, ultimately, to farmland value, whereas higher dry season temperatures will be beneficial. High wet season temperatures can destroy or slow down crop productivity, but high dry season temperatures are crucial for the ripening and maturation of crops and thus farm productivity (Rahman et al., 2017). On the other hand, dry season temperatures exhibited an inverted U-shaped relationship with farmland value, whereas wet season temperatures had a U-shaped relationship. The positive and negative signs for dry and wet seasons temperature indicate that increases or decreases in temperature would have a harmful or beneficial effect on farmland value, respectively. In addition, both the dry and wet season precipitation levels had an

Table 3
Estimates of the impact of climate change on farmland value across the seven selected AEZs in Bangladesh obtained from Ricardian models.

Variables	Model 1		Model 2	
	Coefficient	Robust t-statistics	Coefficient	Robust t-statistics
Temperature, wet season	−821267.40**	−2.32	−617083.50**	−2.21
Temperature, wet season squared	14766.45**	2.31	11110.94**	2.21
Temperature, dry season	160334.70**	2.10	154258.40***	2.82
Temperature, dry season squared	−3758.31**	−2.10	−3650.63***	−2.83
Precipitation, wet season	366.29**	2.33	234.16**	2.26
Precipitation, wet season squared	−0.45**	−2.49	−0.24**	−2.03
Precipitation, dry season	1768.07**	1.97	2914.37***	3.57
Precipitation, dry season squared	−37.26*	−1.83	−66.81***	−3.65
Highland			1748.24	1.36
Lowland			−7736.85***	−2.87
Farmers' age			−65.49	−1.11
Household size			−217.15	−0.60
Farm size			6585.46***	9.05
Loamy soil			8104.94***	2.91
Clay soil			−1972.34	−0.74
Access to irrigation			2605.92**	2.04
Market access			2843.13	1.22
Access to extension services			2145.41*	1.91
Access to bank credit			1523.65	1.18
Constant	9665641.00**		6881699.00**	2.00
N	420		420	
F	2.17**		9.80***	
Adjusted R^2	0.0992		0.4162	

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 4
Marginal impacts of climate on farmland value (US$/ hectare).

Variables	Full model
1 °C increase in temperature on farmland value (US$/hectare)	
Temperature, wet	−1083.85
Temperature, dry	716.34
Annual temperature	−367.51
Annual elasticity	−0.40
1 mm/month increase in precipitation on farmland value (US$/hectare)	
Precipitation, wet	11.88
Precipitation, dry	117.68
Annual precipitation	129.56
Annual elasticity	0.14
Total climate	−237.95

1US$ = 80.64 BDT, considering the average exchange rates during the survey (2017).

Table 5
Marginal impacts of climate across seven AEZs.

AEZs	Wet season	Dry season	Annual
1 °C increase in temperature on farmland value (US$/hectare)			
Old Brahmaputra Floodplain	−1030.63	661.95	−368.68
Young Meghna Estuarine Floodplain	−1261.21	114.21	−1147.00
High Ganges River Floodplain	−2059.39	906.69	−1152.70
Old Meghna Estuarine Floodplain	−2112.60	366.72	−1745.88
Tista Meander Floodplain	−746.83	1116.46	369.63
Northern & Eastern Hills	−924.21	976.61	52.50
Eastern Surma-Kushiyara Floodplain	512.51	871.73	1384.24
1 mm/month increase in precipitation on farmland value (US$/hectare)			
Old Brahmaputra Floodplain	18.18	102.01	120.19
Young Meghna Estuarine Floodplain	23.04	422.78	445.82
High Ganges River Floodplain	34.93	324.24	359.17
Old Meghna Estuarine Floodplain	33.62	117.27	150.89
Tista Meander Floodplain	13.45	533.69	547.14
Northern & Eastern Hills	−7.80	−89.71	−97.51
Eastern Surma-Kushiyara Floodplain	−32.30	−585.29	−617.59

inverted U-shaped relationship and positive correlations with farmland value, thereby indicating that precipitation in both seasons is beneficial for farm productivity in Bangladesh (Abidoye et al., 2017a). These findings suggest that long-term variability in temperatures and precipitation will affect farmland value in the seven AEZs in Bangladesh, although further research based on a larger sample size should be considered to validate these results. Our study observations are, to some extent, consistent with the results obtained by Arshad et al. (2016a) in Pakistan, mainly due to largely similar climatic conditions in these two countries.

4.2. Flooding, soils, socioeconomic variables and farmland value

In the second model, we included "flooding" to better assess the impact of climate change on land value given that Bangladesh faces frequent flood every monsoon. The Ricardian model that included flooding is superior to the traditional Ricardian model and provides highly plausible results. Flooding is harmful to crops and farm productivity. In the analysis, we combined the three lowland classifications into a single lowland variable and the two highland classifications into a single highland variable. Thus, the analysis captured flooding by shifting land between the highlands and the lowlands. The results showed that the highlands, which were unaffected by floods, were positively correlated with farmland value. On the other hand, the negative association between lowlands and farmland value indicates that the lowlands are highly vulnerable to floods, which are responsible for reducing farm productivity, resulting in lower farmland value. "Highlands" is a relative term in Bangladesh because even the highlands are frequently flooded every year, although only for a short period.

The positive correlation between access to irrigation facilities and farmland value implies that irrigation increases farmland value. In Bangladesh, farmers widely apply irrigation especially groundwater irrigation to hedge against drought and heat stress (Alam, 2015), which has an important effect on increasing farm productivity. Due to higher abstraction, the groundwater levels are decreasing in many regions of

Table 6
Impacts of selected climate scenarios on farmland value (US$/hectare).

Climate projection models	Changes in temperature in^{0}C	% change in precipitation	Changes in land values
CanESM2: 2021-2060	2.04	3.39	−4296.01 (−10%)
BNU-ESM: 2021-2160	1.81	−4.80	−3352.18 (−8%)
CanESM2: 2061-2100	4.47	19.97	−9558.87 (−24%)
BNU-ESM: 2061-2100	3.68	5.47	−7294.10 (−18%)

Percentage changes are shown in parentheses.

Bangladesh, which may lead to an increase in salinity and irrigation costs, with likely negative effects on land value in the long term (Acharjee et al., 2017). Therefore, surface water irrigation is important for reducing the growing pressure on groundwater resources (Alam, 2015). Farmers in Bangladesh are highly reliant on irrigation, so future studies should examine the role of irrigation as an adaptation measure in response to climate change. Another comparative study with and without water quotas could assess the impact of climate change on the net profit of farmers as investigated by Fleischer et al. (2007) in Israel.

Farm size had a hill-shaped relationship with the farmland value, which reflects the effects of economies of scale, such that the productivity of a farm will increase as the farm size increases. Farmers with large farms may deploy modern technologies/methods as climate change adaptation techniques, thereby resulting in higher farm productivity. Therefore, large farms are associated with higher productivity compared to small farms. Arshad et al. (2016a) reported similar observations in Pakistan. The positive relationship between availability of agricultural extension services and land value indicates that farmers with more access to extension services are more capable of increasing their farms' productivity. This finding implies that new technologies and updated agricultural information are dispersed through extension services, which can help farmers to improve their farm production, thereby affecting farmland value in the study area (Delaporte and Maurel, 2016). Access to extension information and services could also improve the knowledge of farmers and thus increase their capacity to improve farmland quality and infrastructure and to adapt to climate variability (Haq et al., 2015). The positive association between loamy soil and farmland value demonstrates that loamy soil increases the productivity of crops. As loamy soil is highly fertile, with a crop productivity rate that is higher than that of clay soil, it ultimately has a positive effect on land value for farmers.

4.3. Estimates of marginal impacts

Table 4 shows the marginal impact of each variable by season to understand how temperature and precipitation may affect farmland value. The analysis implies that marginal impact of temperature in the wet season was negative and correlated on farmland value whereas positive correlation was observed in the dry season. Increased temperatures in the earlier part of the wet season may be beneficial by facilitating primary growth and the development of crops, whereas a warmer climate in the later stages could have disadvantageous effects on crop growth (Hossain et al., 2019a). On the other hand, comparatively low temperatures in the beginning of the dry season may have negative effects on crop growth, but a temperature rise in the later stages would be beneficial for the overall growth and development of crops (Miah et al., 2016; Hossain et al., 2019b). Moreover, the negative annual elasticity result indicates that increased temperature would decrease farmland value.

The marginal impacts of precipitation during both the wet and dry seasons were positive on land value. A marginal increase in wet season precipitation would have a minimal positive effect on farmland value, which indicates that early precipitation in the wet season would be more conducive to farm productivity than excessive precipitation in the later stages (Hossain et al., 2019a). Therefore, the timely arrival of summer precipitation and its regularity are very important for farm productivity in this country. By contrast, increased precipitation in the dry season would be beneficial for farm productivity and enhance land value. Thus, more precipitation in the dry season is crucial for better farm productivity in Bangladesh (Hossain et al., 2019b). Moreover, the positive annual elasticity result implies that increased precipitation would increase farmland value.

We analyzed the relationship between the annual climate and farmland value to understand the possible offsets between the wet and dry season temperatures and precipitation. By combining the seasonal effects (Table 4), a marginal decrease in the annual temperature and an increase in the annual precipitation was observed. The seasonal effects appeared to offset each other, thereby resulting in nonsignificant annual effects. Our analysis indicates an overall negative impact on farmland value (US$ −237.95), however, the loss resulting from the annual marginal temperature was very small (only 1%), especially given the high temperatures in Bangladesh. As a humid tropical region, it may be expected that marginal warming would be harmful to agriculture and farmland value but our findings demonstrate that the impact of high temperature appears to be offset by the high rainfall in Bangladesh. Similar findings have been reported by Abidoye et al. (2017b) in their recent study on Bangladesh. High rainfall allows for a very high proportion of farmland in Bangladesh to be irrigated, especially in the monsoon season. Compare to rainfed farmland, irrigated farmland can endure much higher temperatures, thereby allowing more cropping seasons per year and increasing land value. The additional cropping seasons and irrigation will compensate for the lower production in the hottest months. In addition, to overcome the irregular rainfall pattern and unequal distribution, farmers may employ supplementary irrigation to mitigate the effects of high temperatures. Furthermore, spreading awareness among farmers about the future occurrence of climatic extremes and initiating crop insurance programs could be an adaptation strategy to compensate for crop damage caused by floods in Bangladesh (Arshad et al., 2016b). Recent studies were conducted by Abidoye et al. (2017a) and Abidoye et al. (2017b) in South and Southeast Asia, including Bangladesh, and Abidoye et al. (2017a) found small positive marginal effects on farm revenue, whereas Abidoye et al. (2017b) found small negative effects. A comparison of our marginal results with these previous findings indicates that they are highly consistent.

4.4. Marginal impacts of climate across seven AEZs

Based on the coefficients obtained from the Ricardian regression model with Eq. (2), we calculated the marginal impacts of temperature and precipitation for each zone to examine the distribution of the impacts across seven AEZs in Bangladesh (Table 5). We found that increased temperatures were harmful to farm value in the wet season (except in the relatively colder climate zone, such as the Eastern Surma-Kushiyara Floodplain) but beneficial in the dry season. The Young Meghna Estuarine Floodplain, High Ganges River Floodplain, and Old Meghna Estuarine Floodplain zones are characterized by a hot climate which indicates that higher temperatures decreased land value in these zones. However, increased precipitation increased land value in both the wet and dry seasons, except in the Northern and Eastern Hills and

Eastern Surma-Kushiyara Floodplain zones. These two zones are greatly influenced by heavy seasonal rainfall, especially in the wet season. Table 5 also shows that dry season rainfall increased farmland value to a greater extent compared with wet season rainfall. Our findings are supported by the results of Seo et al. (2005) in the Sri Lankan's climate context.

Moreover, Table 5 demonstrates that there will be losses and gains in land value due to climate change, and the marginal impacts will not be uniformly distributed across these seven AEZs in Bangladesh. Thus, it is important for government policy planners to exploit the benefit of the gains and reduce the losses by assessing the efficiency of the existing adaptation mechanisms in Bangladesh and finding ways to support them.

4.5. Climate projections and their impacts on farmland value

By using Eq. (4) and the parameters from the fitted land value model in Table 3, we then examined the effects of the AOGCM scenarios on farmland value. The estimations revealed that both models (CanESM2 & BNU-ESM) anticipated increasing temperatures across studied AEZs of Bangladesh whereas rainfall was fluctuated. Changes in rainfall can be either beneficial or harmful depending upon whether rainfall levels increase or decrease respectively in the climate scenarios. Table 6 shows that as temperature increased, the reduction in farmland value per hectare was greater in the period from 2061 to 2100 than that from 2021 to 2060 based on the climate projections obtained by both AOGCMs. Our findings are consistent with those of Abidoye et al. (2017b) as they also reported negative impacts of future climate scenarios on farmers' net revenues in South and Southeast Asia. Therefore, implementation of appropriate adaptation strategies will be crucial for reducing the negative impacts of these climate scenarios on farmland value, particularly with respect to temperature.

5. Conclusions

In this paper, we investigated the impact of climate change on farmland value in Bangladesh using Ricardian modeling. The analysis indicates that seasonal precipitation and temperature variability play a role in the determination of farmland value. Floods will be responsible for reducing land value, especially in lowland regions. Among the socioeconomic variables, farm size, soil types, access of extension services, and availability of irrigation facilities are positively associated with farmland value. The marginal impacts result imply that farmland value is elastic to climate change, although the rate of reduction is shown to be minor and limited. The impacts of future climate change projected by two AOGCMs scenarios reveal that climate change will have a negative impact on land value depending on the climate model and source of farm income.

Immediate action is required to increase the resilience of the farming sector in Bangladesh based on the considerations of the current and anticipated impacts of climate change. Thus, we suggest some key policy recommendations based on the findings obtained in this study. These recommendations include strengthening the research capacity to support the development of flood- and drought-resistant varieties as well as different farm management techniques according to the changes in climate, promoting crop diversification programs, and enhancing agricultural extension systems to disseminate up-to-date adaptation technologies to farmers. These measures are necessary to mitigate the risks to the farming sector in the context of climate change. Improving land use management, providing subsidized irrigation and groundwater access, strengthening enterprise diversification activities, diversifying employment opportunities, and stimulating off-farm employment activities will make Bangladesh more resilient to climate change. To maintain farm productivity and farmland value, the results obtained in this study may guide development practitioners and government policy makers in the design of appropriate adaption strategies for Bangladesh. Moreover, the adaptation policies should target different AEZs according to the potentials and constraints in each zone rather than recommending uniform interventions. The present study suggests that our current knowledge of the economic impact of climate change on farmland value in Bangladesh is insufficient, thus further research and in-depth analyses are required.

Acknowledgments

This work was financed by Fritz Thyssen Foundation, Germany under the award number 40.18.0.009WW and National Natural Science Foundation of China (Project Nos. 71673223 & 71473197). We are grateful to Professor Dr. Robert Mendelsohn, Yale University, School of Forestry and Environmental studies, New Haven, USA for his valuable comments on an earlier version of this manuscript.

Disclosure statement

The authors declare no conflicts of interest.

Author contribution

Mohammad Shakhawat Hossain conceived the idea, collected data and wrote the initial draft together with Lu Qian. Muhmmad Arshad and Harald Kächele contributed in data analysis, results interpretation, editing and final write-up. Imran Khan and Md Din Il Islam contributed in data management and M. Golam Mahboob made an input in the literature search.

Appendix A

Characteristics the AEZs of Bangladesh selected for the present study.

AEZs no.	AEZs name	Climate classification	Soil characteristics	Physiography	Selected districts
3	Tista Meander Floodplain	Feebly arid	Sandy loam, loamy, silt clay-loam	Floodplains	Kurigram
9	Old Brahmaputra Floodplain	Semi-humid	Silt loam to silt clay-loam	Floodplains	Mymensingh
11	High Ganges River Floodplain	Feebly arid	Silt loam, Silt clay-loam	Floodplains	Rajshahi
18	Young Meghna Estuarine Floodplain	Semi-humid	Silt loam	Floodplains	Barisal
19	Old Meghna Estuarine Floodplain	Semi-humid	Silt loam	Floodplains	Comilla
20	Eastern Surma-Kushiyara Floodplain	Humid	Heavy silt clay loam	Floodplains	Sylhet
29	Northern & Eastern Hills	Humid	Yellow brown to strong brown	Tertiary hills	Rangamati

Source: BARC (2005).

Appendix B

Classification of land according to flooding depth and frequency.

Land Type	Flooding depth	Frequency
Highland	Shallow	24.68%
Medium highland	0–90 cm	49.84%
Upper lowland	90–180 cm	16.43%
Medium Lowland	180–300 cm	7.67%
Lower lowland	> 300 cm	1.38%

Source: BARC (2005).

References

Abidoye, B.O., Kurukulasuriya, P., Reed, B., Mendelsohn, R., 2017a. Structural Ricardian analysis of South-East Asian agriculture. Climate Change Econ. 8 (16). https://doi.org/10.1142/S201000781740005X.

Abidoye, B.O., Mendelsohn, R., Ahmed, S., Amanullah, S., Chasidpon, C., Baker, L., Dobias, R., Ghosh, B., Gunaratne, L.H.P., Hedeyetullah, M.M., Mungatana, E., Ortiz, C., Simoes, M., Kurukulasuriya, P., Perera, C., Sooriyaarachchi, A., Supnithadnapor, A., Truong, T., 2017b. South-East Asian Ricardian studies: Bangladesh, Sri Lanka, Thailand, and Vietnam. Climate Change Econ. 8, 7. https://doi.org/10.1142/S2010007817400024.

Acharjee, T.K., Ludwig, F., Halsema, G.V., Hellegers, A., Supit, I., 2017. Future changes in water requirements of *Boro* rice in the face of climate change in North-West Bangladesh. Agric. Water Manag. 94, 172–183 https://doi.org/j.agwat.2017.09.008.

Alam, K., 2015. Farmers' adaptation to water scarcity in drought-prone environments: a case of Rajshahi district, Bangladesh. Agric. Water Manag. 148, 196–206. https://doi.org/10.1016/j.agwat.2014.10.011.

Amjath- Babu, T.S., Krupnik, T.J., Arshad, M., Aravindakshan, S., Kaechele, H., 2016. Climate change and indicators of probable shifts in the consumption portfolios of dryland farmers in Sub-Saharan Africa: implications for policy. Ecol Indi. 67, 830–838.

Arshad, M., Kächele, H., Krupnik, T.J., Amjath-Babu, T.S., Aravindakshan, S., Abbas, A., Mehmood, Y., Müller, K., 2016a. Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. Int. J. Sustainable Dev. World Ecol. https://doi.org/10.1080/13504509.2016.1254689.

Arshad, M., Amjath-Babu, T.S., Kächele, H., Müller, K., 2016b. What drives the willingness to pay for crop insurance against extreme weather events (flood and drought) in Pakistan? a hypothetical market approach. Clim. Dev. 3, 234–244. https://doi.org/10.1080/17565529.2015.1034232.

Arshad, M., Amjath-Babu, T.S., Krupnik, T.J., Aravindakshan, S., Abbas, A., Kachele, H., Muller, K., 2017. Climate variability and yield risk in South Asia's rice–wheat systems: emerging evidence from Pakistan. Paddy Water Environ. 15 (2), 249–261. https://doi.org/10.1007/s10333-016-0544-0.

Arshad, M., Amjath-Babu, T.S., Aravindakshan, S., Krupnik, T.J., Toussaint, V., Kächele, H., Müller, K., 2018. Climatic variability and thermal stress in Pakistan's rice and wheat systems: a stochastic frontier and quantile regression analysis of economic efficiency. Ecol Indi. 89, 496–506. https://doi.org/10.1016/j.ecolind.2017.12.014.

Ay, J-S. and Latruffe, L., 2013. The empirical content of the present value model: a survey of the instrumental uses of farmland prices. Working paper, Factor Markets Coordination: Centre for European Policy Studies (CEPS), Brussels, Belgium.

Banglapedia-climate, 2014. Encyclopedia of Bangladesh. http://www.en.banglapedia.org/index.php?title=Climate.

Banglapedia-agriculture, 2016. Encyclopedia of Bangladesh. http://www.en.banglapedia.org/index.php?title=Agriculture.

BARC, 2005. Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council, Dhaka.

BBS, 2016. Bangladesh Bureau of Statistics. Statistical Year Book Bangladesh. http://www.bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/.../Yearbook-2016.

Bobojonov, I., Aw-Hassan, A., 2014. Impacts of climate change on farm income security in central Asia: an integrated modeling approach. Agric. Ecosyst. Environ. 88, 245–255. https://doi.org/10.1016/j.agee.2014.02.033.

Bozzola M, Capitanio F, Massetti E, Mendelsohn R., 2014. A Ricardian analysis of the impact of climate change on Italian agriculture. Manuscript.

Buck, S., Auffhammer, M., Sunding, D., 2014. Land markets and the value of water: hedonic analysis using repeat sales of farm-land. Am. J. Agric. Econ. 94, 953–969. https://doi.org/10.1093/ajae/aau013.

Chatzopoulos, T., Lippert, C., 2015. Adaptation and climate change impacts: a structural Ricardian analysis of farm types in Germany. J. Agric. Econ. 66, 537–554. https://doi.org/10.1111/1477-9552.12098.

Chatzopoulos, T., Lippert, C., 2016. Endogenous farm-type selection, endogenous irrigation, and spatial effects in Ricardian models of climate change. Eur. Rev. Agric. Econ. 43, 217–235. https://doi.org/10.1093/erae/jbv014.

Chylek, P., Li, J., Dubey, M.K., Wang, M., Lesins, G., 2011. Observed and model simulated 20th century Arctic temperature variability: Canadian Earth System Model CanESM2. Atmos. Chem. Phys. Discuss. https://doi.org/10.5194/acpd-11-22893-2011.

Cline, W.R., 1996. The impact of global warming on agriculture: comment. Am. Econ. Rev. 86, 1309–1312.

DDM, 2017. Department of Disaster Management. Disaster Report, 2017. Ministry of Disaster Management & Relief. Government of People's Republic of Bangladesh.

Delaporte, I., Maurel, M., 2016. Adaptation to climate change in Bangladesh. Climate Policy 18, 49–62. https://doi.org/10.1080/14693062.2016.1222261.

Dewan, A.M., Nishigaki, M., Komatsu, M., 2003. Floods in Bangladesh: a comparative hydrological investigation on two catastrophic events. J. Faculty Environ. Sci. Technol. 8, 55–62.

Fezzi, C., Bateman, I.J., 2015. The impact of climate change on agriculture: nonlinear effects and aggregation bias in Ricardian models of farmland value. J. Assoc. Environ. Resour. Econ. 2, 57–92. https://doi.org/10.1086/680257.

Fleischer, A., Lichtman, I., Mendelsohn, R., 2007. Climate change, irrigation, and Israeli agriculture: will warming be harmful? Ecol. Econ. 65, 508–515. https://doi.org/10.1016/j.ecolecon.2007.07.014.

Haq, N., Hugé, J., Boon, E., Gain, A.K., 2015. Climate change impacts in agricultural communities in rural areas of coastal Bangladesh: a tale of many stories. Sustainability 7, 8437–8460. https://doi.org/10.3390/su7078437.

Hossain, M.S., Qian, L., Arshad, M., Shahid, S., Fahad, S., Akhter, J., 2019a. Climate change and crop farming in Bangladesh: an analysis of economic impacts. Int. J. Clim. Change Strategies Manage. 11 (3), 424–440. https://doi.org/10.1108/IJCCSM-04-2018-0030.

Hossain, M.S., Arshad, M., Qian, L., Zhao, M., Mehmood, Y., Kächele, H., 2019b. Economic impact of climate change on crop farming in Bangladesh: an application of Ricardian model. Ecol. Econ. https://doi.org/10.1016/j.ecolecon.2019.106354.

IFRC, 2010. Bangladesh Cyclone Sidr: Final Report. International Federation of Red Cross and Red Crescent Societies. http//www.ifrc.org/docs/appeals/07/mdrbd003fr.pdf.

IPCC, 2007. Climate change: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

IPCC, 2014. Food security and food production systems. In: Field, C.B. (Ed.), Impacts, Adaptation, And Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge (UK).

Ji, D., Wang, L., Feng, J., Wu, Q., Cheng, H., Zhang, Q., Yang, J., Dong, W., Dai, Y., Gong, D., Zhang, R.H., Wang, X., Liu, J., Moore, J.C., Chen, D., Zhou, M., 2014. Description and basic evaluation of BNU-ESM version 1. Geosci. Model Dev. https://doi.org/10.5194/gmd-7-2039-2014.

Kanwar, S.B., Bohara, A.K., 2017. Climate sensitivities and farmland values in Nepal: a spatial panel Ricardian approach. J. Dev. Agric. Econ. 9, 145–161. https://doi.org/10.5897/JDAE2017.0822.

Kelly, D.L., Kolstad, C.D., Mitchell, G.T., 2005. Adjustment costs from environmental change. J. Environ. Eco. Manage. 50, 468–495.

Kurukulasuriya, P., Ajwad, M.I., 2007. Application of the Ricardian technique to estimate the impact of climate change on smallholder farming in Sri Lanka. Clim. Change. 81, 39–59. https://doi.org/10.1007/s10584-oo5-9021-2.

Kurukulasuriya, P., Kala, N., Mendelsohn, R., 2011. Adaptation and climate change impacts: a structural Ricardian model of irrigation and farm income in Africa. Climate Change Econ. 2, 149–174. https://doi.org/10.1142/S2010007811000255.

Massetti, E., Mendelsohn, R., 2011. Estimating Ricardian models with panel data. Climate Change Econ. 2, 301–319. https://doi.org/10.1142/S2010007811000322.

Mahmood, N., Arshad, M., Kachele, H., Ma, H., Ullah, A., Muller, K., 2019. Wheat yield response to input and socioeconomic factors under changing climate: evidence from rainfed environments of Pakistan. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2019.06.266.

Mendelsohn, R., Nordhaus, W., Shaw, D., 1994. The impact of global warming on agriculture: a Ricardian analysis. Am. Econ. Rev. 84, 753–771 http://www.jstor.org/stable/2118029.

Mendelsohn, R., Nordhaus, W., 1996. The impact of global warming on agriculture: reply to Cline. Am. Econ. Rev. 86, 1312–1315.

Mendelsohn, R., Dinar, A., 2003. Climate, water, and agriculture. Land Economics 79, 328–341. https://doi.org/10.2307/3147020.

Mendelsohn, R., 2008. The impact of climate change on agriculture in developing countries. J. Nat. Resour. Pol. Res. 1, 5–19. https://doi.org/10.1080/19390450802495882.

Mendelsohn, R., Massetti, E., 2017. The use of cross-sectional analysis to measure climate impacts on agriculture: theory and evidence. Rev. Environ. Econ. Policy 11, 280–298. https://doi.org/10.1093/reep/rex017.

Miah, M.G., Rahman, M.A., Rahman, M.M., Saha, S.R., 2016. Impacts of climate variability on major food crops in selected agro-ecosystems of Bangladesh. Ann. Bangladesh Agric. 20, 61–74.

Miranowski, J.A., Hammes, B.D., 1984. Implicit prices of soil characteristics for farmland in Iowa. Am. J. Agric. Econ. 66, 745–749.
Mishra, D., Sahu, N.C., Sahoo, D., 2015. Impact of climate change on agricultural production of Odisha (India): a Ricardian analysis. Reg. Environ. Change. https://doi.org/10.1007/s10113-015-0774-5.
Moore, F., Lobell, D., 2014. Adaptation potential of European agriculture in response to climate change. Nat. Clim. Change 4, 610–614. https://doi.org/10.1038/nclimate2228.
Peterson, W., 1986. Land quality and prices. Am. J. Agric. Econ. 68, 812–819.
Quaye, F., Nadolnyak, D., Hartarska, V., 2018. Climate change impacts on farmland values in the Southeast United States. Sustainability 10, 3426. https://doi.org/10.3390/su10103426.
Rahman, M.A., Kang, S., Nagabhatla, N., Macnee, R., 2017. Impacts of temperature and rainfall variation on rice productivity in major ecosystems of Bangladesh. Agric. Food Secur. https://doi.org/10.1186/s40066-017-0089-5.
Ricardo, D., 1817. On the Principles of Political Economy and Taxation. John Murray, London.
Roco, L., Bravo-Ureta, B., Engler, A., Jara-Rojas, R., 2017. The impact of climate change adaptation on agricultural productivity in central Chile: a stochastic production frontier approach. Sustainability 9, 16–48. https://doi.org/10.3390/sus9091648.
Rosenzweig, C., Parry, M.L., 1994. Potential impact of climate change on world food supply. Nature 367, 133–138. https://doi.org/10.1038/367133a0.
Ruane, A.C., Major, D.C., Yu, W.H., Alam, M., Hussain, S.G., Khan, A.S., Hassan, A., Hossain, M.B.T., Goldberg, R., Horton, R.M., Rozenzweig, C., 2012. Multi-factor impact analysis of agricultural production in Bangladesh with climate change. Global Environ. Change 23, 338–350. https://doi.org/10.1016/j.gloenvcha.2012.09.001.
Sanghi, A., Alves, D., Evenson, R., Mendelsohn, R., 1997. Global warming impacts on Brazilian agriculture: estimates of the Ricardian model. Econ Aplic. 1, 7–34.
Seo, S.N., Mendelsohn, R., Munasinghe, M., 2005. Climate change and agriculture in Sri Lanka: a Ricardian valuation. Environ. Dev. Econ. 10, 581–596. https://doi.org/10.1017/S1355770X05002044.
Seo, S.N., Mendelsohn, R., 2008. A Ricardian analysis of the impact of climate change on South American farms. Chilean J. Agric. Res. 68, 69–79.
Shahid, S., 2010. Recent trends in the climate of Bangladesh. Climate Res. 42, 185–193. https://doi.org/10.3354/cr00889.
Thapa, S., Joshi, G.R., 2011. A Ricardian analysis of the climate change impact on Nepalese agriculture. MPRA Paper No. 29785. https://mpra.ub.uni-muenchen.de/29785/.
Van Vuuren, D.P., Edmonds, J.A., Kainuma, M., Riahi, K., Thomson, A.M., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S.J., Rose, S., 2011. The representative concentration pathways: an overview. Clim. Change 109, 5–31. https://doi.org/10.1007/s10584-011-0148-z.
World Bank, 2010. Climate Change Risks and Food Security in Bangladesh, World Bank, Sher-e-Bangla Nagar, Agargaon, Dhaka 1207.

View publication stats