



Influence of climate-induced disasters and climatic variability on cropping pattern and crop production in Bangladesh

Md. Shafiqul Islam¹ · Shimul Roy^{1,2}  · Rezuana Afrin¹ · Md. Younus Mia¹

Received: 17 August 2018 / Accepted: 19 October 2019 / Published online: 25 October 2019
© Springer Nature B.V. 2019

Abstract

The southern part of Bangladesh is one of the most affected regions facing the devastating impacts of climate change particularly in case of crop production. Impacts of climate-induced disasters and climatic variability on cropping pattern and crop production in *Satkhira* district have been studied. Thirty-five year (1980–2014) climatic data (temperature, humidity, and rainfall) were used for seasonal (*Kharif-I*, *Kharif-II*, and *Robi*) trend analysis. It has been identified that the cropping pattern needed to be modified by local farmers due to climate change impacts and crop production has declined severely in the study areas. For instance, in the *Kharif-II* season, during the period 2008–2009 with an agricultural land area of 13,670 hectares, the average production was only 2.58 mt per hectare. The study shows a significant strong positive correlation between seasonal average rainfall and seasonal average humidity ($r=0.75$, $p<0.05$) during the *Robi* season. A significant strong negative correlation between seasonal average temperature and seasonal average humidity ($r=-0.60$, $p<0.05$) during the *Kharif-I* season was also found. We suggest some adaptation strategies to cope with the changing condition such as increased use of salt- and flood-tolerant varieties, floating bed vegetable cultivation, and dyke cropping system (mainly for vegetable), which can eventually reduce vulnerabilities and increase food security.

Keywords Climate change · Climatic parameters · Satkhira · Adaptation

✉ Shimul Roy
shimul.roy84@gmail.com

Md. Shafiqul Islam
er_08_shafiqul@yahoo.com

Rezuana Afrin
afrin.mbstu038@gmail.com

Md. Younus Mia
mdmia1998@gmail.com

¹ Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Santosh, Tangail 1902, Bangladesh

² School of Energy and Environment, City University of Hong Kong, Hong Kong SAR, China

1 Introduction

As a densely populated deltaic region, Bangladesh is facing the early impacts of climate change mainly because of its geographical location, elevation from the sea level, and dominance of floodplains. Some studies (Aggarwal et al. 2013; Gregory and Ingram 2000; Rosegrant and Cline 2003; Rokonuzzaman et al. 2018; Huq et al. 2015) reported that Bangladesh is facing tremendous challenges of climate change impacts (coastal flooding, droughts, tropical cyclones, tidal surges, and soil salinity) on agricultural sector.

In Bangladesh, the cropping pattern is principally dominated by rice, whereas two-crop combinations, three-crop combinations, and sometimes four-crop combinations are usually observed. *Aus*, *Aman* (transplanted and broadcast), and *Boro* are the main rice varieties that are largely practiced with other crops including wheat, sugarcane, jute, potatoes, vegetables, etc. Huq and Shoaib (2013) reported that among the various rice varieties, the contribution of transplanted *aman* (*T. aman*) is highly significant, which covers more than 46% of the total paddy area of the country followed by *Boro* (26.85%), *Aus* (17.59%), and broadcast *Aman* (9.26%). The changing pattern of seasonal climatic variables such as average temperature, rainfall, humidity, and day length can have a greater influence on agricultural cropping pattern and crop production as reported in different studies (Chen et al. 2016; Zakaria et al. 2014; Rokonuzzaman et al. 2018; Sikder and Xiaoying 2014; IPCC 2007a). Additionally, different climatic hazards such as coastal flooding, droughts, cyclones, storm surges, and sea level rise can adversely affect cropping pattern and decline crop production. For instance, Haque et al. (2016) reported the production loss of 698,391 tonnes *Aman* rice and 1446 acres of *Boro* seedbed in 2007–2008 due to the tropical cyclone *Sidr* on 2007.

Agriculture is highly vulnerable to the climate impacts in the coastal regions of Bangladesh where a significant portion of the population principally depends on it for their livelihood. Adaptation in the agricultural sector is one of the crucial aspects that can reduce crop production loss and vulnerability. Calzadilla et al. (2014) asserted that the increasing effects of climate change on the agricultural sector are a matter of great concern, whereas adaptation options might help to improve the worst situation. Abedin and Shaw (2013) asserted that as the relationship between climate impacts and crop production is inversely related, adaptation approaches can contribute significantly to reduce agricultural vulnerability in the coastal region of Bangladesh. These include appropriate cropping pattern, sustainable management of irrigation water, seed choices, and so on.

In Bangladesh, some studies (Sikder and Xiaoying 2014; Rokonuzzaman et al. 2018; Huq et al. 2015; Abedin and Shaw 2013) have been conducted on climate change impacts on agriculture sector emphasizing vulnerability and adaptation strategies. However, climate impacts on agricultural cropping system especially, in the southern coastal part, are not covered in most of these studies. Under this circumstance, the southwestern region (Satkhira district) has been chosen as the appropriate location for our study, which is highly vulnerable to several climate-induced disasters (saltwater intrusion due to sea level rise and cyclone). The objectives of the study were to find out existing agricultural cropping system; to evaluate how the cropping pattern and crop production are affected due to climate-induced hazards and climatic variability; and to identify potential adaptation options for agricultural cropping system in the study area.

2 Literature review

Agricultural sector has been affected seriously throughout the world due to the devastating impacts of climate change (Ramankutty et al. 2002; Osborne et al. 2012; Sikder and Xiaoying 2014; FAO 2016; Van Meijl 2017; Adams et al. 1998), whereas crop agriculture is the highly vulnerable sector in South Asia (Islam et al., 2010; Arnell et al. 2016; ADBI 2009; Mall et al. 2006; Kumar 2009; Mondal 2010). South Asia is the most vulnerable region of the world to the adverse impacts of climate change (McCarthy et al. 2001), whereas crop productivity has been seriously hampered as a result of climate change impacts on different sectors including freshwater availability, soil moisture, changes in rainfall pattern, increasing temperature (Arnell et al. 2016). According to Sikder and Xiaoying (2014), the agricultural yield can be highly influenced by seasonal variation and altered due to various climatic variables including changes in rainfall pattern, temperature, variability in day-length duration, and surface water runoff. It is estimated by several studies (Fischer et al. 2002; Parry et al. 2004; IPCC 2007b; Cline 2007) that by 2100, crop production can be declined by 10–40% due to climate change impacts, and most importantly, if the agricultural sector becomes fail to take appropriate adaptation strategies. For instance, different climate change scenarios show that in South Asia, rice production is estimated to decrease by 2–10% (Pathak et al. 2003; Knox et al. 2011) while irrigated maize, sugarcane, and sorghum productions are estimated to decline by 7–25% (Knox et al. 2011). However, Nelson et al. (2009) reported a substantial reduction in all crops yields in the South Asian countries.

Suitability of cropping would be reduced for approximately half of all cropland, and most places of South, Southeast, and East Asia would reduce the productivity of major crops (spring wheat, soybean, and maize) mainly because of water stress and flooding triggered by global climate change (Arnell et al. 2016). For instance, in Southeast Asian region, with every 1 °C rise in temperature the production of rice is projected to reduce by 2–10% (Pathak et al., 2003; Knox et al., 2011). Aggarwal et al. (2000) and Pathak et al. (2003) also identified a declining trend in rice productions during the last two decades in the Southeast Asian region.

In Bangladesh, climate change-induced events such as riverbank erosion, recurring floods, and drought in dry season have been expanding the vulnerability with profound impacts on crops yields and cropping patterns (Rokonuzzaman et al. 2018). In recent years, climate of Bangladesh has shown a significant change (Shahid 2010) and global warming-induced changes in minimum and maximum temperature and amount of rainfall are evidence of it (Ahmed and Alam 1999). According to IPCC (2007c), 'Bangladesh will experience 5–6% increase in rainfall and 1.9 °C increase in temperature by 2030'. It reflects that a relatively large change in the probability of extreme events can be produced due to small changes in values of climatic parameters (Groisman et al. 1999; Rodrigo 2002; Su et al. 2006; Shahid 2011). As a result, a large decline in cereal (rice, wheat) production will be caused by the extreme climate change events such as higher temperature (Stern 2006) or unreliable precipitation in Bangladesh (CDMP II 2013). For instance, crop production will be reduced by about 30% due to the rise in temperature; especially, yield of *Boro* rice would be declined by 55–62% and wheat by 61% by 2050 (Mondal 2010).

3 Methodology and data

3.1 Study area

The study was conducted in two different Upazilas (*Assasuni* and *Kalaroa*) of *Satkhira* district, Bangladesh, which is bordered to the north by *Jessore* district, on the south by the Bay of Bengal, to the east by *Khulna* district, and to the west by 24-Parganas district of West Bengal, India. The annual average maximum and the minimum temperature of *Satkhira* district reaches 35.5 °C (95.9 °F) and 12.5 °C (54.5 °F), respectively, and the annual rainfall is 1710 mm (67 inch). *Assasuni* Upazila is located at 22.5500°N and 89.1681°E (Fig. 1) with a total area of 402.36 sq. km., and *Kalaroa* Upazila is located at 22.8750°N and 89.0417°E (Fig. 1) with a total area of 232.64 sq. km. (Banglapedia 2015). The foremost reason behind selecting these two Upazilas is that as a part of the southern coastal region of Bangladesh soil salinity problem and climate-induced disasters are common here that have profound impacts on local agricultural cropping pattern and crop production. Moreover, to the best of our knowledge, no previous studies have been conducted regarding climate impacts on cropping system in this district. Therefore, we consider these two Upazilas to provide a general overview of cropping pattern and crop production in relation to the influence of climate-induced disasters and climatic variability. In our study, the local people of the study area were the respondents for field survey, and among them, 85% were male and 15% were female. Most of the respondents (37%) were in the age group of

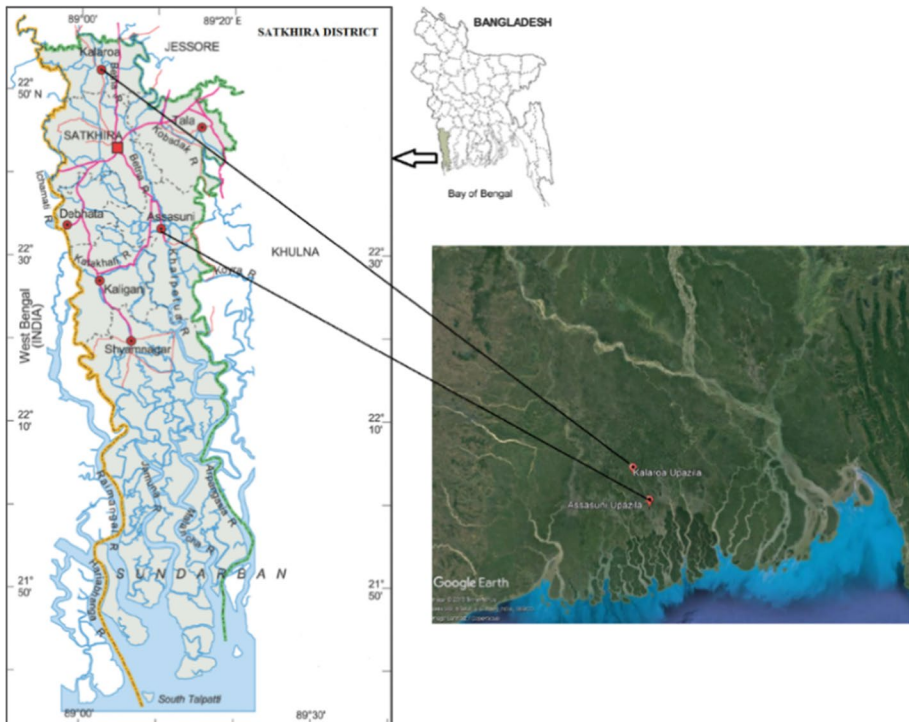


Fig. 1 Map of Satkhira district showing the study area (Assasuni and Kalaroa Upazila)

35–44 years. A relatively higher percentage (42%) of the respondents does not have any formal education. It has been identified that among the respondents, 44% were the farmer, 17% were agricultural labor, 6% were businessman, 12% were fisherman, 7% were boatman, and 14% were from other occupations (Field survey, 2015).

3.2 Data collection and analysis

Both primary and secondary data sources were used in this study. Primary data were collected through observation, questionnaire survey, key informant interview (KII), and focus group discussion (FGD) with the farmers and local communities. Interviews were conducted with different professionals for experiencing the true gradual impact of climate change in this area. The inherent reason for conducting the KII was that the local people are the direct observer of the climatic hazards and their frequency in the study areas. However, they do not have in-depth knowledge about the inherent causes of the changes. Therefore, we also decide to conduct interviews with some experts for cross-checking the ideas gathered from local people. Five KII have been conducted with the personnel of Government Organizations (GOs) (i.e., Upazila Agriculture Extension Officers) and NGOs workers of BRAC and Muslim Aid.

FGD was conducted with farmers on March 29–30, 2015. Two FGD sessions were conducted on 29th in *Assasuni* Upazila, and another two FGD sessions were conducted on March 30, 2015, in *Kalaroa* Upazila where a total of 37 participants actively participated. During the FGD session, they were asked some key questions based on the study objectives such as climate-induced hazards, local agricultural cropping pattern and crop production, changes in crop production rate (mainly rice) over time, and food security and adaptation techniques applied in the local scale.

The questionnaire survey is also conducted in this study, which is considered as a useful tool that can provide in-depth and detail information about the study in a less time-consuming manner. This kind of survey is often conducted on a random basis and is considered a well-known technique that enables researchers to make inferences regarding the wider population (Kelley et al., 2003). A total of 100 respondents ($n = 100$) have been selected randomly from the two selected Upazilas. Both open-ended and close-ended questions were used in the questionnaire. However, the use of open-ended questions was more frequent to obtain in-depth information regarding disaster appearance and vulnerability, cropping pattern, sowing and harvesting period of crops, and adaptation practices. Oppenheim (2000) stated that the key advantage of using open-ended questions is the freedom it gives to the respondents of sharing their knowledge and experiences about answering the question.

Apart from primary data, the collection of secondary data such as cropping pattern and crop production, data on meteorological parameters (temperature, rainfall, and humidity) of the study areas were also very important. Data on cropping pattern and crop production were collected from different sources including Agriculture Extension Office (AEO) of *Kolaroa* and *Assasuni* Upazila, local Upazila offices, and NGOs. Crop production (i.e., *Aus*, *Aman* and *Boro* rice) and agricultural land area data of *Assasuni* Upazila for three different seasons (*Kharif-I*, *Kharif-II*, and *Robi*) were collected from the local AEO. For *Kolaroa* Upazila, the only available data on crop production (*Aman* rice and Mustard seed) for *Kharif-II* and *Robi* season were collected from the local AEO. Thirty-five year (1980–2014) climatic data (temperature, humidity, and rainfall) were collected from the Bangladesh Meteorological Department (BMD).

The collected data were tabulated and coded, and then, MS Excel and SPSS-14 software were used for calculation and data analysis. The findings of the study were presented as graphs, percentages, and tabular forms. Pearson correlation among annual average crop production (i.e., *Aus*, *Ropa aman*, and *Boro* rice) in three different seasons (*Kharif-I*, *Kharif-II*, and *Robi*) and seasonal average climatic data (temperature, rainfall, and humidity) has also been performed. Based on the data availability, Pearson correlation has been performed. Annual average crop production data during the period 1996–2014 of *Assasuni* Upazila have been used for correlation as no crop production data were available before 1996, and for the *Kolaroa* Upazila, data on transplanted *Aman* rice only for the year 2014–2015 were available. Hence, the correlation has been performed only for the *Assasuni* Upazila.

4 Results and discussion

4.1 Cropping seasons—its characteristics and main cultivated species

In general, the climate and soil of Bangladesh are favorable for the cultivation of a variety of crops in a piece of land in almost every part of the country. However, this favorable condition is worsening due to climate change impacts. The cropping season in Bangladesh is usually categorized as *Kharif* and *Robi* season. *Kharif* season is again divided into two seasons, namely *Kharif-I* (also called pre-*Kharif* season) and *Kharif-II*. Each of the seasons has been differentiated by its distinct characteristics and types of major crops grown as shown in Table 1. This study also identified these three cropping seasons in the study areas with a variety of cultivated species (Table 1).

In the study areas, *Aus* rice is found to be the dominant rice species for the *Kharif-I* season along with other crops and vegetables. Huq and Shoib (2013) reported that currently the *Kharif-I* crops are cultivated under the irrigated condition due to the substantial improvement in the irrigation system of the country. During the *Kharif-II* season, T. *Aman* (transplanted *Aman* rice) is found to be the main rice species in the Satkhira district. For instance, various types of T. *Aman* rice varieties have been practiced during this period and a record of T. *Aman* rice production in *Kharif-II* season for the period of 2014–2015 in the *Kolaroa* Upazila is shown in Table 2. *Boro* rice is the dominant rice species during the *Robi* season (dry season) where along with vegetables, pulses, wheat, mustard, and different kinds of *Boro* rice including IRR128, IRR144, IRR126, and IRR129 are cultivated in this region. Table 3 shows the production of mustard seed in *Kolaroa* Upazila during the *Robi* season as the production of other crops and vegetables such as *Boro* rice, wheat, potato, lentil, onion, and carrot was not available during the study period (2014–2015). However, from the field observation, it is revealed that in the study areas along with different rice varieties farmers are currently sowing pulses, oilseeds, potatoes, and vegetables on some plots that are formerly practiced with only rice and wheat.

4.2 Cropping patterns

Agricultural cropping patterns in Bangladesh largely depend on a variety of factors including meteorological condition (e.g., rainfall intensity and distribution, temperature range), soil moisture, soil textural classes, type of land for cultivation, etc. Variation in these factors may result in substantial variation in the cropping patterns in different

Table 1 Basic characteristics of the cropping seasons

Season	Basic characteristics			References	
	Duration	Meteorological condition	Soil moisture		
<i>Kharif -I (Pre-Kharif)</i>	Mid-March to mid-July	Temperature lower than <i>Kharif-I</i> but higher than <i>Rabi</i> season, unreliable rainfall is observed	Soil moisture is lower than <i>Kharif-II</i>	Identified major crops <i>Aus</i> (rice), jute, sesame, turmeric, green gram, oil seeds, chili, vegetable (brinjal, lady's finger, basil, gourd, etc.)	Huq and Shoaib (2013), BBS (2016), Shaw et al. (2013)
<i>Kharif -II</i>	Mid- July to mid-November	Characterized by higher temperature, rainfall, and humidity; precipitation > 0.5 PET continuously observed during this period	Higher soil moisture compared to all other seasons	<i>Ropa aman</i> (rice), Vegetable	Huq and Shoaib (2013), BBS (2016), Shaw et al. (2013)
<i>Rabi</i>	Mid-November to mid-March	Characterized by the dry condition (winter season); lower temperature and rainfall	Soil moisture become low during this period due to the dry condition	<i>Boro</i> (rice), wheat, potato, mustard seed, lentil, onion, carrot, vegetable, etc.	Huq and Shoaib (2013), BBS (2016)

PET potential evapotranspiration

Table 2 Transplanted *Aman* rice production at *Kharif-II* season in *Kolaroa* Upazila (2014–2015)

Crops name (local)	Variety name (local)	Cultivated land (hec.)	Total production (mt.)	Average production (mt./hec.)
<i>Ropa aman</i>	BR-10	425	2040	4.8
	BR-11	527	2213	4.2
	BR-23	340	1428	4.2
	BRR1-30	68	326	4.8
	BRR1-33	102	459	4.5
	BRR1-39	51	230	4.5
	BRR1-41	85	340	4.0
	BRR1-49	1774	8870	5.0
	BRR1-51	234	1053	4.5
	BRR1-52	442	1989	4.5
	BRR1-54	221	884	4.0
	BINA-7	3535	17,675	5.0
	BINA-8	187	898	4.8
	BINA-10	221	928	4.2
	SHARNA	4268	17,072	4.0
NERICA	30	120	4.0	
Total		12,510	56,525	

Source: Calculated from AEO (2014) (*Kolaroa* and *Assasuni* Upazila)

HYV high yield variety

Table 3 Crop production during the *Robi* season in *Kolaroa* Upazila (2014–2015)

Crops name	Variety name (local)	Cultivated land (hec.)	Total production (mt.)	Average production (mt./hec.)
Mustard seed	TORI-7	1172	1406	1.2
	BARI-9	413	660	1.6
	BARI-13	25	35	1.4
	BARI-15	340	544	1.6

Source: Calculated from AEO (2014) (*Kolaroa* and *Assasuni* Upazila)

regions of the country. A large variety of agricultural crops are generally practiced throughout the country in different seasons along with the dominant rice varieties.

It is evident that the agricultural cropping pattern in Bangladesh is generally rice dominated. Shahid (2011) reported that only rice contributes around 71% of the total crop sector in Bangladesh. There are three main rice types are identified in Bangladesh—*Aus*, *Aman*, and *Boro* (Huq and Shoaib 2013). In the study areas, three different categories of rice, namely *Aus*, *Aman* (transplanted and broadcast varieties), and *Boro*, have been identified with specific growing and harvesting period as shown in Table 4. Figure 2 shows that cropping pattern in the study areas mainly comprises of ‘two-crop combinations’ and ‘three-crop combinations,’ whereas the dominant cropping pattern

Table 4 Sowing and harvesting period of different rice varieties

Rice (local name)	Sowing period	Harvesting period
<i>Aus</i>	Mid-March to mid-April	Mid-July to early August
<i>Aman</i> -Broadcast	Mid-March to mid-April	Mid-November to mid-December
<i>Aman</i> -Transplanted	End June to early September	December to early January
<i>Boro</i> -Local	Mid-November to mid-January	April to May
<i>Boro</i> -HYV	December to mid-February	Mid-April to June

Source: FGD and KII (2015)

Aus—*Aus* rice usually planted during the summer season, which may extend from March–April under the rain-fed and/or irrigated condition

Aman—*Aman* rice is usually cultivated during the wet season, which may extend from June–November under rain-fed condition

Boro—*Boro* rice grown during the dry season (January–May) under the irrigated condition

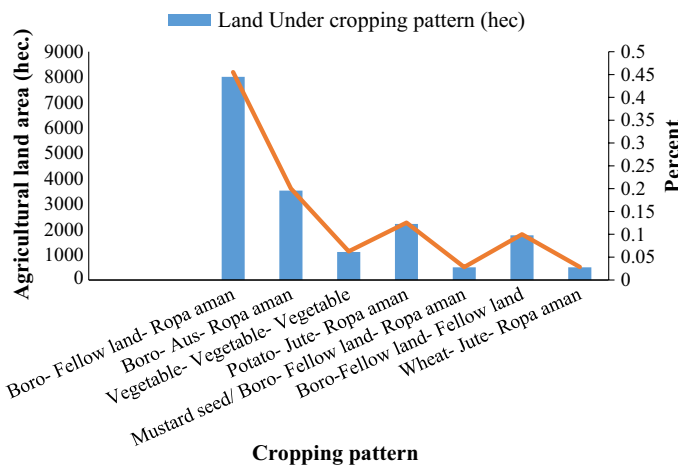


Fig. 2 Existing cropping patterns with respect to agricultural land area and land use percentage in 2014

is the fallow land—*Ropa aman*. The previous study conducted by Shaw et al. (2013) reported *Fallow–T. Aman–Fallow* and *Fallow–T. Aman–Boro* as the main cropping pattern in the Satkhira region of Bangladesh.

4.2.1 Climate change impacts on cropping patterns

In the study areas of Satkhira district, the practices of cropping patterns are changing over time because of climate change impacts such as saltwater intrusion due to coastal flooding as well as cyclones (e.g., *Sidr* and *Aila*), which is intensified by the effects of climate change. Saltwater intrusion and increase in soil salinity have serious negative impacts on agriculture in these areas, especially during the winter season. Abedin and Shaw (2013) asserted that once salt penetrates to the plant root system, it becomes unfavorable for the whole plant (crops that are not salt tolerant) to survive. The currently practiced rice varieties may not be able to cope with the increased salinity. As a result, the food production

system does not seem to have a better future in the event of a climate change. Most farmers follow cropping patterns that involve sequential cropping, mixed cropping, and relay cropping. Generally, deep-rooted crops (such as jute) are grown after shallow-rooted crops (such as rice), which helps to uptake of soil nutrients from different depths and assists to improve soil quality. Existing cropping patterns with respect to agricultural land area and percentage of land use in the study areas have been presented for the year 2014 (Fig. 2). The study revealed that compared to the wide range of cropping patterns practiced in the past (Table 5), only a few of them are currently practicing by the local farmers because of the changes in soil salinity status, water availability, and coastal flooding all of which have been triggered by the climate-induced disasters and variability in climatic parameters.

4.2.2 Impacts on crop production

Figure 3a–c shows the yearly crop (*Aus*, *Ropa aman*, and *Boro* rice) production (mt/hect.) in relation to the agricultural land area in three different cropping seasons at *Assasuni* Upazila. It should be noted that during the study period (2014–2015) yearly rice production data of *Assasuni* Upazila (1995–2014) were only available. It has been identified that in *Assasuni* Upazila land area for crop cultivation varies in three different seasons, which may be due to effects of frequent climate-induced disasters mainly cyclone in that region as identified by most of the respondents (62%) of the study during field survey. These disaster events consequently make the land unsuitable for cultivation. This is because the land area becomes inundated by saline water (during and after the cyclone) or soil salinity may increase due to saltwater intrusion as the study area is in the coastal belt of Bangladesh. As a result, crop production is found to be declined during the years when tropical cyclones approached in the southern part of the country. For instance, tropical cyclones *Sidr* and *Aila* approached in the southern part of Bangladesh in November 2007 and May 2009, respectively. As a result, crop production has declined severely. Our study showed that in the *Kharif-II* season (extend from mid-July to mid-November), during the period 2008–2009 with an agricultural land area of 13,670 hectares the average production was only 2.58 Mt per hectare. In *Kharif-I* season (extend from mid-March to mid-July), during the period 2008–2009 with an agricultural land area of 641 hectares the average production was only 9.32 Mt per hectare as shown in Fig. 3a–c.

Table 5 List of cropping patterns in the study area in the past few decades

Cropping patterns (local)

1. Boro–fallow land–Ropa aman	10. Fallow land–fallow land–Ropa aman
2. Boro–Aus–Ropa aman	11. Vegetable–vegetable–vegetable
3. Mustard seed–jute–Ropa aman	12. Vegetable–fallow land–Ropa aman
4. Lentil–vegetable–Ropa aman	13. Potato–jute–Ropa aman
5. Lentil–jute–Ropa aman	14. Mustard seed/Boro–fallow land–Ropa aman
6. Potato–vegetable–Ropa aman	15. Spices–jute–Ropa aman
7. Vegetable–sesame–Ropa aman	16. Wheat–Aus–Ropa aman
8. Sugarcane–sugarcane–sugarcane	17. Boro–fallow land–fallow land
9. Vegetable–jute–fallow land	18. Wheat–jute–Ropa aman

Source: FGD and KII (2015)

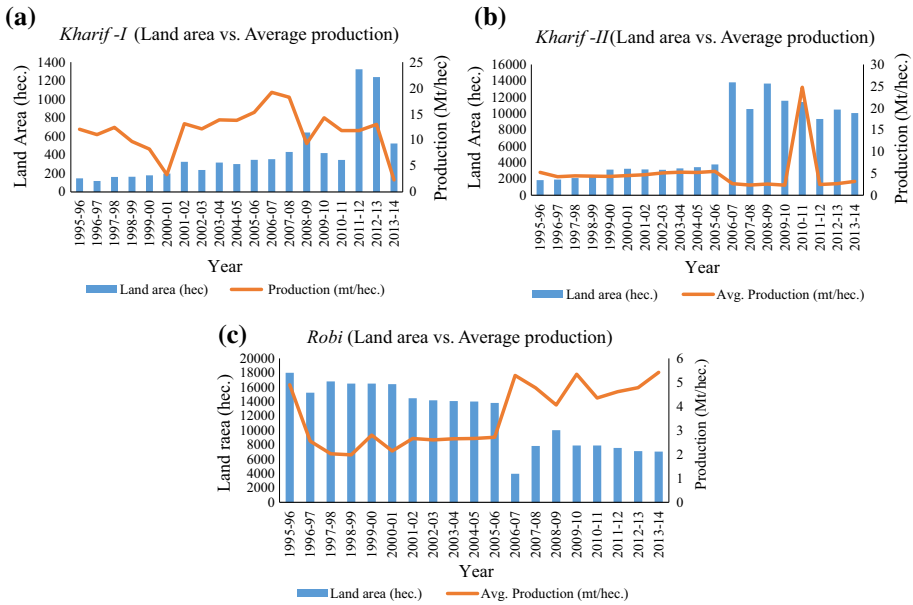


Fig. 3 Yearly crop production in relation to the agricultural land area at Assasuni Upazila: **a** Production of *Aus* in *Kharif-I*; **b** production of *Ropa aman* in *Kharif-II*; and **c** production of *Boro* rice in *Robi* season

4.3 Variability in climatic parameters

This section describes the seasonal trend of climatic variability (average temperature, average humidity and average rainfall for *Kharif-I*, *Kharif-II*, and *Robi* season) in the southern part of Bangladesh. Figure 4 is drawn using the average temperature of three different seasons during the period 1980–2014, which indicates that during the *Kharif-I* and *Kharif-II* season, the lowest average temperature in the study area was 24 °C and 22 °C, respectively, in 1980 and the highest average temperature was 30.4 °C and 28.7 °C in 1985 and 1987,

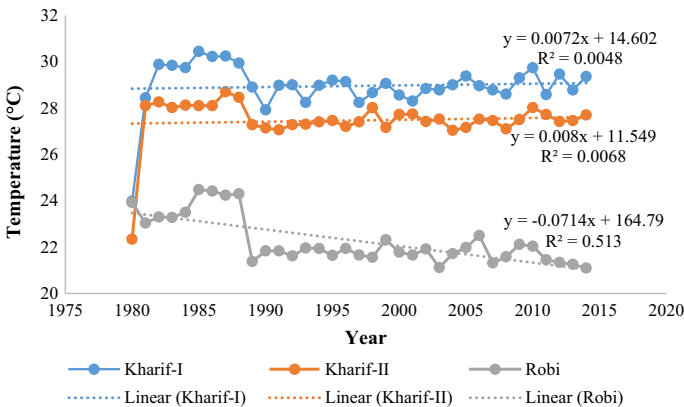


Fig. 4 Temperature pattern in *Kharif-I*, *Kharif-II* and *Robi* season (1980–2014)

respectively. During the *Robi* season, the average temperature was found lower compared to the other two seasons with the highest temperature of 24.5 °C in 1985 (Fig. 4). The study identified a slightly moderate trend in average temperature of *Kharif-I* and *Kharif-II* season and a decreasing rate (0.071%) of average temperature in *Robi* season where the value of the coefficient of determination is 0.513.

Trend analysis of seasonal average relative humidity shows opposite results compared to the trend analysis result of average temperature in three different seasons. For instance, the study shows an increasing trend (0.248%) of average humidity during *Kharif-I* and *Kharif-II* season as well as an increasing trend of 0.431% was observed during the *Robi* season as shown in Fig. 5. The highest humidity during the *Kharif-I* and *Kharif-II* season was recorded at 79.8% in 1997 and 85% in both 1995 and 1998, whereas the lowest value was recorded at 56% and 61% in 1980 during these two seasons (Fig. 5).

Regarding average rainfall, the trend analysis shows a similar result of the trend analysis of annual average temperature. For instance, the average rainfall distribution in *Robi* season over the study area shows a decreasing rate of 0.40% during the period 1980–2014 where the value of the coefficient of determination is 0.0487 (Fig. 6). However, a moderate trend in average rainfall during the *Kharif-I* and *Kharif-II* season was found as shown in Fig. 6. The highest average rainfall (340.8 mm) was found in 1986 during the *Kharif-II* season as maximum rainfall occurs in this season, whereas, in *Kharif-I* season, the highest average rainfall was 266.8 mm in 1981 as shown in Fig. 6.

4.4 Correlation among annual average crop production and climatic parameters

Pearson correlation among annual average crop production (*Aus*, *Ropa aman*, and *Boro* rice) and seasonal average climatic data (e.g., temperature, humidity, and rainfall) for three different cropping seasons (*Kharif-I*, *Kharif-II*, and *Robi*) has been performed in this study as shown in Tables 6, 7, and 8. The study found a significant strong negative correlation between seasonal average temperature and seasonal average humidity ($r = -0.60$, $p < 0.05$) during the *Kharif-I* season (Table 6). A significant strong positive correlation between seasonal average rainfall and seasonal average humidity ($r = 0.75$, $p < 0.05$) during the *Robi* season was also observed as shown in Table 8.

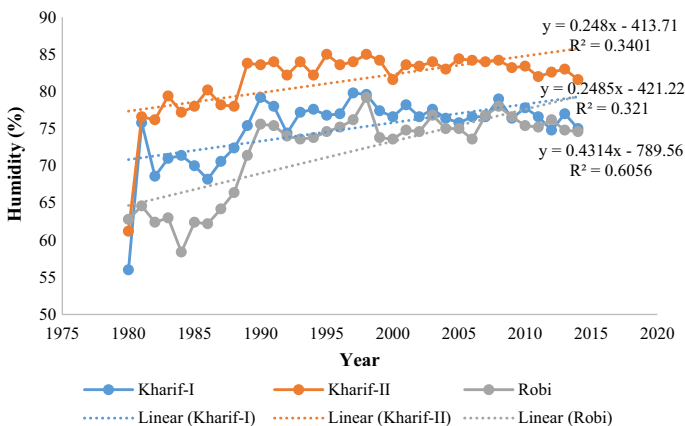


Fig. 5 Humidity pattern in *Kharif-I*, *Kharif-II* and *Robi* season (1980–2014)

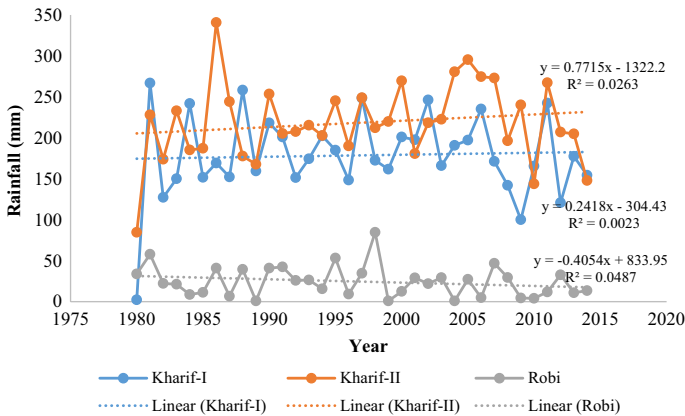


Fig. 6 Rainfall pattern in *Kharif-I*, *Kharif-II* and *Robi* season (1980–2014)

Table 6 Pearson correlation among annual average crop production (*Kharif-I*) and seasonal average climatic data (1996–2014) of *Assasuni* Upazila

	Avg. production (<i>Kharif-I</i>)	Seasonal avg. temperature	Seasonal avg. humidity	Seasonal avg. rainfall
Avg. prod. (<i>Kharif-I</i>)	1			
Seasonal avg. temperature	.046	1		
Seasonal avg. humidity	.166	-.601**	1	
Seasonal avg. rainfall	.057	-.525*	.210	1

*Correlation is significant at the 0.05 level (two-tailed)

**Correlation is significant at the 0.01 level (two-tailed)

Table 7 Pearson correlation among annual average crop production (*Kharif-II*) and seasonal average climatic data (1996–2014) of *Assasuni* Upazila

	Avg. production (<i>Kharif-II</i>)	Seasonal avg. temperature	Seasonal avg. humidity	Seasonal avg. rainfall
Avg. prod. (<i>Kharif-II</i>)	1			
Seasonal avg. temperature	.141	1		
Seasonal avg. humidity	-.295	-.199	1	
Seasonal avg. rainfall	.320	-.365	.113	1

4.5 Disaster vulnerability and disaster appearances in the southern part of Bangladesh

The results from the surveyed areas reflect that local people are realizing the changing pattern of the local climate, which makes them more vulnerable to frequent disasters resulting

Table 8 Pearson correlation among annual average crop production (*Robi*) and seasonal average climatic data (1996–2014) of *Assasuni* Upazila

	Avg. production (<i>Robi</i>)	Seasonal avg. temperature	Seasonal avg. humidity	Seasonal avg. rainfall
Avg. prod. (<i>Robi</i>)	1			
Seasonal avg. temperature	–.359	1		
Seasonal avg. humidity	.119	–.397	1	
Seasonal avg. rainfall	–.191	–.410	.754**	1

*Correlation is significant at the 0.05 level (two-tailed)

**Correlation is significant at the 0.01 level (two-tailed)

in serious losses in the local agricultural system. The majority (60%) of the local respondents assumed that the southern part of Bangladesh is becoming disaster prone due to climate change while 15% and 18% assumed this region is becoming disaster prone due to anthropogenic activities and geographical location, respectively, as shown in Fig. 7a. Sikder and Xiaoying (2014) reported some key factors that make Bangladesh as one of the highly vulnerable countries in Asia to climate change impacts including its geographical location and greater dependency on agriculture, which is considered as one of the most climate-sensitive sectors.

As mentioned earlier, cyclone is the most frequently occurred phenomena in the southern region of Bangladesh; however, most of the local people reported that massive cyclone hits in the coast of Bay of Bengal in every 6–8 years. It should be noted that in 1991, 2007, 2009 three massive cyclones hit in the coast of the Bay of Bengal that caused serious losses in agriculture, economy, and loss of life and property. However, this study identified some major disaster events that are vulnerable to the agricultural sector in the study area, whereas most of the respondents (62%) identified cyclone as the main disaster event followed by flood (18%) and saltwater intrusion (11%) as shown in Fig. 7b. The study conducted by Sikder and Xiaoying (2014) also identified similar disaster events including

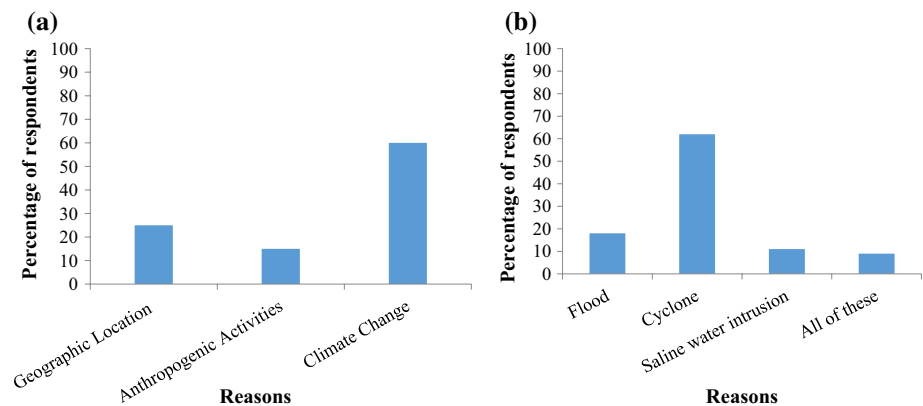


Fig. 7 **a** Main reasons for disaster vulnerability, and **b** various types of disaster appearance in the southern part of Bangladesh

cyclones and storm surges, saltwater intrusion and flooding all of which are frequent in the southern region and highly responsible for agricultural losses.

4.6 Adaptation practices in the agricultural cropping sector

Adaptation refers to ‘adjustment in ecological, economic, social and human systems’ in response to actual and expected climatic changes and impacts (IPCC 2007a; ADPC and BCAS 2008). It is evident that climate change has been generating devastating impacts, especially in the agricultural sector in Bangladesh. A significant amount of net cropped areas remains as fallow land in the coastal areas in *Robi* and *Kharif-I* seasons, due to the influence of climate change impacts (e.g., coastal flooding and saltwater intrusion). Haque et al. (2016) reported the production loss of 230,681 tonnes *Aman* rice and 94,164 tonnes *Aus* rice due to excessive rainfall and coastal flooding during the period 2007–2008. Moreover, the salinity problem is exacerbating the overall crop production scenario in the coastal region of the country. As an adaptation strategy, the practice of different salt-tolerant rice varieties (BRRI-47, BRRI-40, and BRRI-41) has been reported by Abedin and Shaw (2013). The BRRI-47 can tolerate 12–18 dS/m, and BRRI-40 and BRRI-41 can tolerate 8 dS/m salinity during their seedling stage. However, our study has identified the following adaptation strategies based on the field observation, FGD, and KII that could be the potential solution to cope with the climate-induced impacts in the agricultural cropping system in the southern region of Bangladesh:

- a. *Salt-tolerant species*: Increased use of salt-tolerant rice varieties such as BRRI-40, BRRI-41, BRRI-47, BRRI-52, and BRRI-53, which can tolerate up to 8-12/13ppt salinity and could be a potential adaptation strategy for the southern region of Bangladesh.
- b. *Flood-tolerant species*: The cultivation of flood-tolerant species (e.g., BRRI-17) could be practiced as a potential adaptation option to cope with the coastal flooding in the southern region.
- c. In the flood-prone areas, some other potential adaptation options could be practiced including floating bed vegetables, dyke cropping system (mainly for vegetable cultivation) with adequate height and width as innovated by the Practical Action Bangladesh under their ‘Community-based Adaptation to Climate Change Project’ in the Satkhira district, Bangladesh.

5 Conclusion

The agricultural sector in Bangladesh is highly sensitive to climate change impacts and is heavily influenced by climatic variability, which results in changing cropping pattern and also makes crop productivity vulnerable. It has been observed that in the southern coastal region several climate-induced disasters caused serious losses in agriculture and the economy in the last decade. This study identified that the local farmers change their cropping pattern due to climatic impacts. Crop production has declined in the study areas (*Kalaroa* and *Assasuni* Upazila) because of the impacts of cyclones and saltwater intrusion in the agricultural land. Rice which is the dominant crop in the coastal districts of Bangladesh has been affected seriously due to climate change impacts. Although local farmers take some adaptation strategies, these are practicing on a very small scale, which may be due to lack of awareness, poor facilities, and inadequate information from the concern authorities.

This study, therefore, suggests that government should provide proper adaptation strategies and reform the agricultural policy for the coastal regions to reduce vulnerability and increased food security as the majority of the coastal people depends on coastal agricultural for their livelihood and economy.

Acknowledgements The authors sincerely thank the Ministry of Science and Technology (MOST), the People's Republic of Bangladesh for financial support and gratefully acknowledge the Bangladesh Meteorological Department (BMD) for providing climatic data as well as the Agricultural Extension Office (AEO) of Kolaroa and Assasuni Upazila for providing us the crop production data.

References

- Abedin, M. A., & Shaw, R. (2013). Agriculture adaptation in coastal zone of Bangladesh. In *Climate change adaptation actions in Bangladesh* (pp. 207–225). Tokyo: Springer.
- Adams, R. M., Hurd, B. H., Lenhart, S., & Leary, N. (1998). Effects of global climate change on agriculture: an interpretative review. *Climate Research*, 11(1), 19–30.
- ADB (2009). Agricultural impact of climate change: A general equilibrium analysis with special reference to Southeast Asia. Asian Development Bank Institute (ADB) Working Paper Series, No. 131.
- ADPC and BCAS (2008). Asian Disaster Preparedness Centre (ADPC) and Bangladesh Centre for Advanced Studies (BCAS). Draft Disaster Management Information Link Report, Comprehensive Disaster Management Programme (CDMP), Component 5b, Ministry of Food and Disaster Management (MoFDM), Government of Peoples Republic of Bangladesh, Dhaka, Bangladesh.
- AEO (2014). Production data of rice varieties and crops in Kolaroa and Assasuni Upazila, Satkhira. Agricultural Extension office (AEO), Department of Agricultural Extension (Personal communication).
- Aggarwal, P. K., Bandyopadhyay, S. K., Pathak, H., Kalra, N., Chander, S., & Kumar, S. S. (2000). Analysis of the yield trends of rice-wheat system in north-western India. *Outlook on Agriculture*, 29(4), 259–268.
- Aggarwal, P., Pathak, H., Kumar, S. bN., & Sharma, P. (2013). South Asia perspectives on climate change and agriculture: Adaptation options. In D. Hillel & C. Rosenzweig (Eds.), *Handbook of climate change and agroecosystems: Global and regional aspects and implications* (pp. 209–222). Joint Publication with the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.
- Ahmed, A. U., & Alam, M. (1999). *Vulnerability and adaptation to climate change for Bangladesh* (pp. 13–20). Berlin: Springer.
- Arnell, N. W., Brown, S., Gosling, S. N., Gottschalk, P., Hinkel, J., Huntingford, C., et al. (2016). The impacts of climate change across the globe: a multi-sectoral assessment. *Climatic Change*, 134(3), 457–474.
- Banglapedia (2015). The National Encyclopedia of Bangladesh. Available at: http://en.banglapedia.org/index.php?title=Satkhira_District. Accessed June 22, 2018.
- BBS (Bangladesh Bureau of Statistics) (2016). Yearbook of Agricultural Statistics-2015. Ministry of Planning Government of the People's Republic of Bangladesh. http://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/1b1eb817_9325_4354_a756_3d18412203e2/Yearbook-2015.pdf. Accessed 24 Mar 2019.
- Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2014). Climate change and agriculture: Impacts and adaptation options in South Africa. *Water Resources and Economics*, 5, 24–48.
- CDMP II (Comprehensive Disaster Management Programme) (2013). Development of four decade long climate scenario & trend temperature, rainfall, sunshine & humidity. Institute of Water and Flood Management, BUET. Study Report (pp. 91–101).
- Chen, S., Chen, X., & Xu, J. (2016). Impacts of climate change on agriculture: Evidence from China. *Journal of Environmental Economics and Management*, 76, 105–124.
- Cline, W. (2007). Global Warming and Agriculture: Impact Estimates by Country. Peterson Institute for International Economics.
- FAO (2016). The state of food and agriculture—Climate change, agriculture and food security. Food and Agriculture Organization of the United Nations, Rome. www.fao.org/publications. Accessed 24 Mar 2019.

- Fischer, G., Shah, M., & van Velthuis, H. (2002). Climate change and agricultural vulnerability. A special report by International Institute for Applied Systems Analysis. Laxenburg, Austria. <http://pure.iiasa.ac.at/id/eprint/6670/1/XO-02-001.pdf>. Accessed 24 Mar 2019.
- Gregory, P. J., & Ingram, J. S. I. (2000). Global change and food and forest production: future scientific challenges. *Agriculture, Ecosystems & Environment*, 82, 3–14.
- Groisman, P. Y., Karl, T. R., Easterling, D. R., Knight, R. W., Jamason, P. F., Hennessy, K. J., et al. (1999). *Weather and climate extremes* (pp. 243–283). Berlin: Springer.
- Haque, M. N., Ali, M. H., & Masum, S. M. (2016). *Climate change impacts on rice production in Bangladesh*. Saarbrücken: Lambert Academic Publishing.
- Huq, 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(7), 8437–8460.
- Huq, S. I., & Shoaib, J. M. (2013). *The soils of Bangladesh*. Dordrecht: Springer.
- IPCC (2007a). Impacts, Adaptation and Vulnerability. In M. L. Parry, O. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Contribution of working group II to the fourth assessment report of the IPCC* (pp. 976). Cambridge: Cambridge University Press.
- IPCC (2007b). Climate Change 2007: Climate change impacts, adaptation and vulnerability. Summary for Policymakers. Inter-Governmental Panel on Climate Change.
- IPCC. (2007c). Climate change 2007: The physical science basis. *Agenda*, 6(07), 333.
- Islam, M. B., Ali, M. Y., Amin, M., & Zaman, S. M. (2010). Climatic variations: Farming systems and livelihoods in the high barind tract and coastal areas of Bangladesh. In R. Lal, M. Sivakumar, S. Faiz, A. Mustafizur Rahman, & K. Islam (Eds.), *Climate change and food security in South Asia* (pp. 477–497). Dordrecht: Springer.
- Kelley, K., Clark, B., Brown, V., & Sitzia, J. (2003). Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care*, 15(3), 261–266.
- Knox, J. W., Hess, T. M., Daccache, A., Perez Ortola, M. (2011). What are the projected impacts of climate change on food crop productivity in Africa and South Asia? DFID Systematic Review, Final Report (pp. 77). Cranfield University.
- Kumar, K. K. (2011). Climate sensitivity of Indian agriculture: do spatial effects matter? *Cambridge Journal of Regions, Economy and Society*, 4(2), 221–235.
- Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: a review. *Climatic Change*, 78(2–4), 445–478.
- McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., White, K. S. (2001). Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 2). Cambridge University Press.
- Mondal, M. H. (2010). Crop agriculture of Bangladesh: Challenges and opportunities. *Bangladesh Journal of Agricultural Research*, 35(2), 235–245.
- Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M. (2009). Climate change: Impact on agriculture and costs of adaptation (Vol. 21). International Food Policy Research Institute.
- Oppenheim, A. N. (2000). *Questionnaire design, interviewing and attitude measurement*. London: Continuum.
- Osborne, T., Rose, G. A., & Wheeler, T. R. (2012). Variation in the global-scale impacts of climate change on crop productivity due to climate model uncertainty and adaptation. *Agricultural and Forest Meteorology*, 170, 183–194.
- Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14(1), 53–67.
- Pathak, H., Ladha, J. K., Aggarwal, P. K., Peng, S., Das, S., Singh, Y., et al. (2003). Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. *Field Crops Research*, 80(3), 223–234.
- Ramankutty, N., Foley, J. A., Norman, J., & McSweeney, K. (2002). The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. *Global Ecology and Biogeography*, 11(5), 377–392.
- Rodrigo, F. (2002). Changes in climate variability and seasonal rainfall extremes: a case study from San Fernando (Spain), 1821–2000. *Theoretical and Applied Climatology*, 72(3–4), 193–207.
- Rokonuzzaman, M., Rahman, M. A., Yeasmin, M., & Islam, M. A. (2018). Relationship between precipitation and rice production in Rangpur district. *Progressive Agriculture*, 29(1), 10–21.
- Rosegrant, M. W., & Cline, S. A. (2003). Global food security: challenges and policies. *Science*, 302(5652), 1917–1919.

- Shahid, S. (2010). Rainfall variability and the trends of wet and dry periods in Bangladesh. *International Journal of Climatology*, *30*(15), 2299–2313.
- Shahid, S. (2011). Impact of climate change on irrigation water demand of dry season Boro rice in north-west Bangladesh. *Climatic Change*, *105*(3–4), 433–453.
- Shaw, R., Mallick, F., & Islam, A. (Eds.). (2013). *Climate change adaptation actions in Bangladesh*. New York: Springer.
- Sikder, R., & Xiaoying, J. (2014). Climate change impact and agriculture of Bangladesh. *Journal of Environment and Earth Science*, *4*(1), 35–40.
- Stern, N. (2006). Stern review: The economics of climate change. http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf. Accessed 24 Mar 2019.
- Su, B., Jiang, T., & Jin, W. (2006). Recent trends in observed temperature and precipitation extremes in the Yangtze River basin, China. *Theoretical and Applied Climatology*, *83*(1–4), 139–151.
- Van Meijl, H., P. Havlik, H. Lotze-Campen, E. Stehfest, P. Witzke, I. Pérez Domínguez, B. Bodirsky, M. van Dijk, J. Doelman, T. Fellmann, F. Humpenoeder, J. Levin-Koopman, C. Mueller, A. Popp, A. Tabeau, H. Valin (2017). Challenges of global agriculture in a climate change context by 2050 (AgCLIM50). *JRC Science for Policy Report, EUR 28649 EN*. <https://doi.org/10.2760/772445>.
- Wang, J., Mendelsohn, R., Dinar, A., Huang, J., Rozelle, S., & Zhang, L. (2009). The impact of climate change on China's agriculture. *Agricultural Economics*, *40*(3), 323–337.
- Zakaria, M., Aziz, M. A., Hossain, M. I., & Rahman, N. M. F. (2009). Effects of rainfall and maximum temperature on aman rice production of Bangladesh: A case study for last decade. *International Journal of Scientific & Technology Research*, *3*(2), 131–137.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.