Chapter 9
Agricultural and Environmental Changes in Bangladesh in Response to Global Warming

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Contents

9.1 Introduction 120
9.2 Materials and Methods 121
9.3 Results and Discussion 122
9.3.1 Carbon Dioxide Emissions, Global Warming, and Bangladesh Environmental Changes 122
9.3.2 Population Growth and Environmental Changes Impact on Agriculture 127
9.4 Conclusions 132
References 133

Abstract Global climate change is a growing concern for Bangladesh. To evaluate the global climate change effects on environmental changes and agricultural production in Bangladesh, long-term data on selected climatic variables (1948–2006), agricultural production (1960–2006), and population growth (1940–2008) were collected, organized and analyzed. Results suggested that although Bangladesh emits less than 0.2% of the global carbon dioxide (CO_2), it is nevertheless facing the impact of global climate change. Average air temperature was found to be increased @ 0.7°C per decade across Bangladesh. As expected, the rainfall distribution varied regionally over time. Total average rainfall increased in the north-eastern (2.6 cm/year) region but decreased in the south-eastern region (1.4 cm/year) or remained same in the north-western and south-western regions of the country. Average sunshine duration decreased by 36 min/decade in between 1962 and 2000. While agricultural land saturation (150% cropping intensity) with increasing population

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growth (1.8%) abounds, food production in Bangladesh under changing climates has improved over time. Total area under rice production slightly decreased, the yield, however, increased (85%). In contrast, total area under wheat (<1% to 7%), maize, potato (<1% to >2%), and oilseed production increased over time. The yield increased from <0.8 to >2 Mg/ha for wheat, 1 to >5 Mg/ha for maize, and 2.5–14 Mg/ha for potato. Total area under jute (>8 to <4%) and legume production decreased but the yield per unit of land increased over time. However, with increasing population, degraded land quality, and potential global warming, agriculture is seen as one of the major vulnerabilities facing Bangladesh in near future. More specifically, a progressive decline in sunshine duration (25%) over a period of 30 years has become a growing concern for agriculture in terms of reduced photosynthesis and food security.

Keywords Gaseous emissions • Food production • Sea level rise • Rainfall amount • Evapotranspiration

Abbreviations

SAARC	South-East Asian Association for Regional Cooperation
GHG	Greenhouse gas
MPO	Master Planning Organization

9.1 Introduction

Human activities over time have led to global climate change by emitting greenhouse gases (GHGs) especially CO_2 from fossil fuel combustion and indiscriminate land-use practices (IPCC 2007; Boden et al. 2009). Among the GHGs, CO_2 is responsible for 72% of the global climate change followed by CH_4 (18%), NOx (9%), and others (1%). Currently, fossil fuel consumption and land-use changes are accounted for 8 and 1.6 billion Mg of annual C emissions, respectively (IPCC 2007; Koonin 2007). The progressive accumulation of CO_2 has changed the atmospheric composition and created global warming by raising air temperature @ 0.2°C per decade since 1950, and consequently affected our environment (IPCC 2007). It is expected that global warming will affect most of the countries of the world to some extent (IPCC 2007). However, there is a growing concern that the impact of global warming will be a major threat to topographically low-lying countries like Bangladesh (Huq 2001; Quader et al. 2004; Ahmed 2006). The UN Climate Panel has already listed Bangladesh as one of the countries of the world most vulnerable to climate change effects (IPCC 2007).

Bangladesh is located in South Asia, between 20°34′8″–26°38′8″ N latitudes, and between 88°01′8″–92°12′8″ E longitudes with an area of about 147,570 km^2 (Rashid 1991). It is a low-lying delta of the transboundary Ganges, Brahmaputra, Meghna and Jamuna rivers. The floodplains occupy 80% of the country (Rashid 1991). Even much before the climate change realities began to unfold; Bangladesh became prone to natural disasters (Rashid 1991; Mirza et al. 2001; Mirza 2002). It's the geography and climate (monsoon) which makes Bangladesh vulnerable to the effects of global warming (Rashid 1991; Mirza et al. 2001; Mirza 2002). Since, the landscape of Bangladesh is only a few meters above the mean sea level, it resides in a water paradox in that it receives massive volumes of water both from trans-boundary rivers and from rains (average 2.3 m annually) during monsoon, but seasonal water shortages are common during dry season (Karim et al. 1990a; Rashid 1991; Mirza et al. 2001; Mirza 2002; Agarwala et al. 2003). Among the 57 transboundary rivers, the Ganges, the Brahmaputra, the Meghna, and the Jamuna, have highest peak discharge of water in the world (Rahman et al. 1990; Mirza et al. 2001; Mirza 2002; Agarwala et al. 2003). About 1,100 km^3 of water enters Bangladesh annually through these rivers, mostly during the monsoon. To put this in perspective, it is equivalent to covering the entire country in water to a depth of 7.5 m. As a result, the country is subjected to frequent water surges and floods (Rahman et al. 1990; Mirza et al. 2001; Mirza 2002).

Bangladesh currently has a population of 150M and will add another 30M by 2025 (http://www.census.gov/ipc, http://www.who.int/research/en). About 20% of the total population living in and around highly productive but most vulnerable coastal areas and islands in the Bay of Bengal (Huq et al. 1998; Faisal and Parveen 2004). Bangladesh has 8.8 M ha of agricultural land, of which more than 85% is cultivated, so there is a limited scope for horizontal expansion of the cultivated area for food production (Karim et al. 1998; Faisal and Parveen 2004). The higher population growth has triggered agricultural intensification to meet the need for increased food production. To meet the increasing food demand for growing population, Bangladesh has no other alternatives to increase the cropping intensity. As a result, the intensive double (59%) and triple (22%) cropping increases the effective crop production by 150% with an associated degradation of land quality from continuous rice monoculture, inadequate soil–water conservation measures, unbalanced fertilization, and indiscriminate use of chemical protection (Karim et al. 1990a, b; Habibullah et al. 1998; Karim et al. 1998; Faisal and Parveen 2004). With increasing population, degraded land quality, and potential global warming, agriculture is seen as one of the major vulnerabilities facing Bangladesh today. The objectives of the paper were to discuss the effects of global warming on climate change and agricultural production, and the anticipated effects of climate change and increasing population growth on environmental degradation and food security of Bangladesh.

9.2 Materials and Methods

Long-term climatic data (1940–2004) collected by Bangladesh Meteorological Department 2008 (http://www.bmd.gov.bd/Mrain.php) and the Department of Environment 2008 (http://www.doe-bd.org) were used. The CO_2 emissions data (2008) were collected from Carbon Dioxide Information Analysis Center (Boden et al. 2009). The data on population statistics (1940–2008) were collected from the International Data Base Entry – U.S. Census Bureau 2008 (http://www.census.gov/ipc/www/idb/informationGateway.php) and World Health Organization 2008 (http://www.who.int/research/en). Bangladesh agricultural information (1960–2004) on total production area and yield of rice, maize, wheat, legumes, fibers (e.g. jute), tubers (e.g. potato), and oilseeds were collected from Food and Agriculture Organization of the United Nations 2008 (http://faostat.fao.org). The collected data were organized, processed, and presented in tables and figures. Excel® and SigmaPlot® software were used to convert the data and for making graphs. Regression analyses were performed to detect trends on climatic variables, agricultural production, and population growth over time using SigmaPlot®.

9.3 Results and Discussion

9.3.1 Carbon Dioxide Emissions, Global Warming, and Bangladesh Environmental Changes

Among all the countries of the world, Bangladesh contributed only 0.14% of the total global CO_2 emissions compared to 19.1% and 20.2% by USA and China, respectively (Table 9.1). Total amount of CO_2 emitted by Bangladesh is about 11.3 Tg/year. In terms of CO_2 emission, Bangladesh ranked 67th globally. Among the countries of the South-East Asian Association for Regional Cooperation (SAARC), Bangladesh ranked 3rd in terms of total amount CO_2 emissions followed by Pakistan (2nd) and India (1st). Further analysis of data showed that Bangladesh ranked 175th in terms of per capita CO_2 emissions globally. Bangladesh was ranked 5th in terms of per capita

Table 9.1 Total CO_2 emissions by Bangladesh as compared with developed and South-East Asian Association for Regional Cooperation (SAARC) countries in 2008 (Boden et al. 2009)

Country	Amount (Tg/year)	% Contribution	Worldwide rank	SAARC rank
Global	8,230	–	–	–
China	1,660	20.2	1	–
USA	1,570	19.1	2	–
India	427	5.2	4	1
Pakistan	38.9	0.47	34	2
Bangladesh	**11.3**	**0.14**	**67**	**3**
Sri Lanka	3.2	0.04	88	4
Nepal	0.88	0.011	126	5
Maldives	0.24	0.003	162	6
Afghanistan	0.19	0.002	163	7
Bhutan	0.10	0.001	175	8

Table 9.2 Per capita CO_2 emissions by Bangladesh as compared with developed and South-East Asian Association for Regional Cooperation (SAARC) countries in 2008 (Boden et al. 2009)

Country	Amount (Mg)	SAARC rank	Worldwide rank
Qatar	21.6	–	1
USA	5.6	–	9
Maldives	0.7	1	109
India	0.34	2	129
Pakistan	0.23	3	152
Sri Lanka	0.16	4	161
Bangladesh	**0.07**	**5**	**175**
Bhutan	0.05	6	182
Nepal	0.03	7	193
Afghanistan	0.01	8	205

CO_2 emissions among the SAARC countries. The per capita emission of CO_2 in Bangladesh was only 70 kg compared with 5.6 and 21.6 Mg/year in US (2nd) and Qatar (1st), respectively (Table 9.2). However, due to rapid industrialization, economic development, and increasing population growth, the use of commercial fuels in Bangladesh has increased sharply, and as a result, the amount of CO_2 emissions was also increased rapidly (Azad et al. 2006). Bangladesh has few indigenous renewable energy sources, and the country is heavily dependent on the imported fossil fuels. Total amount of CO_2 released from petroleum products, natural gas, and coal were 50%, 44%, and 6% CO_2, respectively (Azad et al. 2006). The analysis of energy data projected that petroleum and coal consumption in Bangladesh will be growing by more than 5%/year, however, the proportion of natural gas in total energy consumption will be increasing. In response, the government of Bangladesh has taken bold steps to reduce its future CO_2 emissions through a development of renewable energy sources and greater use of natural gas (Azad et al. 2006).

Although Bangladesh emits less than 0.2% of the global CO_2 emissions, it is nevertheless facing a climate change problem due to global warming from accelerated CO_2 emissions by developed countries (Huq 2001; Quader et al. 2004; Anonymous 2008; Boden et al. 2009). Long-term data analyses have shown that selected climatic variables such as air temperature, rainfall, relative humidity, and sunshine duration in Bangladesh have changed over time (Figs. 9.1–9.5). Average air temperature was found to be increased @ 0.7°C per decade across Bangladesh (Fig. 9.1). In other words, more than 2°C rise in air temperature had taken place from 1950 to 2004. There was a trend in average maximum temperature rising by 0.14°C per decade between 1960 and 2004 (Fig. 9.2a). Similarly, average minimum temperature increased by 0.18°C per decade (Fig. 9.2b). As expected, total annual rainfall distribution varied regionally over time (Fig. 9.3). On average, the rainfall increased by 0.73 cm/year from 1948 to 2001. When the total amount of rainfall distribution in Bangladesh was divided into four different regions, the highest amount of rainfall was found in the north-east region (Fig. 9.4a). Annual total rainfall increased in the north-east region @ 2.6 cm from 1950 to 1992. Maximum rainfall was recorded

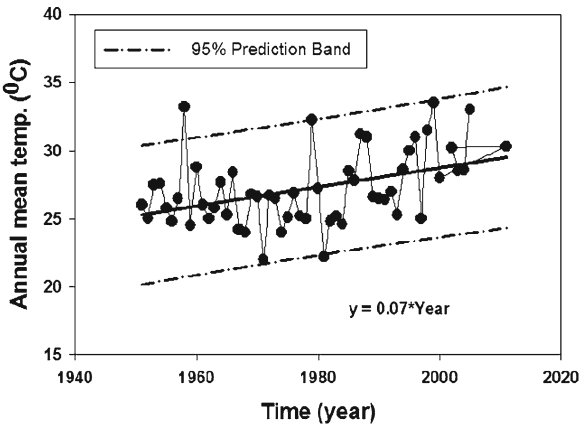

Fig. 9.1 Variations in annual average air temperature over time in Bangladesh (http://www.bmd.gov.bd/Mrain.php and http://www.doe-bd.org)

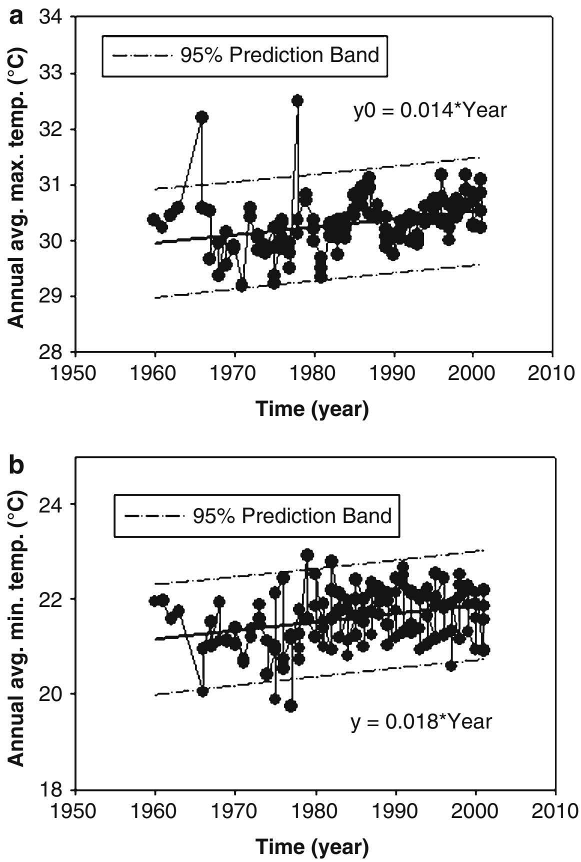

Fig. 9.2 Variations in annual average maximum (**a**) and minimum (**b**) air temperature over time in Bangladesh (http://www.bmd.gov.bd/Mrain.php and http://www.doe-bd.org)

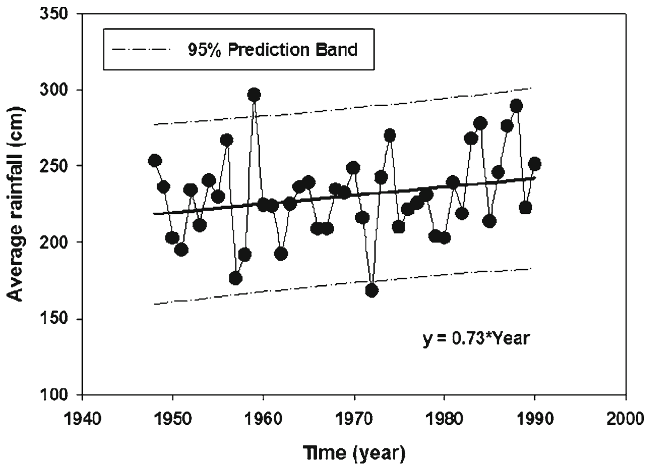

Fig. 9.3 Variations in annual average rainfall over time in Bangladesh (http://www.bmd.gov.bd/Mrain.php and http://www.doe-bd.org)

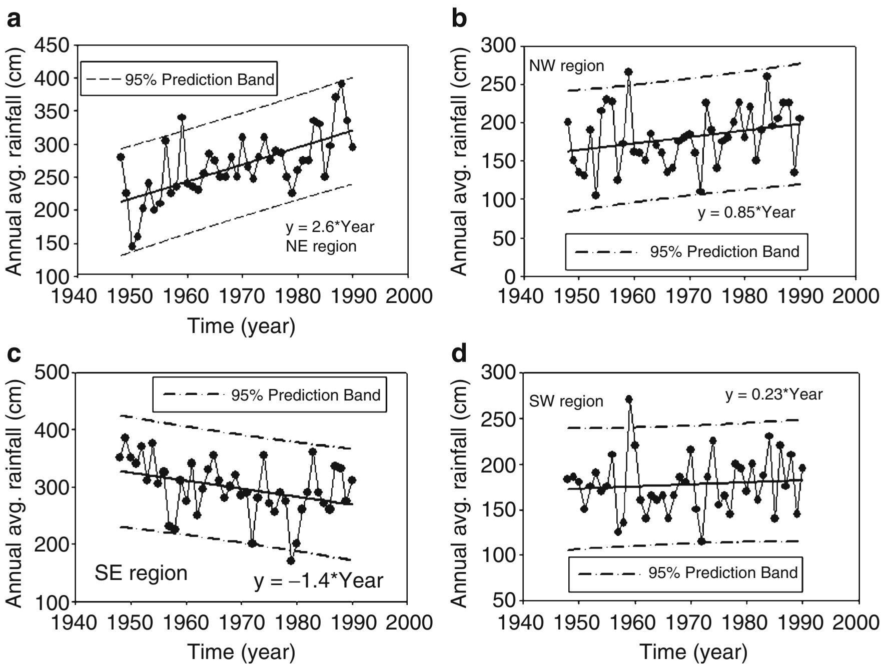

Fig. 9.4 Variations in annual average rainfall over time in north-east (**a**), north-west (**b**), south-east (**c**), and south-west (**d**) regions of Bangladesh (http://www.bmd.gov.bd/Mrain.php and http://www.doe-bd.org)

400 cm as compared to a minimum of 150 cm in the north-east region. However, the amount of total rainfall did not increase consistently in the north-west region. Highest amount of rainfall was recorded 250 cm as compared to the lowest of 100 cm/year (Fig. 9.4b). In contrast, the total rainfall decreased by 1.4 cm/year in the south-east region (Fig. 9.4c). The highest amount of rainfall of 380 cm and the minimum rainfall of 150 cm were recorded in this region. The amount of rainfall in the south-west region of Bangladesh was remained same over time (Fig. 9.4d). Maximum rainfall of about 225 cm and the minimum of 125 cm/year were recorded. Relative humidity increased by 0.81% per decade (Fig. 9.5a). Annual average maximum relative humidity was recorded 85% during 2000s compared with 75% in 1960s. However, the average sunshine duration, in general, was decreasing at an alarming rate of 36 min per decade or 3.6 min/year between 1968 and 2000 (Fig. 9.5b). The sunshine duration was 9.01 ± 0.09 h/day during the period of 1961–1975 which reduced to 5.97 ± 0.11 h/day during the period of 1991–2006.

Several studies have reported a wide spatial and temporal distribution of annual rainfall in Bangladesh (MPO 1991; Anonymous 2008). Annual rainfall reportedly ranged from 120 cm in the extreme west to over 500 cm in the east and north-east regions of the country (MPO 1991). The eastern and southern regions have been receiving more rainfall than western and northern regions of Bangladesh (Anonymous 2008). Moreover, a south to north thermal gradient in winter mean temperature was reportedly developed over time; the southern districts were 5°C warmer than the northern districts (Anonymous 2008). A temperature gradient had also oriented in south-west to north-east direction of the country with the warmer zone in the south-west and the cooler zone in the north-east during pre-monsoon season. As a result, the mean monsoon temperatures were higher in the western districts compared with the eastern districts of Bangladesh. Moreover, various climate models projected that temperature would rise 1.3°C by 2030 and 2.6°C by 2070 with an increase in precipitation, particularly during the monsoon months (Manabe et al. 1991; Mirza 2002; Quader et al. 2004). By the year 2030, the projected rise in monsoon temperature will be 0.7°C with a corresponding rise in winter temperature of 1.3–1.4°C. For 2070, the variation would be 1.7°C and 2.1°C for monsoon and winter temperatures, respectively. It was reported that the winter rainfall would decrease at a negligible rate in 2030, while in 2070 there would not be any appreciable amount of rainfall during winter months. In contrast, the monsoon precipitation would increase at a rate of 12% and 27% for the two projection years, respectively (Manabe et al. 1991; Mirza 2002; Quader et al. 2004).

With higher temperatures increasing evapotranspiration combined with a small decrease in rainfall during dry winter months, even drought, are likely to be expected in the north-western region of Bangladesh. However, net irrigation requirement to meet crop's evapotranspiration is decreasing due to increasing solar dimming (Karim et al. 1990a; Anonymous 2008). The decline in sunshine duration is really a matter of great concern for Bangladesh agriculture (Salam et al. 2003; Ramanathan et al. 2005; Anonymous 2008). A progressive increase in brown cloud coverage over south-Asia due to gradual increase in GHGs and aerosols resulting from accelerated deforestation, rapid urbanization, greater biomass use for cooking and heating, and indiscriminate land-use changes may be responsible of such an alarming rate of decrease in sunshine duration in Bangladesh (Salam et al. 2003, Ramanathan et al. 2005, Anonymous 2008).

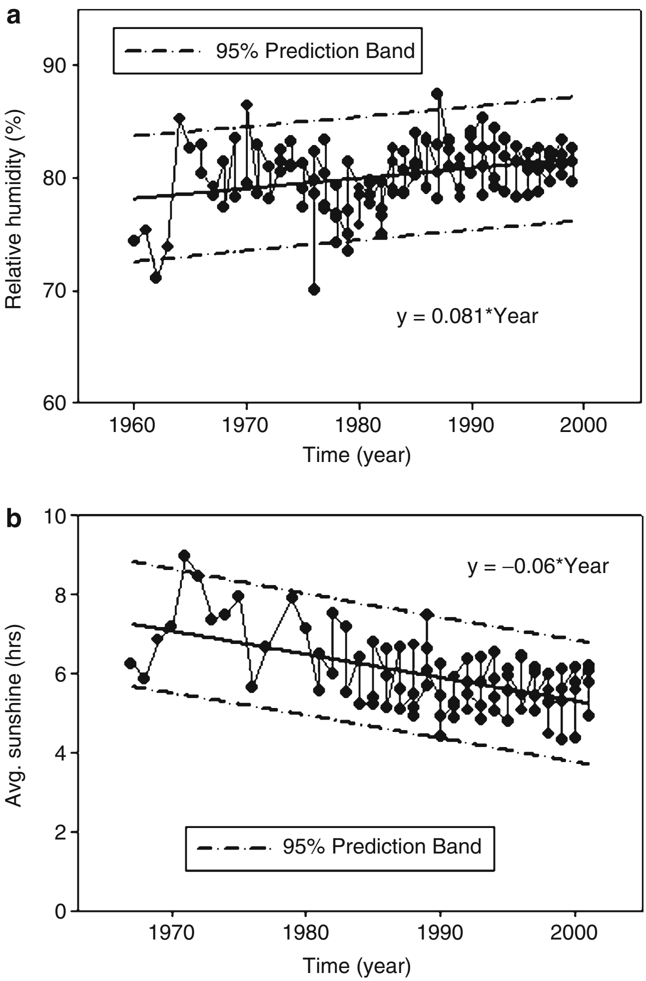

Fig. 9.5 Variations in relative humidity (**a**) and sunshine hours (**b**) over time in Bangladesh (http://www.bmd.gov.bd/Mrain.php and http://www.doe-bd.org)

9.3.2 Population Growth and Environmental Changes Impact on Agriculture

Bangladesh currently has a population approaching 150 M and will add another 100 M before stabilizing (Fig. 9.6a). Although the rate of population growth is declining (Fig. 9.6b), a high population density (>1,000 people/km^2) makes the existing agricultural land is virtually saturated, with a very limited capacity for horizontal expansion of the cultivable lands for crop production. It is projected that most of the increased population will be in urban areas, and much of Bangladesh will essentially become a city state in future (Huq et al. 1998; Faisal and Parveen 2004). The existing population places Bangladesh at great risk of reaching land

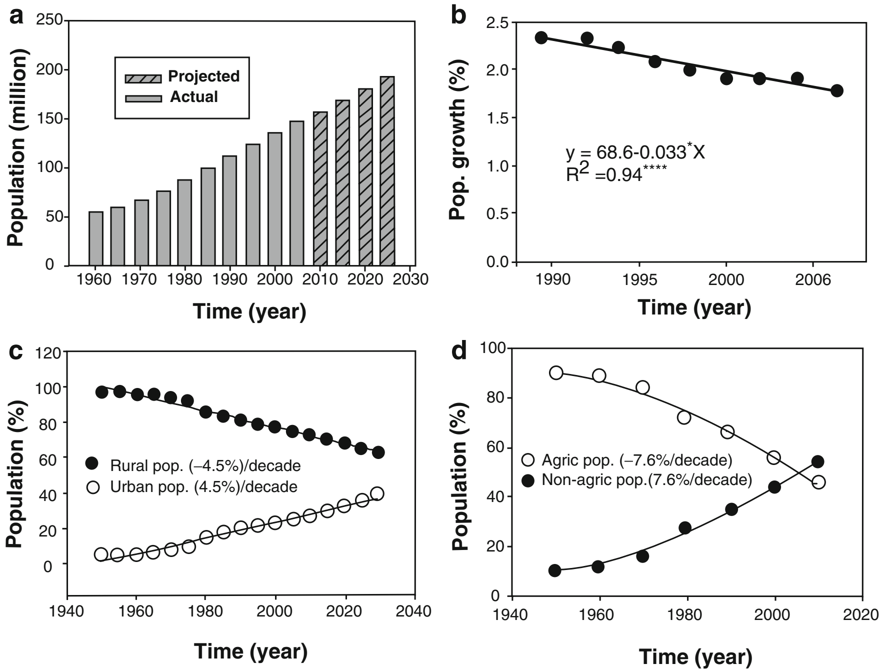

Fig. 9.6 Actual and projected population (**a**), population growth (**b**), urban and rural population (**c**), and agricultural and non-agricultural population (**d**) in Bangladesh (http://www.census.gov/ipc/www/idb/informationGateway.php and http://www.who.int/research/en)

saturation capacity to absorb further population increases into the rural labor force (Fig. 9.6c). Results showed that compared to the mid-1990s, the number of people (rural) working in agriculture sector is declining over time (Fig. 9.6d). These trends suggest that agriculture will not be able to absorb the continuing growth of population into the economically-productive labor force in future. Thus, the continuing population growth in the rural areas will have to find other sources of employment, or they will be driven into the urban areas looking for work. While agricultural land saturation by increasing population growth abounds, the country's agricultural production has improved tremendously in recent decades (http://faostat.fao.org).

Despite floods, droughts, and other problems, production of rice, wheat, maize, legumes, fiber, and tuber crops in Bangladesh has improved over time (Figs. 9.7–9.9. Although the total area under rice production slightly decreased, the yield, however, increased exponentially especially after 1990s (Fig. 9.7). The rice yield increased from <2 Mg/ha in 1960s to about 3.7 Mg/ha in 2000. In contrast, the total area under winter wheat (<1% to 7%) and maize production increased over time (Fig. 9.8ab). The wheat yield increased from <0.8 Mg/ha in 1960s to >2 Mg/ha in 2000s, i.e. four times increase in yield over time. Likewise, the maize yield increased from 1 Mg/ha in 1960s to >5 Mg/ha in 2000s. Total area under tubers especially potato increased linearly (<1% to >2%) over time (Fig. 9.8c).

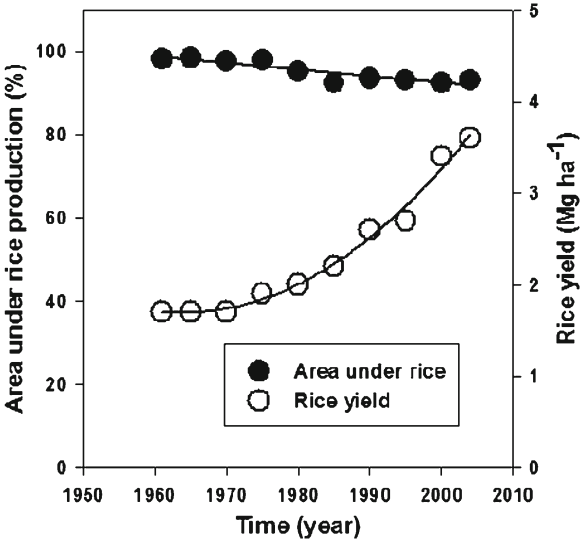

Fig. 9.7 Variations in rice yield and production area over time in Bangladesh (http://faostat.fao.org)

However, the potato yield increased exponentially (2.5–14 Mg/ha). Total area under oilseed crops production increased quadratically, however, the yield increased linearly (Fig. 9.8d). In contrast, the total area under fiber crops (e.g. jute) and legumes decreased over time (Fig. 9.9a,b). Total area under jute production decreased from 8% in 1960s to <4% during 2000s. However, the jute yield increased from 1.5 to 1.9 Mg/ha over time (Fig. 9.9a). The legume yield increased linearly (Fig. 9.9b).

A temporal increase in food production is most probably related to an increase in cropping intensity. It is reported that intensive double (59%) and triple (22%) cropping increases the crop production by 150% using irrigation, abundant chemical fertilization, and widespread use of pesticides (Karim et al. 1990b; Karim et al. 1996; Habibullah et al. 1998; Karim et al. 1998). However, Karim et al. (1996) reported that other than intensive agricultural practices, crop yields potentially responded to atmospheric CO_2 fertilization and a slight increase in air temperature from global climate change impacts. However, as the CO_2 fertilization saturates, yields could decrease. The increase in temperature may have a positive impact on crop production especially rice yields (Karim et al. 1998; Anonymous 2008). In the range of temperatures between 10°C and 32°C, a slight increase in temperatures is considered to be beneficial for crops especially rice. However, with increasing population, degraded land quality, and potential global warming, agriculture is seen as one of the major vulnerabilities facing Bangladesh. The effects of global climate change pose potential risks for Bangladesh, yet the core elements of its vulnerability are primarily contextual. Several projected climate change impacts would in fact reinforce many of these baseline stresses that already pose a serious impediment to food production and agroecosystems functionality in Bangladesh (Huq 2001; Karim et al. 1998; Agarwala et al. 2003; Faisal and Parveen 2004; Quader et al. 2004).

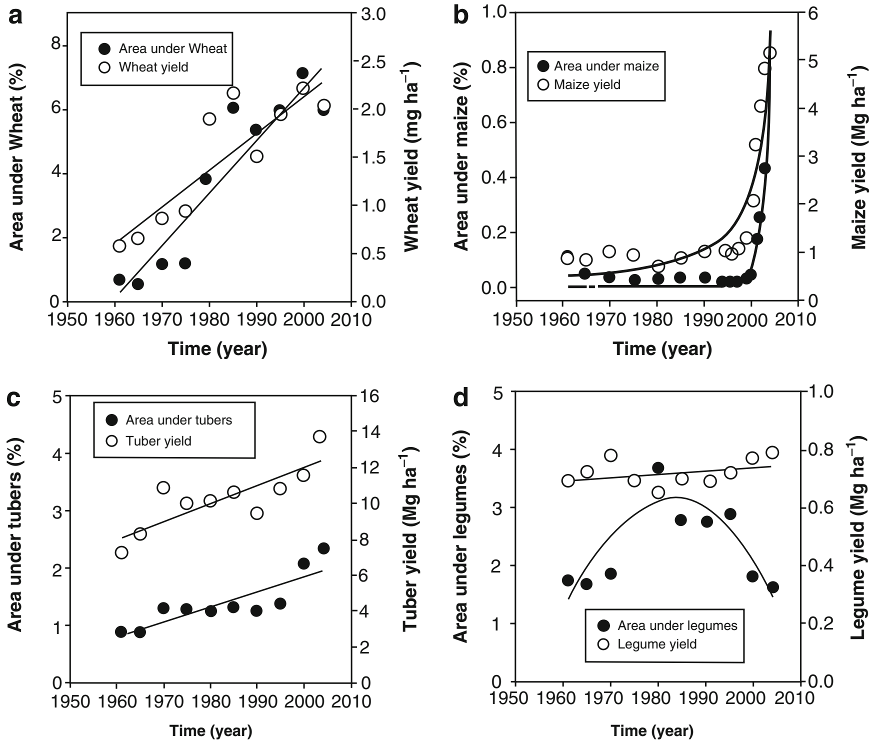

Fig. 9.8 Variations in wheat (**a**), maize (**b**), tubers (**c**), and legume (**d**) yields and production area over time in Bangladesh (http://faostat.fao.org)

Long-term data analysis suggested that the most direct and adverse effect of global warming on crop production across Bangladesh may come from an alarming rate of increase in solar dimming. The optimum day length for growing food crops in Bangladesh is 8–10 h. Due to reduction in sunshine duration by 25%, the light interception and CO_2 assimilation during photosynthesis may be reduced, and affected 15–20% of the crop yields in a typical day length experienced present day Bangladesh (Anonymous 2008). If the trend of decline in rainfall and sunshine duration continues with increasing temperature, catastrophic effects may occur on environmental degradation and agricultural production. Field preparation, planting and harvesting of crops, fertilization, and irrigation scheduling will be affected, and the incidence of pests and diseases will be severe to achieve food security. Other than direct effects of solar dimming from global warming, environmental degradation related to sea level rise and consequent salinity, flooding and soil erosion, and drought may indirectly affect food security in Bangladesh.

Rising sea-levels and consequent salinity may affect crop production by coastal flooding and reduction in availability of lands for growing crops both under ambient conditions, and even more so in the event of storm surges. It will also indirectly

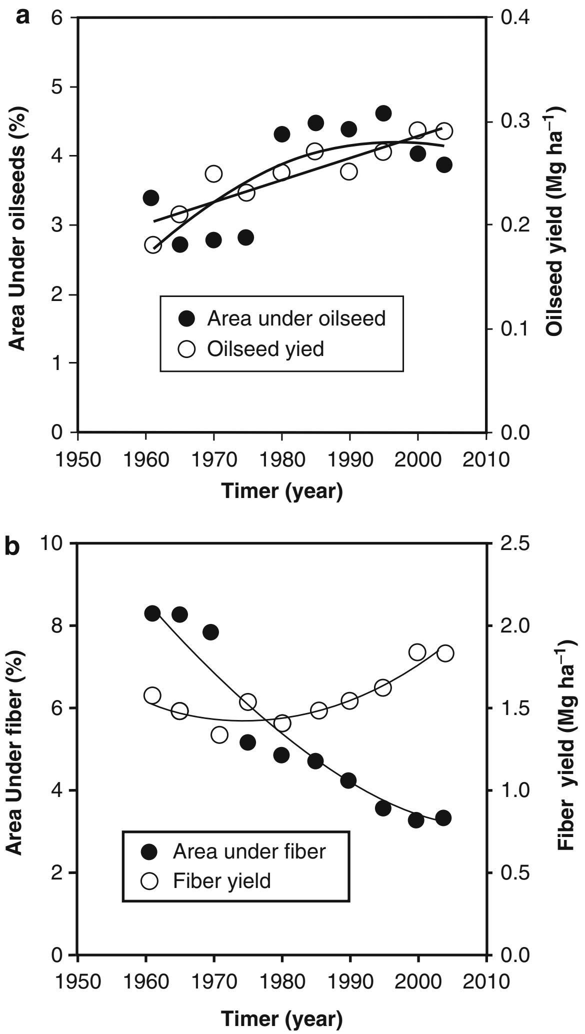

Fig. 9.9 Variations in oilseed (**a**) and fiber (**b**) crops yield and production area over time in Bangladesh (http://faostat.fao.org)

cause riverine flooding by causing more backing up of the Ganges, Brahmaputra, Meghna, and Jamuna rivers along the delta. With the expected 1 m rise in sea level, it is predicted that 20% of the southern Bangladesh will be under water, and will displace 25–30 M people (Habibullah et al. 1998; World Bank 2000; Agarwala et al. 2003; Faisal and Parveen 2004; Ahmed 2006). World Bank (2000) reported a sea level rising of about 3 mm/year in the Bay of Bengal in response to the current level of global warming. Threatening the richest and most productive region of the country, sea level rise and salinity could have dramatic consequences for crop production and the economy of Bangladeshi. It is estimated that in eastern Bangladesh alone 14,000 Mg of grain production would be lost to sea level rise in 2030 and 252,000 Mg would be lost by 2075 (Habibullah et al. 1998; WRI 2001). The impacts of soil and water salinity are already visible in the south-west region of Bangladesh (Karim et al. 1990a, b; Huq et al. 1996; Habibullah et al. 2009).

Several studies have reported that between 30–70% of the Bangladesh is normally flooded annually (Huq et al. 1996; Mirza et al. 2001; Mirza 2002). The huge amount of sediments (>2 Mg/year) brought by the Ganges, Brahmaputra, Meghna, and Jamuna coupled with a negligible flow gradient add to drainage congestion problems and exacerbate the extent of flooding. The climate models projected increased precipitation, particularly during the monsoon season which subsequently will contribute to accelerate runoff (Mirza and Dixit 1997; Mirza et al. 2001, Agarwala et al. 2003; Anonymous 2008). Mirza and Dixit (1997) have reported that a 2°C global warming with a 10% increase in rainfall would increase runoff in the Ganges, Brahmaputra, and Meghna rivers by 19%, 13%, and 11%, respectively. Satellite-image studies of the Ganges–Brahmaputra–Middle-Meghna Rivers have shown that an area of 106,300 ha lost due to flooding and riverine erosion between 1982 and 1992, while the accretion accounted to only 19,300 ha. The net erosion rate from accelerated flooding was therefore estimated at 8,700 ha per annum (Agarwala et al. 2003). Moreover, seasonal drought is a recurring problem in north-western region of Bangladesh due to upstream diversion of transboundary Ganges water by India (Karim et al. 1990a, Mirza et al. 2001). The drought problem is going to be compounded manifolds in future, more so because of the future plan to divert and withdraw greater volume of water from all the transboundary rivers by India. As a result, dry season irrigation scheduling for crops will be drastically affected. It is reported that as high as 47% area of the country is drought vulnerable where 53% of the population is currently living (Karim et al. 1990a, b; Ahmed 2006). Considering that agriculture is one of the pillars of Bangladesh economy-such global climate change impacts have the potential to adversely affect the food production in future. The impacts of increasing population and environmental degradation only exacerbate the climate change problems already facing the agriculture in Bangladesh.

9.4 Conclusions

Bangladesh is vulnerable to global climate change impacts because of its geographical location, high population growth, and greater reliance on climate-sensitive sectors particularly agriculture. Although population growth is declining, a high population density (>1,000 people/km^2) makes the existing agricultural land is virtually saturated for horizontal expansion of lands for agricultural production. Moreover, increasing temperature with less rainfall has already affected biological and physical ecosystems of Bangladesh particularly the north-western region with frequent droughts and the south-western region with increasing soil salinity. However, the most adverse effects of global warming on agriculture may come from an alarming increase (25%) in solar dimming. The decline in sunshine duration (at 36 min per decade) has become a growing concern for agriculture in terms of reduced photosynthesis and food security. Increasing population growth and environmental degradation are going to exacerbate the global climate change effects on agriculture in Bangladesh.

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