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Bangladesh I: Climate Change Impacts, Mitigation and Adaptation in Developing Countries

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Contents

Chapter 1
Climate Change Impacts from the Global Scale to the Regional Scale: Bangladesh

Muhammad Rezaul Rakib, Md. Nazrul Islam, Hasina Parvin, and André van Amstel

Abstract Bangladesh is a beautiful nation. Sadly, it is facing multiple impacts of global warming. The most prominent issues are increased risks of drought, hurricanes, and cyclones; and salt intrusion due to sea level rise and storm surges. Adaptation is difficult and expensive. The Swedish scientist Svante Arrhenius has already warned that an increase in carbon dioxide concentrations in the atmosphere could lead to worldwide temperature increases. Because of various development activities leading to greenhouse gas emissions, the world climate is changing rapidly. Climate change is found in both developing and developed countries, but many developing countries are more affected by climate change and can do less about it. Many poor tropical countries do not have the means to improve their resilience against the effects of climate change. Many island states in the Pacific present examples of this dilemma. Bangladesh is an example of a large country with a large and dense population and is recognized worldwide as being extremely vulnerable to the impacts of global warming and climate change. It is a large delta area vulnerable to sea level rise. Global climate change has already vastly impacted the climate of Bangladesh, as is described in this book. The climate of Bangladesh is heating up and is also changing rapidly because of developments in the rural and urban landscapes. It is unclear if and when this could lead to massive climate change–related migration because of failed crops and failed governance. The designs of embankments, roads, and drainage schemes have already been altered by the government and various agencies. But are these alterations enough in the light of the developments that have occurred rapidly within the last few years? Should not these adaptations be thoroughly evaluated in the light of these new developments?

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1.1 Introduction

Bangladesh is a beautiful nation. Sadly, it is facing multiple impacts of global warming. The most prominent issues are increased risks of drought, hurricanes, and cyclones; and salt intrusion due to sea level rise and storm surges. Adaptation is difficult and expensive (Islam 1994). The Swedish scientist Svante Arrhenius has already warned that an increase in carbon dioxide concentrations in the atmosphere could lead to worldwide temperature increases. Because of various development activities leading to greenhouse gas (GHG) emissions, the world climate is changing rapidly. Climate change is found in both developing and developed countries (Broadus 1993), but many developing countries are more affected by climate change and can do less about it. Many poor tropical countries do not have the means to improve their resilience against the effects of climate change. Many island states in the Pacific present examples of this dilemma (Ahmed 2006). Bangladesh is an example of a large country with a large and dense population, and is recognized worldwide as being extremely vulnerable to the impacts of global warming and climate change (Douma 2007). It is a large delta area vulnerable to sea level rise, and it regularly experiences cyclones and hurricanes, which have become more frequent (Huq et al. 2006). Global climate change has already vastly impacted the climate of Bangladesh, as is described in this book. The climate of Bangladesh is heating up and is also changing rapidly because of developments in the rural and urban landscapes. It is unclear if and when this could lead to massive climate change–related migration because of failed crops and failed governance (Kovats and Alam 2007). The designs of embankments, roads, and drainage schemes have already been altered by the government and various agencies. But are these alterations enough in the light of the developments that have occurred rapidly within the last few years? Should not these adaptations be thoroughly evaluated in the light of these new developments?

According to the World Meteorological Organization, climate is defined as the 30-year average of weather parameters at a particular geographic location (Berger 2007). Climate is the long-term synthesis of day-to-day weather conditions in a given area (Rouf and Elahi 1992). Actually, climate is characterized by long-term statistics (such as mean values and various probabilities of extreme values) on the state of the atmosphere in that area or on meteorological elements in the area. The main climatic elements are precipitation, temperature, humidity, sunshine, wind velocity, cloudiness, evaporation, minimum temperature, and soil temperature at various depths; phenomena such as fog, frost, thunder, and gales; and other factors (Ahammad and Baten 2008). Synthesis implies simple averaging of these variables. Various methods are used to represent climate—for example, average and extreme values, frequencies of values within stated ranges, and frequencies of weather types with associated values of elements. Climate change essentially is a natural phenomenon. During the most recent Ice Age (also called the Pleistocene)—which, roughly speaking, lasted for most of the last 2 million years—the earth's climate was very unstable with well-marked warm and cold periods. Even after the Pleistocene, during the Holocene—the period of human existence and civilization—there have been a number of fluctuations in the climate. Human-induced climate changes on top of these natural fluctuations have been described by the Intergovernmental Panel on Climate Change (IPCC) in their different assessments. Since the Industrial Revolution, human-induced climate change has led to dangerous interference with the climate system. Temperatures are increasing worldwide, and the sea level is rising. The related excessive fossil fuel use and other economic activities are leading to the presence of extra chemical substances in the atmosphere, such as the many industrial gases, with high global warming potential (Houghton 2004).

1.2 Causes of Climate Change

The earth's climate is dynamic—always changing. In the past few million years, there have been spells of cold and intervening warm periods. The causes of these changes in climate have been cosmic and natural, and they have been linked to the Milankovitch cycles—discovered by a Serbian astronomer—describing cosmic variables such as the earth's rotation, the tilt of the earth's axis of rotation, the earth's distance from the sun, and changes in the shape of the earth's orbit around the sun over geological time. What the world is more worried about now is the recent impact of human activities on the climate. To study changes that are occurring in the climate today and changes that have occurred in the past, scientists rely on evidence revealed by studies of tree rings, ice cores, pollen samples, sea sediments, and fossils.

1.2.1 Natural Causes

Climatologists have found evidence to prove that there are a few factors responsible for natural climate change. One of the most important natural factors is the variation in the earth's orbital characteristics (Klein 2005). The variations in the pattern of the earth's orbit around the sun lead to variations in the incoming short-wave solar radiation.

1.2.1.1 The Earth's Tilt

The earth's axis of rotation is tilted away from the perpendicular in relation to the plane of its orbit about the sun. At present, the tilt away from the perpendicular is about 23.5°. This tilt is responsible for our seasons, as the Northern Hemisphere and the Southern Hemisphere alternately lean toward the sun for 6 months of the year. It is also the reason why we experience equinoxes and solstices each year. If the earth's axis were not tilted in this way, there would be no seasons at all; the polar regions would not receive any additional sunlight in the summer and, possibly, the earth would have been locked in a perpetual Ice Age (Bogner et al. 2007).

The Milankovitch cycles, in effect, describe the constantly changing tilt of the earth's axis, the direction of this axial tilt, and the shape of the earth's orbital path around the sun. Naturally, any change in the axial tilt affects the seasons—the greater the tilt, the greater the difference between the seasons in a given place. Change in the shape of the earth's orbit (from nearly circular, as at present, to a more elliptical shape) will mean variation in the amount of solar insolation during the year. It will also change the time that elapses between, say, one summer and the next. We can see how complex the effects of the Milankovitch cycle are when they are combined, but undoubtedly they have a major impact on natural climate change. The result of the incoming radiation calculations according to Milankovitch predicts that a new Ice Age is not expected for the next millennium.

1.2.1.2 Continental Drift

Millions of years ago, all of the continents were merged into one large landmass called Pangaea. Pangaea split up, and the pieces gradually began to drift apart and form the continents we are familiar with today. This was all discovered and described by the German geographer Alfred Wegener. Continents drift very slowly, shifting their positions at a rate that cannot be seen or felt even over a lifetime. This continental drift leads to earthquakes and climate change, as it brings about a change in the physical features of the lithosphere, changes in the positions of the landmasses, and changes in mountains and water bodies. The impacts of the drift are felt in the atmosphere and oceans, thereby affecting the climate. The formation of separate continental landmasses changed the flows of ocean currents and winds. It also led to the isolation of the continent of Antarctica.

The continental landmasses are still moving, though we cannot see or feel this except for the occasional earth tremors. The Indian subcontinent is a good example. Even today it continues to push northward against the Eurasian landmass, forcing the Himalayas to rise upward. It has been proven that the Himalayas is still rising by about 1 mm every year.

1.2.1.3 Ocean Currents

Oceans have a major influence on the earth's climate. They cover 70% of the earth and store more energy from the sun than the atmosphere does. The currents in the oceans flow near the surface and also deep below, thus transferring heat all over the earth. Some currents are warm, and some are cold. In the past, these currents have been known to change directions, slow down, reverse, or even stop.

The earth is also affected by both solar flares and sunspots. Actually, huge storms on the sun—sunspots—can impact the climate of the earth. It is believed that every 11 years, the sun goes through a period of activity known as the solar maximum and then a period of quiet called the solar minimum. Scientists are studying the impact of this cycle on the earth's climate. Some scientists believe that after the warm early Middle Ages, the Little Ice Age in Europe happened when the sun was going through a period of the solar minimum, with no sunspots between 1645 and 1715. From that period in the Netherlands, many paintings can be found in museums, with harsh winter landscapes and people skating on ice. In times of the solar maximum, with many sunspots, solar flares hit the earth regularly. These solar flares cause the solar wind of ionized particles that leads to beautiful auroras in the earth's atmosphere—known in the Northern Hemisphere as the Northern Lights—but they also cause an increase in solar output, warming the earth.

1.2.1.4 Volcanoes

A volcanic eruption is another natural factor that affects climate change. Connections have been noticed between major volcanic eruptions and short-term climate change. These eruptions cause large volumes of SO_2, water vapor, dust, and ash to escape into the atmosphere. They partially block the incoming rays of the sun, leading to cooling. SO_2 combines with water to form sulfuric acid, a major component of acid rain. Such changes were noticed in 1883, when the Krakatau volcano erupted in Western Indonesia—the largest recorded volcanic eruption in modern times.

In April 1991, Mount Pinatubo erupted in the Philippines, emitting millions of metric tons of SO_2 into the atmosphere. Scientists believe that this was primarily responsible for a 0.8 °C drop in global temperature in the following 2 years. Satellite data indicated that the SO_2 released from the volcano hindered sunlight from entering the atmosphere, thereby cooling it.

1.2.1.5 Comets and Meteorites

Comets and meteorites are seen in the sky as shooting stars, moving at great speed. They often burn out in the atmosphere before they reach the earth. However, every few million years they are known to collide with the earth. The impact is said to cause a massive explosion and, as in a volcanic eruption, debris and gases are released into the air, thereby blocking sunlight for months and cooling the earth. Many scientists believe that a comet or a huge asteroid crashed into the earth more than 60 million years ago. The impact of the collision resulted in a thick cloud of dust, which blocked incoming sunrays for the next few years. This not only led to the extinction of some plants and animals—including the great dinosaurs—but also may have caused an Ice Age to set in. There is still a great deal of controversy about this.

1.2.2 Human Causes

In the period following the Industrial Revolution, there was a steady increase in the use of fossil fuels. The Industrial Revolution saw a large-scale onset of industrialization. Industries were set up in all large towns in England and spread to other parts of Europe. Cotton was brought from the colonies and spun, engines were installed, and machines for various purposes were invented and run on fossil fuels. Large mining towns and industrial townships were established, and people began pouring into them. This trend has not changed; in fact, it has spread all over the world. Industries create jobs, and people move from rural areas to cities. This, in turn, has led to more and more areas being cleared to make way for houses, roads, and other facilities.

Large amounts of natural resources are being used for construction, industry, transportation, and consumption purposes. Consumerism has increased by leaps and bounds, creating mountains of waste. All of this has added to a rise in atmospheric GHG levels and brought about changes in the global climate.

The energy sector is undoubtedly the greatest contributor to human-induced GHGs. Oil, coal, and natural gas—all fossil fuels—supply most of the energy needed to run vehicles, and generate electricity for industries, households, etc. This sector is responsible for about three fourths of CO_2 emissions, one fifth of CH_4 emissions, and a large quantity of N_2O. It also produces NO and CO, which are not GHGs but influence the atmospheric chemical cycles that produce or destroy CO_2 and the most important atmospheric GHGs. The present increase in global temperatures has been attributed mainly to an increase in CO_2 levels. Vegetation contains CO_2, which is released into the air in large volumes when vegetable matter decays or is burned. Fossil fuels have been formed over millions of years because of fossilization of plants, trees, and animals. They contain high concentrations of carbon, and when they are burned, it is released into the air as large volumes of CO_2. Changes in land use patterns, deforestation, land clearing, agriculture, and other similar activities have added to this rise in CO_2 emissions. The more CO_2 is added to the atmosphere, the more heat is trapped in it (Mirza 2002).

CH_4 is another important GHG in the atmosphere, second only to CO_2, and it is said to have 20 times the greenhouse effect of CO_2. About one fourth of all CH_4 emissions is said to come from domesticated animals such as dairy cows, goats, pigs, buffaloes, camels, horses, and sheep, which produce CH_4 while chewing cud or defecating (van Amstel 2012).

Another 15–20% of the total CH_4 emissions is said to be released from rice or paddy fields, which are flooded during the sowing and maturation periods. When the soil is covered by water, it becomes anaerobic (lacking in oxygen). Under such conditions, CH_4-producing bacteria and other organisms decompose the soil organic matter, leading to CH_4 emissions. Nearly 90% of the paddy area is found in Asia, where rice is the staple diet.

Population growth is moving hand in hand with consumerism, leading to an increase in waste generation all over the world. Disposal of this waste is becoming a huge problem; when the waste is dumped in landfills and open dumps, it leads to

CH_4 emissions as the matter decomposes. On the other hand, if the waste is put into an incinerator or burned in the open, CO_2 is emitted. CH_4 is also emitted during oil drilling and coal mining, and also from gas pipeline leakage caused by accidents or poor maintenance.

A large volume of N_2O emissions has been attributed to fertilizer application. This, in turn, depends on the fertilizer type, application method, timing, and tilling method.

Leguminous plants such as beans and pulses, which add nitrogen to the soil, also contribute to this.

Aerosols are small particles of matter or minute droplets of liquid in the atmosphere, which are produced by both natural and human sources. Some important aerosols are sulfates produced from volcanoes, marine biota, and burning of fossil fuels; carbonaceous particles from burning of fossil fuels, biomass, and natural sources; mineral dust; and particles of sea salt. The most important direct effect of aerosols is that they reflect solar energy back into space, thus creating a cooling effect on the climate. On the other hand, some aerosols such as soot absorb solar radiation and are thought to exert a warming effect on the climate.

1.2.2.1 Human Influence on Climate Change

Each individual in today's world plays a role, directly or indirectly, in contributing his or her bit to climate change. Therefore, give the following points a thought.

- Electricity is our main source of power in urban areas. It is used to light up our houses, streets, schools, offices, and shops. Our lights, fans, air conditioners, computers, and other household gadgets use power generated mainly by thermal power plants.
- Cars, buses, and trucks are the principal modes of transport of goods and people in most cities. They run mainly on petrol or diesel—both fossil fuels.
- Consumerism has become the key word for industries. The more people consume in terms of luxury goods, essentials, and household goods, the more industry flourishes. Most industries are run on power generated from fossil fuels. To add to this, the more we consume, the more waste we generate.
- A great deal of waste that we generate, such as plastics, does not degrade and remains in the environment for many years, causing damage.
- We use a huge quantity of paper for all of our work in schools and offices. Have we ever thought about the number of trees required for all the paper we consume in a day?
- The felling of timber, used in large quantities for construction of houses, leads to further depletion of forests.
- Often damage to the environment is indirect and not immediately visible. For instance, we might feel that by running gadgets on batteries, we avoid any damage to the environment and climate; no smoke is emitted from our mobile phones, nor gases from our handy cams! However, we forget that the materials that go

into making the batteries and gadgets—various metals, chemicals, plastics, etc.—are made by a chain of many heavy industries, each running on electricity and each generating its own cocktail of polluting substances that contribute to climate change.

- The growth in population means there are more and more mouths to feed. Since the land available for agriculture is limited (and, in fact, it is actually shrinking as a result of ecological degradation),high-yielding varieties of crop are being produced to increase the agricultural output from a given area of land. However, such high-yielding varieties of crops require large quantities of fertilizers. More fertilizer input translates into more emissions of N_2O, besides increased pollution from the fertilizer industry, as well as other polluting effects resulting from fertilizer runoff into water bodies (Bogner et al. 2007).

1.3 Effects of Climate Change

The impacts of climate change will undoubtedly depend on the level of change and the speed at which it occurs. When we look back at the history of the earth through millions of years, we see that during periods of rapid change in the climate, there has been widespread extinction of species and collapse of natural ecosystems (as occurred during the Ice Ages). However, when climate change has occurred at a low speed, the earth has adapted well to it. Today the earth is heating up much faster than at any other time in history. This rapid warming has given rise to serious problems and will lead to more in the coming years if solutions are not found.

Most of the resources are important to our existence on earth. Ecological systems, water resources, food sources, coastal systems, health, and human settlements are sensitive to changes in the climate. The increase in the human population has led to ever-increasing pressure on natural resources, unsustainable management practices, and pollution, which have affected these vital systems. The impacts of global warming are evident in most countries all over the world. Floods and droughts are increasing, and glaciers are melting (Mirza 2002). If the world does not wake up and take action, there will be an extensive loss of biodiversity, an increase in air pollution, changes in agricultural patterns, and damage in coastal areas, which will collectively impact the lives of people (Smith et al. 2007). The less developed countries in Asia, Africa, and South America will be hardest hit, as there is more pressure on their resources and they are economically more stressed than developed countries. To add to the problem, large sections of the population in these countries are not educated, and often awareness is limited. They also have limited infrastructure, unstable government, and a human-degraded natural environment, increasing their vulnerability to climate change.

On the other hand, some countries in the Northern Hemisphere will benefit from climate change. As they become warmer, they will experience longer growing seasons and will require less energy for heating houses and vehicles. Higher latitudes in the Northern Hemisphere and mountain areas will be most affected in this way, as this is where the warming is expected to be greatest. Ecosystems in the Arctic exist in a delicate balance with the region's climate and are thus more sensitive to climate change than temperate or tropical ecosystems (UNFCCC 2005). The Arctic region is highly sensitive to the slightest variations in sunlight, temperature, and precipitation patterns. The Arctic sea ice has become much thinner, and NASA (the US National Aeronautics and Space Agency) expects the ice to be nearly gone before 2050. This is opening up the Arctic for all kinds of economic activities. Even a northern sea passage for cargo vessels is envisaged.

1.3.1 Weather

As the world becomes warmer, we can expect that extreme weather phenomena will increase, causing more misery to humankind and more damage to the environment and life around us. The increase in overall warmth will result in an increase in the level of evaporation of surface water; the air, too, will expand, increasing its capacity to hold moisture. This will lead to increases in heat waves, rainfall, snowfall, and floods. In some areas, the precipitation level will come down, causing droughts. Many developing countries are located in arid and semiarid zones in the tropics and are therefore highly vulnerable to changes in the climate, and they will certainly feel the impact (Nambi 2007). Some scientists believe that the increases in the numbers of hurricanes and cyclones over the oceans are due to changes in the climate. It has been observed through the last decade that many lakes and rivers in the Northern Hemisphere have begun freezing some weeks later and thawing about 2 weeks earlier than normal. This will impact plants, fish, and other life-forms in the lakes.

1.3.2 Ecosystems

Ecosystems provide the essential support systems for all life on earth and are therefore of great importance. They sustain the earth's entire storehouse of species and genetic diversity, and provide food, energy, shelter, medicines, fodder, and grazing grounds. The roots of plants and trees hold the soil together, prevent erosion, and reduce soil degradation. They help control floods, clean and store water, and regulate runoff. They store and process carbon and nutrients. They adapt to natural fluctuations in the climate, but the speed at which the changes are taking place today has made it very difficult for them to adapt or to re-establish themselves after suffering damage. The impacts of the growing human population can be seen in habitat destruction and pollution, threatening the very existence of these natural ecosystems.

Plants and animals in the natural environment are very sensitive to changes in the climate. The ecosystems most likely to be affected by climate change are the ones at higher latitudes, particularly the boreal or tundra forests; the habitats there are likely to shrink. As it becomes warmer in the tropical and temperate zones, the normal range of species will shift north and to higher elevations in the Northern Hemisphere. This will cause changes in the habitats of plants, animals, and other species as they follow the shifting climate. However, if the new habitat is not suitable, these species will suffer and become extinct.

Warming will be greater in the polar regions than near the equator. This will have a serious effect on the sensitive polar ecosystems and their wild species. Continental interiors or places far from the sea will also experience more warming than coastal regions. The rate at which existing ecosystems will vanish will be faster than the rate at which new ecosystems will form.

1.3.2.1 Forests

Forests cover about one fourth of the earth's landmass and provide timber for industries, fuel wood, food, fodder, and medicines. They constitute a source of livelihood for people and also attract tourists. Forests are hosts to most of the world's biodiversity and play an important role in the water cycle and hydraulic system, maintaining the balance and quality of water (Faisal et al. 2005). However, over the years it has been observed that these storehouses of biodiversity and habitats are greatly threatened by changes in the climate.

If the temperature continues to rise, most tree species will not be able to survive in their existing climatic belts. Due to the movement of species to higher latitudes, some existing ecosystems will vanish and new ecosystems will form. But in some cases, extinction of certain species in an ecosystem may lead to the demise of the entire ecosystem. Species dependent on old-growth ecosystems will become very vulnerable, and "weedy" species will increase in number and area. Droughts, floods, pest attacks, disease, forest fires, and human activities will affect forests.

Certain plants and trees are dependent on animals for their seed dispersal. After the extinction of the dodo (a bird found in Mauritius), the Mauritian Calvarias tree also became extinct, as it depended on the dodo for seed dispersal. With the movement of some animals, birds, and insects to higher latitudes, dispersal of seeds and gene exchange will be restricted to a small population, thereby bringing down the high level of genetic diversity required for adaptation to adverse environmental changes.

For people dependent on forests for their livelihoods, food, and medicines, any shift or depletion in the forests will have serious socioeconomic consequences. Climate change can also affect soil characteristics, lead to changes in species composition in the ecosystem, and effect the spread of pests and diseases. Coastal areas all over the world have a rich diversity of ecosystems and host numerous human socioeconomic activities. For the past few thousand years, estuaries, wetland, beaches, and other coastal ecosystems are known to have adapted dynamically and naturally to gradual changes in the sea level and prevailing winds. It has been established that sea level rise has taken place at a constant 1–2 mm per year in the past. However, the IPCC has projected an average annual rise of up to 5 mm, with a probable range of 2–9 mm, by the year 2100. Most of the rise in the sea level will occur mainly because water expands when heated. An increase in the melting of icebergs, ice sheets, glaciers, and ice caps will add to this rise, which will increase salinity in the deltas, estuaries, and other freshwater sources; cause coastal erosion; and increase coastal flooding. It will also lead to increases in the sea surface temperature and ocean circulation. All of this will affect fish production all over the world.

The main coastal ecosystems at risk are wetlands, coral reefs, mangroves, atolls, and river deltas. The sea level rise will lead to destruction or displacement of wetlands and low-lying areas, coastal flooding, and erosion (Alam 2004). Changes in these ecosystems will have major negative impacts on biodiversity and habitats, as well as on tourism, fisheries, and economies. Saltwater intrusion will reduce the quality and quantity of freshwater. Coastal cropland will be destroyed, and millions of people living in coastal areas and on small islands, especially in less developed countries, will be displaced.

1.3.3 Wildlife

Climate change has an enormous effect on wildlife. Wildlife is at risk from climate change. Some of the effects on wildlife are described in Sects. 1.3.3.1–1.3.3.7.

1.3.3.1 Migratory Birds

For migratory birds, the weather and food sources along the migration route are very important for successful completion of their journey. The timing of migrations is essential to all migratory birds because of their dependence on relatively stable weather patterns. During a migration, they eat large amounts to build enough fat reserves and energy to help sustain them on the journey. Changes in climate bring about a shift in feeding sites and changes in local weather along their traditional routes, endangering the success of their migration (Alam and Rabbani 2007). In fact, it has been observed that birds are no longer heading only to the equatorial regions but more to the north or south. The most threatened migratory birds are ducks and geese. According to the IUCN (International Union for Conservation of Nature), about two thirds of the world’s 9600 birds species are declining in population. Some migratory birds such as the American robin now migrate about 2 weeks earlier than they did 20 years ago.

1.3.3.2 Reindeer and Caribou

Among the most threatened animals in the tundra region are reindeer and caribou. During the winter months, reindeer and caribou migrate south to areas where food is available and where they can give birth to their calves. With ecosystems from the south moving north, these animals are likely to come into contact with species from unfamiliar warmer areas. Some of these new species may compete for the same limited natural resources, and some may even be predatory.

1.3.3.3 Adelie Penguins

Adelie penguins in the northern part of the Antarctic feed on krill that live in the Antarctic Ocean. As the ice sheets melt and fall apart, their feeding sites are getting more difficult to reach. In summer, changes in the patterns of snowfall and snow melt are leading to shifts in their nesting sites (where they lay eggs and tend to their chicks), thus reducing the rate of successful breeding.

1.3.3.4 Seals and Whales

With the increase in ocean temperatures and decreases in food supplies, some species of seals and whales are dwindling in number. These creatures feed mainly on krill found in the Arctic seas. With global warming, new fish species are coming in from warmer areas and starting to compete for the same food.

1.3.3.5 Amphibians

The population of amphibians is decreasing all over the world. Frogs and toads seem to be very sensitive to climate change, and a number of species are known to have become extinct or endangered. One of the best examples is the golden toad, which was found in the forests of South America but is now believed to be extinct. With climate change, amphibians seem to become more susceptible to parasites and fungi.

1.3.3.6 Polar Bears

Polar bears are threatened with starvation, as their hunting season has been shortened and there is a decline in their main source of food—ringed seals. Besides, they rely on sea ice as a platform from where they hunt the seals. This ice is thinning and melting sooner than it did a few decades back. It is important for them to feed on the seals, as they need large amounts of fat to sustain them before the summer sets in; in the following 4–5 months they move ashore and can survive without food for long periods. The females must have enough reserves to carry and feed their cubs. As a result, they face a decrease in their main source of food. It has been observed that since 1981 the number of cubs has gradually declined.

1.3.3.7 Other Species

Marmots in the mountains, which usually hibernate for around 8 months, are coming out of hibernation much earlier now as the winters become shorter. In 1996, Dr. Camille Parmesan observed that while the numbers of butterflies in Mexico and southern California decreased, the same breed's numbers had increased in Canada. This distinctly shows a migration by insects to the north, to a similar climate. Though there are cases of disappearance of some species of butterflies and moths, insects can generally adjust better to climate change, since they move about easily and breed frequently.

According to a recent report from the WWF (Worldwide Fund for Nature; previously known as the World Wildlife Fund), the giant pandas of China's Wolong Nature Reserve, the grizzly bears of the USA's Yellowstone National Park, and the tigers of India's Kanha National Park are some of the animals that will be seriously affected by global warming.

1.3.4 Effects on Marine Organisms

1.3.4.1 Corals

Corals will grow to keep pace with sea level rise but, on the other hand, rising temperatures and acidity in the sea will damage them. They are very sensitive to changes in the water temperature and also to pollutants. This has been clearly observed during the warming caused by El Nino. One of the most severe and geographically extensive coral bleaching events in recorded history took place in 1998, leading to destruction of corals in many areas and causing extensive damage to the Great Barrier Reef off the northeastern coast of Australia.

1.3.4.2 Salmon

Salmon thrive well in cold water and are extremely sensitive to climate change. They are threatened today by the expected increase in the seawater temperature. Conditions during the spawning period need to be very stable for the fish to reproduce and for their eggs to survive. An increase in water temperature and a decrease in water flow lead to deaths in the migration phase (Hodson and Hodson 2008). The process by which a female releases her eggs and a male fertilizes them is known as spawning. This process is unique because mature salmon swim upstream against all odds and obstacles to the creeks where they were born—guided by an unusually strong sense of smell—and then they lay their eggs and die.

1.3.4.3 Zooplankton

Zooplanktons are small organisms, such as copepods and krill, which float on the sea surface and feed on plankton. Increased warming of the oceans has led to a decline in the growth of plankton and hence to a decline in zooplankton numbers. In some warm current regions in the ocean, the decrease in zooplankton has further reduced the numbers of fish and seabirds that feed on zooplankton.

1.3.5 Food and Agriculture

With the rapid rise in the human population, the demand for food is expected to double in the next few decades. Any significant change in the climate could have a major impact on agriculture and affect the world's food supply.

As more land is brought under agricultural cultivation, pressure on natural ecosystems will rise. There will be a rise in the emissions of GHGs associated with agricultural activities and a decrease in natural carbon sinks as forests are cleared. This will result in further changes in the temperature, precipitation, length of growing seasons, and atmospheric CO_2 concentration. Extreme weather conditions such as high temperatures, heavy precipitation, floods, droughts, storms, and cyclones affect crop production. Rising temperatures and heavy rainfall can even destroy crops (Chowdhury and Faisal 2005). Regular or frequent droughts endanger the water supply and also increase the amount of water needed for plant evapotranspiration. Intensive agriculture has led to great stress on the land and a variety of problems such as chemical and biological runoff, soil salination, soil erosion, and water logging. Sea level rise threatens agriculture in low-lying coastal areas through rises in salination or flooding.

When the weather is warmer, conditions become favorable for insect pests to multiply. As the number of warmer days grows, pests such as grasshoppers are able to complete multiple reproductive cycles, thereby increasing their population considerably over a single season. Changing wind patterns may change the spread of wind-borne pests, fungi, and bacteria that cause crop disease. Soil and water resources have degraded, causing additional pressure on agriculture.

Agriculture in the tropics will be vulnerable to rising temperatures. Crops such as rice are grown in most areas in the maximum temperature range, and any increase in the temperature will make them highly vulnerable, probably leading to lower production (Navaratne 2007).

At higher latitudes, there will be longer growing seasons, as well as lower winter mortality, as the winter season will become shorter and the growth rate will be faster. Agriculture in these areas will benefit from the temperature rise, and an increase in production is predicted. However, migration of some species to higher latitudes, and consequent changes in ecosystem relationships, could cause problems. The introduction of certain pests, weeds, and plants could cause more harm than good.

The build-up of GHGs will have direct effects on plant growth and therefore on the yield of food crops. The increasing CO_2 concentration in the atmosphere is expected to help some plants grow better and damage others that are not able to cope with it.

1.3.6 Health

The local climate always directly affects the human population. It has been observed that rising temperatures lead to an increase in heat-related diseases (as has been observed in countries such as India), and mortality rates rise to high levels. Moreover, if winter temperatures plunge, mortality rates also increase. Hippocrates, the famous Greek philosopher and thinker, stated that the weather can influence where and when epidemics occur. Even today scientists all over the world hold this fact to be true. Mosquito-borne diseases are generally associated with warm weather, intestinal diseases such as cholera and typhoid with rains, flu (influenza) with cold weather, and viral fever with seasonal changes. Floods and droughts lead to varied health problems, including epidemics (Fields 2005).

Air in the cities has become extremely polluted by emissions from vehicles and neighboring industries. Smog—a common sight in large cities—is a major health menace. It is formed by a combination of various nitrous gases with water vapor and dust. A large proportion of the gases that form smog is produced when fuels are burned. Climate change can also affect human health by increasing the adverse effects of urban air pollution. Fluctuations in the weather—mainly in the temperature, precipitation, and humidity—can lead to and exacerbate the spread of infectious diseases. In fact, it is believed that people in urban areas will feel the impact of climate change more than those in rural areas. In urban areas, concrete construction, paved and tarred roads, and other similar activities have created heat islands, which aggravate the warming and lead to a rise in the number of illnesses. Elderly persons, children, and those with cardiovascular problems will be most affected.

As the tropical habitats of insects such as tiger and zika mosquitoes spread toward the poles, there will be a sharp increase in the spread of vector-borne diseases. The transmission mechanisms of many infectious diseases, especially those borne by mosquitoes, are particularly sensitive to climate conditions. The incidence of malaria—one of the most serious and widespread human health problems—will be greatly affected by climate change, as it is sensitive to weather conditions. Cases of dengue, zika, and other mosquito-transmitted diseases have increased in the last few years, along with cases of yellow fever and encephalitis. There has also been a rise in non-vector-borne infectious ailments such as salmonella, giardiasis, cholera, and various viral diseases. Increased warmth and moisture in the air cause increases in these diseases. Diseases such as the plague, carried by rodents, are also expected to increase with climate change.

1.4 Global Warming and Climate Change

Global warming is accelerating rapidly. Already, many countries, ecosystems, and people are suffering from its impacts. Global warming has affected weather patterns and disrupted the variability and trends in climate, resulting in increases in climate-related extreme events such as heavy rainfall, floods, cyclones, storm surges, etc. These claim thousands of lives, destroy billions of dollars' worth of properties, and disrupt the livelihoods of hundreds of millions of people.

In 1991, the IPCC raised an alarm globally for the first time by presenting scientific evidence of global warming, emissions increases, and climate change impacts. This resulted in worldwide recognition that some serious actions are necessary to save our planet. In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) led to the establishment of an intergovernmental process to identify and implement the response measures necessary to curb global warming and address its negative impacts. The convention led to the development of the Kyoto Protocol in 1997, which provides mechanisms, targets, and a timetable for GHG emission reductions. To help vulnerable countries and people adapt to climate change and increase their resilience, additional support was also agreed upon. Since then, 20 years have passed and a fifth IPCC assessment report has been published (Cruz et al. 2007). Climate change, which emerged from the environmental crisis, has now become established as a major challenge to development, poverty reduction efforts, livelihood options, biodiversity, and human security. In terms of the progress made in reducing GHG emissions, the report card is disappointing. The convention's commitments to address the current impacts and future risks of global warming through support to reduce vulnerability and implement adaptation measures are yet to materialize in a manner that will match current and future priorities. Funding through the creation of the Special Climate Change Fund (SCOF) and the Least Developed Countries Fund (LDCF) under the convention has been only a fraction of the amount required, as a priority, by the poorest and most vulnerable countries. The Adaptation Fund under the Kyoto Protocol is yet to demonstrate its potential to mobilize financial resources to match priority investments to reduce vulnerability, adapt, and increase resilience. For almost a decade, the negotiation process has been pursued to include all major countries that may have a role with regard to a collective global effort.

In 2006, in his review, *The Economics of Climate Change*, Sir Nicholas Stern demonstrated that the cost of inaction now—in both GHG emission reductions and adaptation to climate change—will result in damages and losses of biblical proportions. Science has confirmed that the future impacts of global warming and climate change will have severe and far-reaching consequences for today's generations and many more to follow. In their fifth assessment report, the IPCC also confirmed this year that global warming is accelerating rapidly, its impacts are already evident, and urgent action must take place now, as the projections clearly define a roadmap of worsening impacts over the coming decades (Cruz et al. 2007). The UNFCCC Secretariat has made available a report that summarizes the financial requirements to support both adaptation and mitigation requirements over the next few decades.

Sufficient and collective actions to combat global warming and climate change must be taken now, without further delay. Millions are already suffering. The poor of this world are already victims and will suffer the most from unavoidable global warming and adverse future impacts (Climate Change Cell 2006). To prevent dangerous climate change, we must all address the interlinked challenge of energy for sustainable development without adding more GHGs to the atmosphere. Decisions need to be taken now. How are we to prevent dangerous climate change? Who should limit their emissions, how much, and by when? Who should bear the responsibility for those already affected or support those at risk to minimize losses? There may be no simple solutions, as the problems and concerns are quite complex. Our common future rests in the hands of our collective leadership and political decisions.

1.4.1 The Challenge of Global Warming in Bangladesh

Rapid global warning has caused fundamental changes in our climate. Neither country nor people know this better than Bangladesh, where millions of people are already suffering. Sudden, severe, and catastrophic floods have intensified and are taking place more frequently because of increased rainfall in the monsoon. Over the last 20 years, Bangladesh has been ravaged by floods of catastrophic proportions, in 1998, 2004, and 2007. Heavy downpours over short spells have resulted in landslides. Cold spells claim human lives, as well as damaging crops. Droughts often affect even coastal districts. Bad weather makes coastal waters risky for fishing expeditions. Damages and losses due to extreme climatic events such as floods, cyclones, tornadoes, and droughts are phenomenal to the victims, as well as the state. These are early signs of global warming effects (Dutta 2007). Sea level rise in the coming decades will create over 25 million climate refugees; this number is nearly twice the entire population of the Netherlands. Bangladesh is recognized worldwide as one of the countries that are most vulnerable to the impacts of global warming and climate change (BCAS 1994). This vulnerability is due to its unique geographic location, dominance of floodplains, low elevation from the sea, high population density, high levels of poverty, and overwhelming dependence on nature and its resources and processes. The country has a history of extreme climatic events, claiming millions of lives and destroying past development gains (Banglapedia National Encyclopedia of Bangladesh 2008). The people and the social system have knowledge and experience of coping with their effects—to some degree. Variability in rainfall patterns, combined with increased snow melt from the Himalayas and temperature extremes, are resulting in crop damage and failure, preventing farmers and their dependents from having meaningful earning opportunities. In a changing climate the pattern of impacts is eroding our assets, investments, and future. This applies to families, communities, and the state. Global warming and climate change threaten settlements, and the number of people displaced from their land by riverbank erosion, permanent inundation, and sea level rise is increasing rapidly every year (Elahi et al. 2007). The resources and efforts of the government and people are quickly drained by efforts to address the impact of just one event—and then another event strikes. The impacts of global warming and climate change have the potential to challenge our development efforts, human security, and future. Bangladesh must move on in its pursuit to develop and taking into account its vulnerability, susceptibility, and capacity to manage climate risks and adaptation (Akhtar 2007). In this respect, the government has taken bold steps to prepare and respond to the challenge already facing us. To help the country and its people build the necessary capacity and resilience, regional and international cooperation is essential. Major rivers that draw freshwater and sediment from upstream basins to the Bay of Bengal, going through Bangladesh, originate in neighboring countries, and water flow during both summer and dry periods is critical for agriculture and for food and drinking water security. Collective actions are necessary now to understand the risks and take action. International efforts to plan responses to climate change must be made urgently to avoid the unmanageable and manage the unavoidable. The case of Bangladesh—one of the first and major victims of human-induced global warming and climate change—must be taken seriously and addressed collectively. Our future is in our hands. We must secure the well-being and development of Bangladesh by making the people and the country resilient, through provision of the necessary resources and support, both internal and external. Together, we must address this challenge and demonstrate our integrity to the human race.

1.4.2 Bangladesh and Climate Change

The impacts of global warming and climate change are global. For Bangladesh they are most critical, as a large part of the population is chronically exposed and vulnerable to a range of natural hazards. Already, the human suffering and cost to development are massive for this country and its people, who are victims of human-induced global warming. Between 1991 and 2016, 93 major disasters were recorded in Bangladesh, resulting in nearly 200,000 deaths and causing US$5.9 billion in damages, with large losses in agriculture and infrastructure. Since then, the country has been experiencing recurring floods frequently. The monsoon floods of the year 1998 are part of what the World Meteorological Organization sees as a global pattern of record extreme weather conditions (Chowdhury 2002). Climatic hazards—including extreme events such as floods, cyclones, tornadoes, storm surges, and tidal bores—are not new to Bangladesh, and the country has a scarred history, claiming many lives and resulting in losses of assets and belongings. Some of the worst disasters in terms of mortality have taken place in this land. In Bangladesh, in the past few decades, the effects of global warming have been evidenced in climate variability, climate change, and extreme events. More adverse impacts are projected for the coming decades, particularly for the low-lying coastlines and floodplain ecosystems that characterize Bangladesh.

1.4.3 Understanding the Challenge

Global warming will continue for many decades, resulting in dangerous consequences for countries such as Bangladesh, which is unique in its vulnerability. The impacts of climate variability, climate change, and extreme events will lead to severe stress on overall development, the environment, and human society for generations ahead. Understanding the challenges over time is a primary and urgent need. Also, the challenges need to be explored from an intergenerational perspective. Ultimately, the better we understand the challenges, the greater the chance we will have to plan and respond to those challenges effectively.

1.4.3.1 Geographic Location

The geographic location and geomorphologic conditions of Bangladesh have made the country one of the most vulnerable to climate change, particularly to sea level rise. Bangladesh is situated at the interface of two different environments, with the Bay of Bengal to the south and the Himalayas to the north. This peculiar geography of Bangladesh causes not only life-giving monsoons but also catastrophic ravages of natural disasters, to which now are added climate change and sea level rise. The country has a very low and flat topography, except in the northeastern and southeastern regions. About 10% of the country is hardly 1 m above the mean sea level (MSL), and one third is subject to tidal excursions. The country has three distinct coastal regions: the western, central, and eastern coastal zones.

The western part, also known as the Ganges tidal plain, comprises the semi active delta and is crisscrossed by numerous channels and creeks. The topography is very low and flat (Paul and Bhuiyan 2004). The southwestern part of the region is covered by the largest mangrove forest in the world, popularly known as the Sundarbans—a declared World Heritage Site and home to the Royal Bengal tiger. The mangrove forests act as a deterrent to the furiousness of tropical cyclones and storm surges. The central region is the most active one, and continuous processes of accretion and erosion go on there. The very active Meghna River estuary lies in this region (Alam et al. 2007). The combined flow of the three mighty rivers—the Ganges, the Brahmaputra, and the Meghna (commonly known as the GBM river system, which ranks as one of the largest river systems in the world)—discharges under the name of the Meghna into the northeastern corner of the Bay of Bengal. This estuarial region has seen the most disastrous effects of tropical cyclones and storm surges in the world and is very vulnerable to such calamities. The eastern region, being covered by hilly areas, is more stable, and it has one of the longest beaches in the world.

1.4.3.2 Economic Profile

Bangladesh ranks low on just about all measures of economic development. This low level of development, combined with other factors such as its geography and climate, makes the country quite vulnerable to climate change. Bangladesh is a very densely populated country, where over 160 million people live in a small area around the capital in 2016. Higher population density increases vulnerability to climate change because more people are exposed to risk, and opportunities for migration within the country are limited (BMDA 2007). The monthly per capita income in Bangladesh is US$1466 in 2016. This ranks below the average per capita income in South Asian countries, as well as the per capita income in low-income countries. More than a third of the people still live in poverty, the majority of whom live in rural areas, risk-prone locations, and urban slums. About one fourth of the country's gross domestic product (GDP) comes from agriculture, which makes the country's economy relatively sensitive to climate variability and change.

1.4.3.3 Social Status

The majority of the population is still dependent on agriculture for income and livelihood. In 2016, Bangladesh ranked 137th in the Human Development Index. Access to income and employment is limited, with a large service sector and climate sensitive agricultural and industrial sectors. Access to drinking water is also insecure in some parts of the country all year round because of saline intrusion in coastal areas, while in a large part of the country; the groundwater is contaminated with arsenic (Habibullah et al. 1999). The country also has to ensure access to health and education services for its nationals to deliver a future generation that can cope effectively in tomorrow's world. With 40% of the active workforce unemployed, livelihood options are disappearing, and only limited opportunities can be found to diversify earnings (Christian Aid 2006). The society has demonstrated its will and efforts in responding to national emergencies, particularly with regard to natural hazards such as floods, tornadoes, landslides, cyclones, storm surges, cold spells, etc. However, the uncertain weather conditions and frequent and extreme events have eroded household and community safety nets. Local and national governments struggle to reallocate development resources and to access external resources to help people and the economy recover.

1.4.4 Impacts of Climate Change: The Poorest Are Hit Earliest and Hardest

People are more susceptible to the destruction caused by hurricanes and flooding, for a variety of reasons. The poor typically live in housing that is more susceptible to damage from winds, heavy rain, and floodwater. Floods result in greater exposure to waterborne diseases. Areas that are historically prone to flooding or mudslides are often inhabited by the poor. To understand how global warming and climate change will impact Bangladesh in the future, influence its development aspirations, and define its roadmap for sustainable development, three considerations are critical: the location, the population, and the economy (Ali 1999). The location of Bangladesh is in a deltaic plain of a major river basin, making it susceptible to floods and cyclones. The country is densely populated within a small area, and is one of the most densely populated countries in the world. The country is also very poor, and the majority of its people live below subsistence level, making them already vulnerable. According to the UNDP (United Nations Development Program), Bangladesh scientists believe that because of sea level rise, coastal Bangladesh has already experienced severe impacts especially in terms of coastal inundation and erosion, saline intrusion, deforestation, loss of biodiversity and agriculture, and large-scale migration. About 0.83 million hectares of arable land is affected by varying degrees of soil salinity (Karim et al. 1990). During the period 1973–1987, about 2.18 million tons of rice was damaged by drought and 2.38 million tons by flooding. Each year, drought affects about 2.32 million hectares and 1.2 million hectares of cropped land during the kharif (summer; from November to June) and rabi (winter; from July to October) seasons, respectively, while soil salinity, water logging, and acidification affect 3.05 million hectares, 0.7 million hectares, and 0.6 million hectares of cropland, respectively (BRAC 2000).

1.4.5 Threats to Islands

A sea level rise of 0.5 m over the last 100 years has already eroded 65% of the landmass (250 km^2) of Kutubdia, 227 km^2 of Bhola, and 180 km^2 of Sandwip. Over the past 100 years, this once 1000 km^2 island has been reduced to a small 21 km^2 landmass (Islam et al. 1999). In the event of any further sea level rise, islands such as these and the entire coastal area would be hit hard, resulting in billions of dollars of losses in GDP; an economic downturn; ecological damage; and lost livelihoods, assets, and options (Singh 2001). The temperature and rainfall projections for Bangladesh over the coming decades show significant temperature increases in both the monsoon and winter periods. The projections for rainfall indicate more rain during the monsoon and less rain during dry periods. Very small changes in the temperature and rainfall can lead to severe consequences for a country such as Bangladesh, which is already stressed environmentally, socially, and economically. Also, the variations can be quite significant when down scaled to a specific location.

1.4.6 Climate Change and Flood Hazards in Bangladesh

Water risks are a part of life in this low-lying country, dominated by the reaches of the Ganges, Brahmaputra, and Meghna Rivers (Ali et al. 1998). However, scientists and environmental activists say the September flood of 2015, which happened during a lunar high tide, was very unusual for that time of year. What is even more worrisome, they say, is that climate change is making the unusual more routine. Locals say the result is a massive upheaval of traditional village life. For many years, floods have been bringing saline water further inland, destroying rice fields that once sustained the villages. Shrimp farms—many built with World Bank investments—have rapidly replaced rice paddies, but residents say the shrimp farms employ a fraction of the people needed to harvest rice. At the same time, a cheap form of food—rice—is being replaced with a pricey one. The Bangladesh government earns more than US$40 million annually in shrimp exports, but few Bengalis can afford to eat shrimp themselves (Hoq 1999). To make matters even worse, the frequency of devastating storms, such as the one that devastated the region in September 2015, has increased. They used to be one-in-20-year events. Scientists have calculated that floods of that magnitude now happen almost once every 5 years.

1.5 Conclusion

The aim of this chapter has been to provide a very basic but important understanding of climate change in general and in Bangladesh in particular. This provides a basis on which to assess the issues regarding climate change critically. The following chapters provide more detail of the situation in Bangladesh concerning climate change issues, and they provide sufficient material to gain a deeper understanding of the multi scale impacts of climate change in Bangladesh.

References

Ahammad R, Baten AM (2008) Impacts of climate change: global to local. The Daily Star. Dhaka: Feb 15 2008

Ahmed AU (2006) Bangladesh climate change impacts and vulnerability: a synthesis. Climate Change Cell, Bangladesh Department of Environment, Dhaka

Akhtar R (2007) Heat waves and cold waves in India: adaptation strategies in the plains and the mountainous areas. In: 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24th–28th Feb 2007

Alam M (2004) Adverse impacts of climate change on development of Bangladesh: integrating adaptation into politics and activities. CLACC working paper no. 1, Bangladesh. Bangladesh Centre for Advanced Studies, Dhaka

Alam M, Rabbani MDG (2007) Vulnerabilities and responses to climate change for Dhaka. Environ Urban 19:81–97. In: Reid H, Simms A, Johnson V (eds) Up in smoke? Asia and the Pacific: the threat from climate change to human development and the environment. New Economics Foundation, London

Alam M, Rahman S, Haider MS, Hasan S (2007) Relationship between climate change and incidence of malaria in Chittagong hill tracts. 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED &The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007

Ali MY (1999) Fish resources vulnerability and adaptation to climate change in Bangladesh. In: Huq S, Karim Z, Asaduzzaman M, Mahtab FU (eds) Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht, pp 113–124

Ali MM, Haque MM, Rahman R, Rashid S (1998) Bangladesh floods view from home and abroad. University Press Limited, Dhaka

Approtech Consultants Limited (1994) Vulnerability of Bangladesh to climate change and sea level rise: concepts and tools for calculating risk in integrated coastal zone management. Technical Report, vol I: Text. Bangladesh Centre for Advanced Studies, Resource Analysis, the Netherlands and Approtech Consultants Limited, Dhaka

Banglapedia National Encyclopedia of Bangladesh (2008) Asiatic Society of Bangladesh, vol 10 BCAS (Bangladesh Centre for Advanced Studies). Resource Analysis, the Netherlands

Barind Multipurpose Development Authority (BMDA) (2007) Rajshahi: development activity. Barind Multipurpose Development Authority, Rajshahi

Berger R (2007) Adapting to drought in Kenya: the experience of practical action in central Kenya. 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007

Bogner J, Abdelraie Ahmed M, Diaz C, Faaij A, Gao Q, Hashimoto S, Mareckova K, Pipatti R, Zhang T (2007) Waste management. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panelon Climate Change. Cambridge University Press, Cambridge/New York

BRAC Annual Report (2000) BRACU Repository Home, Dhaka, Bangladesh

Broadus JM (1993) Possible impacts of, and adjustments to, sea-level rise: the case of Bangladesh and Egypt. In: Warrick RA, Barrow EM, Wigley TML (eds) Climate and sea level change: observations, projections and implications. Cambridge University Press, Cambridge, pp 263–275

Chowdhury A (2002) Disasters: issues and responses. In: Gain P (ed) Bangladesh environment: facing the 21st century, 2nd edn. Society for Environment and Human Development (SEHD), Dhaka, pp 217–235

Chowdhury JK, Faisal AM (2005) In: Nishat A (ed) Nursery and planting techniques of wetland plants. International Union for Conservation of Nature (IUCN), Bangladesh Country Office, Dhaka

Christian Aid (2006) In: Cunningham M, Jacques A (eds) The climate of poverty: facts fear and hope. London, Christian Aid

Climate Change Cell (2006) Climate variability and change in Bangladesh impacts, vulnerability and risks. Climate Change Cell/Bangladesh Department of Environment, Dhaka

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C, Huu Ninh N (2007) Asia. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: 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, pp 469–506

Douma A (2007) Mainstreaming and partnership (panel discussion). 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007

Dutta A (2007) Report of participatory community vulnerability assessments (PVCA) of Kandi, Kotalipara and Gopalganj, Prepared for Church of Bangladesh. PRIP Trust, Dhaka

Elahi KM, Ahmed KS, Mafizuddin M (2007) Riverbank erosion, flood and population displacement in Bangladesh. Riverbank Erosion Impact Study (REIS), Dhaka
Faisal AM, Khan MH, Hussain B, Kar SP (2005) Community based plantation in floodplain areas. International Union for Conservation of Nature (IUCN), Bangladesh Country Office, Dhaka
Fields S (2005) Environmental health perspectives. 113(8). August 2005. In: Cunningham M, Jacques A (eds) Christian Aid, 2006. The climate of poverty: facts fear and hope. Christian Aid, London
Habibullah M, Ahmed AU, Karim Z (1999) Assessment of food grain production loss due to climate induced enhanced soil salinity. In: Huq S, Karim Z, Asaduzzaman M, Mahtab FU (eds) Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht, pp 55–70
Hodson MJ, Hodson MR (2008) Cherishing the earth: how to care for God's creation. Monarch Books, Oxford
Hoq E (1999) Environmental and socio economic impacts of shrimp culture in south-western Bangladesh. Trop Agric Res Ext 2:111–117
Houghton J (2004) Global warming: the complete briefing, 3rd edn. Cambridge University Press, Cambridge
Huq S, Ahmed AU, Koudstaal (1996) Vulnerability of Bangladesh to climate change and sea level rise, climate change and world food security. Bangladesh Center for Advanced Studies, Dhaka
Huq SMI, Joardar JC, Parvin S, Correll R, Naidu R (2006) Arsenic contamination in food-chain: transfer of arsenic into food materials through groundwater irrigation. J Health Popul Nutr 24:305
Islam T (1994) Vulnerability of Bangladesh to climate change and sea level rise: concepts and tools for calculating risk in integrated coastal zone management, summary report. Bangladesh Centre for Advanced Studies, Resource Analysis, the Netherlands and Approtech Consultants Limited, Dhaka
Islam SMR, Huq S, Ali A (1999) In: Huq S, Karim Z, Asaduzzaman M, Mahtab FU (eds) Beach erosion in the Eastern coastline of Bangladesh. Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht, pp 71–92
Karim et al (1990) Salinity problems and crop intensification in the coastal regions of Bangladesh. The Bangladesh Agricultural Research Council, Dhaka
Klein RJT (2005) From "climate change so what?" to "climate change what to do?" International Workshop on Community Level Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED, CIDA, IUCN & The Ring. Pan Pacific Sonargaon Hotel, Dhaka, 16–18 Jan 2005
Kovats S, Alam M (2007) Early summary findings of the health case studies of CLACC. 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007
Mirza MMQ (2002) Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. Glob Environ Chang 12(2002):127–138
Nambi AA (2007) Vulnerability assessment and enhancing adaptive capacity to climate change in semi-arid regions of India. 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007
NAPA (National Adaptation Programme of Action) (2005) National Adaptation Programme of Action (NAPA) final report. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka
Navaratne CM (2007) Enhancement of crop security in southern dry zone of Sri Lanka through climate change adaptation. 2nd International Workshop on Community Based Adaptation to Climate Change. Organized by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24–28 Feb 2007

Paul BK, Bhuiyan RH (2004) The April 2004 Tornado in north-central Bangladesh: a case for introducing tornado forecasting and warning systems. Quick Response Research Report 169. National Hazards Research and Applications Information Center, Boulder

Rouf KA, Elahi KM (1992) Research method in social science: theory and application. Sojoneso Publication, Dhaka

Singh OP (2001) Cause–effect between sea surface temperature, precipitation and sea level along the Bangladesh coast. Theor Appl Climatol 68:233–243

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

UNFCCC (United Nations Framework Convention on Climate Change) (2005) Key GHG data: greenhouse gas (GHG) emissions data for 1990–2003 submitted to the UNFCCC. Bonn, United Nations Climate Change Secretariat

van Amstel AR (2012) Methane. Its role in climate change and options for control. PhD thesis. Wageningen University, Wageningen

Chapter 2
Climate of Bangladesh: Temperature and Rainfall Changes, and Impact on Agriculture and Groundwater—A GIS-Based Analysis

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Abstract Climate change has become a subject of great interest to the scientific community, since it has major impacts on the physical and human environment on the global, regional, and local scales. The climate of Bangladesh is changing, and its vital agricultural sector and groundwater resources will face the greatest impacts. Rising temperatures, high variability in rainfall, and seasonal shortages of rain will affect the local water balance and will be harmful for agriculture, as will the consequences of climate change such as floods, droughts, cyclones, tidal surges, and soil salinity changes. Therefore, country-level information about climate variability and changes, particularly temperature and rainfall changes, is needed. It is widely recognized that policy makers need reliable and well-synthesized information about climate change and its impacts in order to formulate sustainable management policies for resources and the environment.

This chapter illustrates and analyzes the decadal trends and changing patterns of temperature and rainfall in Bangladesh, using the available historical data and geographic information systems (GIS) and maps for the period of 1971–2010. The decadal mean, mean minimum, and mean maximum temperatures, and the decadal average, premonsoon, and postmonsoon rainfall are assessed and analyzed. The short-term (2011–2020) predictions for temperature and rainfall, using an autoregressive integrated moving average (ARIMA) time series analysis model, are also evaluated and analyzed spatially. Moreover, the impacts of temperature and rainfall changes on agriculture and groundwater resources are discussed.

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There was an increasing trend in the mean (0.19 °C decade^{-1}), mean minimum (0.17 °C decade^{-1}), and mean maximum (0.21 °C decade^{-1}) temperatures in Bangladesh during 1971–2010, and these temperatures (mean, mean minimum, and mean maximum) predominantly increased over the three decades of 1981–2010. The decade of 2001–2010 was the warmest decade in Bangladesh, and the maximum temperature increased faster than the minimum temperature. The northwest and northeast of the country are more susceptible to a rising minimum temperature, while the southeast and central southern parts are more vulnerable to a rising maximum temperature. It was predicted that warming would continue predominantly in these parts of the country in 2011–2020. The mean temperature of the country would increase by about 0.18 °C, in comparison with 2001–2010, indicating about 0.76 °C warmer temperatures in the decade of 2011–2020 than in 1971–1980.

Though the decadal average rainfall showed an increasing trend at 76 mm decade^{-1} during 1971–2010, there was a general trend toward decreasing rainfall in the pre- and postmonsoon seasons, in which rainfall declined by 8 and 4 mm decade^{-1}, respectively. The pre- and postmonsoon rainfall in Bangladesh declined sharply during the two decades of 1991–2010. However, the monsoon rainfall increased by 57 mm decade^{-1}. The model-predicted rainfall showed that during 2011–2020, the average and monsoon rainfall would increase by 119 and 21 mm, respectively, in comparison with 1971–1980. Declines in pre- and postmonsoon rainfall of 5 and 9 mm, respectively, were observed during this decade in comparison with 1971–1980. Greater decreases (of 30–252 mm) in premonsoon rainfall were noted in the western, southwestern, southern and, to some extent, northwestern parts of the country, and the decreases (of 100–289 mm) in rainfall would continue in these parts in 2011–2020, indicating areas vulnerable to decreases in premonsoon rainfall. Greater decreases (of 18–75 mm) in postmonsoon rainfall were noted in the southern, southeastern, eastern, and northwestern parts of the country, and it was anticipated that the decline (of 10–111 mm) in the rainfall in these areas would persist in 2011–2020. Moreover, the rainfall projections for 2011–2020 indicated that the monsoon rainfall would also decrease in the southwestern, central, and northwestern parts of the country, and greater decreases (of 200–221 mm) in the monsoon rainfall were projected for Rajshahi, Bogra, Dhaka, Faridpur, and Khulna in comparison with 1971–1980.

Since Bangladesh is basically an agrarian country, the expected temperature and rainfall changes would be harmful for its agriculture, because the drought situation would be prolonged and the use of groundwater for irrigation would increase in the country. In particular, because of the increases in the minimum and maximum temperatures and the decreases in seasonal rainfall, the environmental suitability for wheat, boro rice, and other crops grown in the pre- and postmonsoon seasons would be reduced and overextraction of groundwater during the dry season would create geo-environmental problems such as increasing saltwater intrusion and lowering of the water table, thus the country might face worsening of food security in the near future. Hence, agricultural practices, harvesting of surface water, and optimum use of groundwater need to be incorporated into mitigation policies and programs to combat the effects of future climate change.

2.1 Introduction

Climate change is a big concern for society, and the scientific community all over the world has analyzed its causes and consequences. Climate change due to global warming has a great impact on our environment and society on the local, regional, and global scales. The Intergovernmental Panel on Climate Change (IPCC) has reported that the global surface temperature increased by 0.74 °C during the period of 1906–2005 (IPCC 2007). In the IPCC's 2014 report (IPCC 2014), this was updated, and it was mentioned that the average temperature of the earth increased by approximately 0.85 °C during 1880–2012 and could increase by a further 0.3–4.8 °C by the end of the twenty-first century (Hartmann et al. 2013). Climate change is a consequence of anthropogenic (IPCC 2007) and astronomical causes (Soon et al. 2000; Landscheidt 2000); however, there is ever-increasing evidence that human activities have a greater influence on the concentration of greenhouse gases in the atmosphere and that this influence will increase more in the future, thereby leading to climate change on the earth (IPCC 2014). The IPCC (2014) stated that most of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas emissions (Hegerl et al. 2007). Since the industrial revolution, use of fossil fuels has increased, since they are the main source of energy; therefore, continual emission of greenhouse gases (particularly CO_2, CH_4, and N_2O) into the atmosphere traps heat and causes an increase in temperature in the lower atmosphere. Thus, keeping in mind the climate change problem, the United Nations Framework Convention on Climate Change (UNFCCC) has set forth a plan to stabilize CO_2 concentrations in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system (UNFCCC 2009).

Many countries in tropical and subtropical regions are expected to be more vulnerable to warming because additional warming will affect their marginal water balance and will be harmful for their agricultural sectors. It has been observed that coupled with global warming, there are strong indications that rainfall changes are already taking place on both a global scale (Hulme et al. 1998) and a regional scale (Yu and Neil 1993; Rodríguez-Puebla et al. 1998; Trenberth et al. 2007). It has been reported that Bangladesh is one of the countries that are most vulnerable to climate change (IPCC 2007), because it is a low-lying delta area, located on the Bay of Bengal in the delta of the Ganges, Brahmaputra, and Meghna Rivers, and the impacts of climate change are devastating also because of Bangladesh's high population density. Because of global climate change, the climate in Bangladesh is also changing and has become more erratic in recent decades. The vital agricultural sector and groundwater resources of Bangladesh will face immense problems from the consequences of climate change, such as floods, droughts, tornadoes, cyclones, tidal surges, sea level rise, and soil salinity change. Bangladesh is already experiencing unusually strong tropical storms; more recurrent heat waves; heavy rainfall, resulting in severe floods; low seasonal rainfall, causing droughts; sea level rise; and other similar events (GOB 2012).

In order to assess the climate change impact on vegetation, agriculture, water, and the economy, country-level information about rainfall and temperature and their spatiotemporal change patterns are needed, particularly for Bangladesh, since it is a very densely populated country and has a low adaptive capacity. Bangladesh is overwhelmingly dependent on agriculture; about 32% of the total gross domestic product (GDP) comes from this sector, which supports 61% of the overall employment (BBS 2010). Land use in Bangladesh is dominated by agricultural uses, and about 60% of the cultivated land is used for crop production. Since agriculture is the mainstay of the economy of Bangladesh and is very sensitive to the impacts of climate change—particularly its vital agricultural sector and groundwater resources—climate change scenarios need to be considered seriously and addressed properly in integrated development planning and strategies. It is widely recognized that policy makers need reliable and well-synthesized information about climate change and its impacts in order to formulate sustainable management policies for resources and the environment. Several studies have been carried out, particularly focusing on trends in the temperature and rainfall in Bangladesh (Divya 1995; Jones 1995; Ahmad and Warrick 1996; Karmakar and Shrestha 2000; Mia 2003; Das et al. 2006; Shahid 2010; Rahman 2012). However, it is evident from the literature that the optimum time and space scales for climate change, especially for temperature and rainfall, have not been well studied in Bangladesh, particularly with regard to recent data (Shahid 2011; Rahman 2012; Hasan et al. 2014). It is well documented that the need for more detailed information about climate change on the regional and local scales, which is of particular interest to nations and economic groups, can be met by analysis of recent data observations (IPCC 2014). Therefore, country-level analysis of recent weather data and information about climate variability and change—particularly changes in temperature and rainfall—are needed for adaptation to the changes and impacts, and to formulate an appropriate strategy to overcome the problem.

The purpose of this chapter, therefore, is to analyze the decadal changes in temperature and rainfall in Bangladesh, along with historical data and geographic information system (GIS) data, during 1971–2010. In particular, the decadal trends and spatial patterns of decadal changes in the mean, mean minimum, and mean maximum temperatures and the decadal averages in pre- and postmonsoon rainfall are assessed and analyzed. A short-term (2010–2020) forecast of the temperature and rainfall, using an autoregressive integrated moving average (ARIMA) time series analysis model, is also evaluated and analyzed. Finally, the impacts of temperature and rainfall changes on agriculture and groundwater resources are discussed. For the purposes of this analysis, monthly data sets of minimum and maximum temperatures and rainfall from 34 stations throughout Bangladesh (Table 2.1 and Fig. 2.1) for the period of 1971–2010, provided by the Bangladesh Meteorological Department, Dhaka, Bangladesh, are used and analyzed.

This chapter is organized as follows: an overview of climate of Bangladesh is described in Sect. 2.2; GIS techniques and statistical techniques that are used to calculate decadal trends, changes, and predictions of temperature and rainfall are discussed in Sect. 2.3; trends, changes, and spatial patterns of temperature are

Table 2.1 Locations of weather stations in Bangladesh

No.	Station name	Latitude (N)	Longitude (E)	Elevation (m)
1	Dhaka	23° 47′	90° 23′	08.45
2	Tangail	24° 15′	89° 56′	10.20
3	Mymensing	24° 44′	90° 25′	10.00
4	Faridpur	23° 36′	89° 51′	08.10
5	Madaripur	23° 10′	90° 11′	07.00
6	Ctg Patenga	22° 13′	90° 48′	05.50
7	Cox's Bazar	21° 27′	91° 58′	02.10
8	Chandpur	23° 14′	90° 42′	04.88
9	Comilla	23° 26′	91° 11′	07.50
10	Feni	23° 02′	91° 25′	06.40
11	Hatiya	23° 27′	91° 06′	02.44
12	Kutubdia	21° 49′	91° 51′	02.74
13	M Court	22° 52′	91° 06′	04.87
14	Rangamati	22° 38′	92° 09′	68.89
15	Sandwip	22° 29′	91° 26′	02.10
16	Sitakunda	22° 43′	89° 05′	03.96
17	Teknaf	20° 52′	92° 18′	05.00
18	Khulna	22° 47′	89° 32′	02.10
19	Jessore	23° 12′	89° 20′	06.10
20	Satkhira	22° 43′	89° 05′	03.96
21	Chuadanga	23° 39′	88° 49′	11.58
22	Mongla	22° 28′	89° 36′	01.80
23	Barisal	22° 43′	90° 22′	02.10
24	Patuakhali	22° 20′	90° 20′	01.50
25	Bhola	22° 41′	90° 39′	04.30
26	Khepupara	21° 59′	90° 14′	01.83
27	Rajshahi	24° 22′	88° 42′	19.50
28	Bogra	24° 51′	89° 22′	17.90
29	Ishurdi	24° 09′	89° 02′	12.90
30	Rangpur	25° 44′	89° 16′	32.61
31	Dinajpur	25° 39′	88° 41′	37.58
32	Sayedpur	25° 45′	88° 55′	39.60
33	Sylhet	24° 54′	91° 53′	33.53
34	Srimangal	24° 18′	91° 44′	21.95

Data source: BMD (Bangladesh Meteorological Department), Dhaka 2013

discussed in Sect. 2.4; trends, changes, and spatial patterns of rainfall are discussed in Sect. 2.5; future model-predicted changes and spatial patterns of temperature and rainfall for the decade of 2011–2020 are discussed in Sect. 2.6; the impacts of temperature and rainfall changes on agriculture and groundwater are discussed in Sect. 2.7; and conclusions and some recommendations are given in Sect. 2.8.

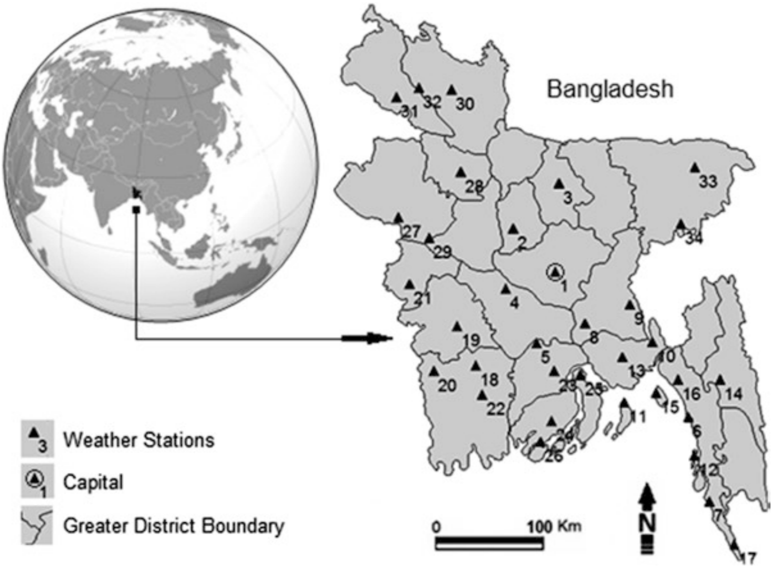

Fig. 2.1 Spatial distribution of weather stations in Bangladesh

2.2 Climate of Bangladesh: An Overview

Bangladesh, one of the South Asian countries, is located between the latitudes of 20° 34′ and 26° 38′ N and between the longitudes of 88° 01′ and 92° 41′ E (Fig. 2.1), with an area of 144,000 km^2. Geographically, Bangladesh is bounded by India in the north (Assam and Meghalaya), northeast (Assam, Tripura, and Mizoram), and west (West Bengal); by Myanmar in the southeast; and by the Bay of Bengal in the south. Bangladesh is a flat and fertile land, except for the hilly regions in the northeast and southeast (Rashid 1991). The Himalayas and the Tibetan Plateau are situated in the north. Bangladesh enjoys a typical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. The climate of Bangladesh is basically controlled by the monsoon, premonsoon, and postmonsoon circulations (Rashid 1991). Bangladesh has a dry and mild winter (postmonsoon) season from November to February, a hot summer or premonsoon season from March to May, and a humid summer or monsoon (sometimes called rainy) season from June to October. The average mean temperature in Bangladesh is 25.75 °C; it ranges from 18.85 to 28.75 °C (monthly averages). The average mean minimum and mean maximum temperatures are 21.18 and 30.33 °C, respectively (Table 2.2).

Seasonally, the hot summer is the warmest season in Bangladesh; the mean temperature ranges from 23 to 31 °C. During this period, there are some rains accompanied by the northwester and hailstorms, often with recurrent tornadoes. April and

Table 2.2 Long-term average temperature and rainfall in Bangladesh

Month	Mean minimum temperature (°C)	Mean maximum temperature (°C)	Mean temperature (°C)	Rainfall (mm)
January	12.50	25.20	18.85	9
February	15.10	27.80	21.45	26
March	19.60	31.60	25.60	52
April	23.10	33.20	28.15	130
May	24.50	32.90	28.70	277
June	25.60	31.90	28.75	459
July	25.60	31.10	28.35	523
August	25.70	31.40	28.55	420
September	25.40	31.50	28.45	318
October	23.60	31.50	27.55	160
November	19.20	29.50	24.35	42
December	14.20	26.40	20.30	10
Average	21.18	30.33	25.75	2426[a]

Data source: BMD (Bangladesh Meteorological Department), Dhaka, 2013
[a]Total annual rainfall

May are the hottest months in Bangladesh, with a maximum temperature of 45.1 °C recorded on May 19, 1972, at Rajshahi (Table 2.2). January is the coldest month, with a minimum temperature of 2.8 °C recorded on February 4, 1968, at Srimangal (Table 2.2). The rainfall in Bangladesh is very much seasonal, and about 75% of the total rainfall occurs in the monsoon/humid summer months (June, July, and August), caused by the moisture-laden southwest trade winds, which are drawn to the Indian subcontinent by the intense heat and consequent low pressure over the south Asian continent. In contrast, rainfall over the country during winter is very scanty; only 3% of the total rainfall is observed in this season (Table 2.2). The driest month of the season is December, and the northwest is the driest part of the country. About 22% of the total rainfall occurs in the hot summer season. The climate of the country is one of the wettest in the world. The average rainfall in the country is 2426 mm per year (BBS 2013), and the rainfall varies from 1400 to 4400 mm over the country. A wide spatial and temporal distribution of rainfall exists; generally, northeastern Bangladesh receives the greatest average rainfall. The average relative humidity in the country ranges from 70% to 78%, and March and April are the least humid months (with a lowest observed relative humidity of 57%). The highest humidity (over 80%) is observed in June to September.

As mentioned, Bangladesh is highly vulnerable to the impacts of climate change because of its geographical location, flat deltaic topography with very low elevation, higher variability in rainfall, more extreme weather events, high population density, high level of poverty, agrarian-based economy, and low capacity to address the devastating impacts of climate change (IPCC 2007). Therefore, detailed information about climate change—particularly the temperature and rainfall in Bangladesh—is needed to understand the changing patterns and the behavior of the changes so that planning and strategies can be formulated to overcome the problems caused by climate change.

2.3 Methodological Background

2.3.1 Statistical Techniques

To analyze the temperature and rainfall of Bangladesh, three statistical methods were applied to the observed temperature and rainfall time series data from the 34 weather stations over the period of 1971–2010. Statistically, the temperature and rainfall data were analyzed by decadal trends, decadal changes, and ARIMA time series analysis. For trend analysis, linear regression using a least-squares method was applied (Moore and McCabe 2003), and the least squares were calculated by Eq. 2.1:

$$y = ax + b \tag{2.1}$$

$$a = \frac{\sum\left(x-\overline{x}\right)\left(y-\overline{y}\right)}{\sum\left(x-\overline{x}\right)^2} \tag{2.1.1}$$

$$b = \overline{y} - a\overline{x} \tag{2.1.2}$$

where x and y represent independent and dependent values, respectively; a is the coefficient of each x value; b denotes the constant value; and $\overline{x}$ and $\overline{y}$ are the sample means. The trend is determined to be significant at the 95% level ($p < 0.05$). The changes in temperature and rainfall were analyzed on a decadal scale. Therefore, the changes in temperature and rainfall were assessed by interdecadal differences, using Eq. 2.2. The decades for which data were analyzed were the 1970s (1971–1980), 1980s (1981–1990), 1990s (1991–2000), and 2000s (2001–2010):

$$D_i = \overline{x}_i - \overline{x}_j \tag{2.2}$$

where D_i represents the change value for decade i; $\overline{x}_i$ is the mean value for decade i; and $\overline{x}_j$ is the mean value for the preceding decade j. For data processing of trends and decadal change, Excel statistical software was used (version 2010). In addition, future predictions of temperature and rainfall changes for the decade of 2011–2020 (the 2010s) were evaluated using an ARIMA time series model (Box and Jenkins 1976), along with monthly time series data. An ARIMA model can be used for seasonal as well as nonstationary time series data; therefore, an ARIMA model was considered for future predictions. The ARIMA (p, d, q) model has an autoregressive (AR) retrospectively weighted series denoted as p, a difference lag

(I) to achieve a stationery series denoted as *d*, and a retrospectively weighted moving average (MA) random error series represented as *q*. The appropriate values of autoregressive order *p* and moving average *q* are chosen by examining the autocorrelation function (ACF) and partial autocorrelation function (PACF) of the time series. The details of the ARIMA model can be found in Box and Jenkins (1976) and Yurekli et al. (2007). The ARIMA model is expressed here by Eq. 2.3:

$$\varphi(B)\nabla^d Y_t = \theta(B)\varepsilon_t \tag{2.3}$$

where:

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p \tag{2.3.1}$$

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots - \theta_q B^q \tag{2.3.2}$$

where Y_t and ε_t represent time series and random error terms at time t, respectively; B is the backward shift operator; ∇^d describes the differencing operation for data series to make the data series stationary; d is the number of differencing operations; ϕ_p, θ_q are the model parameters; and $\phi(B)$ and $\theta(B)$ are of order p and q. The time series often contain seasonal effects, for which seasonal differencing is used to remove the seasonal effects. Thus, the ARIMA models have two general forms: nonseasonal ARIMA (p, d, q) and multiplicative seasonal ARIMA $(p, d, q)(P, D, Q)_S$, where p, d, q are nonseasonal parts of the model and P, D, Q are seasonal parts of the model (Box and Jenkins 1976). This can be represented by Eq. 2.4:

$$\phi(B)\phi(B_s)(1-B)^d(1-B_s)^D Y_t = C + \theta(B)\theta(B_s)\varepsilon_t \tag{2.4}$$

where:

$$\phi(B_s) = 1 - \phi_1 B_s - \phi_2 B^{2_s} - \ldots - \phi_P B^{P_s} \tag{2.4.1}$$

$$\theta(B_s) = 1 - \theta_1 B_s - \theta_2 B^{2_s} - \ldots - \theta_Q B^{Q_s} \tag{2.4.2}$$

where $\phi(B_s)$ is the seasonal autoregressive part of order P ($AR_s(P)$); $\theta(B_s)$ is the seasonal moving average part of order Q ($MA_s(Q)$); $(1 - B)^d$ is the differencing of order d ($I(d)$); $(1 - B_s)^D$ is the seasonal differencing of order D ($I_s(D)$); and s is the period of the seasonal pattern appearing. Here, a time series module along with ARIMA models in SPSS statistical analysis software (SPSS 2007) was used to perform the simulations of temperature and rainfall data for each station. To find out the changes in the temperature and rainfall during the decade of 2001–2010, the monthly predicted values were calculated for the year and then for the decade.

Afterward, changes were calculated and interpolated spatially using inverse distance weighting (IDW) and GIS to generate the spatial pattern of the changes in temperature and rainfall.

2.3.2 Geographic Information System

A GIS is a computer-based system for acquiring, storing, manipulating, editing, interpreting, analyzing, and representing spatial data, along with nonspatial data. GIS is capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information (Dai et al. 2001). Advanced spatial analysis with numerical modeling using GIS is able to analyze what happened in the past, is happening in the present, and will happen in the future in geographic space. Therefore, GIS is an approach to managing phenomena geographically and temporally. Spatial distribution of meteorological data is becoming important as inputs into spatially explicit landscape, regional, and global models (Li et al. 2006). In recent decades, for environmental assessment through different components and techniques, GIS—along with numerical modeling—has emerged as a powerful tool (Krivtsov 2004; Rahman and Saha 2008, 2009) and has been used widely for development of automated methods and supporting spatial modeling and analysis (Paudyal 1996; Boyle et al. 1998; Rahman and Saha 2007; Rahman et al. 2009; Rahman et al. 2014). Geographical variables such as temperature and rainfall cannot be measured in all parts of space, therefore the point observation data and spatial interpolation technique are used to get complete spatial coverage of the variable. Point-based spatial interpolation is the process of estimating the surface values at unsampled points, using the known surface values at surrounding points. We analyzed the changes in temperature and rainfall on the basis of spatiotemporal analysis; therefore, the spatial distribution patterns of temperature and rainfall in different time periods were represented using GIS. Since we analyzed point time series data (here, weather station data), IDW interpolation and GIS were applied to present and analyze the findings spatially. In the IDW technique, points that are close to an output pixel obtain large weights and points that are farther away from an output pixel obtain small weights. The values of points that are close to an output pixel are thus of greater importance to this output pixel value than the values of points that are farther away. Integrated land and water information system (ILWIS) software was used for the interpolation and GIS analysis (ILWIS 2005). ILWIS and IDW were also used to generate the spatial patterns of the forecasted values for temperature and rainfall.

2.4 Changes in Temperature (1971–2010)

2.4.1 Temperature: Decadal Trends and Changes

Analysis of decadal changes in temperature and rainfall is the most important aspect of climate variability and change study. Here, we analyze the decadal trends and the magnitude of the decadal changes in temperature in Bangladesh using 40 years of observed temperature data for the period of 1971–2010. In the decadal trend analysis, we found that the mean temperature in Bangladesh increased on average by 0.19 °C per decade, while the mean minimum and mean maximum temperatures increased by 0.17 and 0.21 °C per decade, respectively (Table 2.3). The trends were statistically significant at the 95% confidence level. Therefore, during the stipulated time period, there was significant warming in Bangladesh. If we compare these trends with those from previous studies (Jones 1995; Ahmad and Warrick 1996; Shahid 2010), the presently obtained trends show much greater trends of warming than those previous findings. For example, Shahid (2010) obtained 0.097, 0.091, and 0.102 °C per decade increases in the mean, mean minimum, and mean maximum temperatures, respectively, for the period of 1958–2007. Thus, it may be noted that the present analysis indicates rapid warming in recent decades.

Decadal analysis shows that in Bangladesh the mean temperatures were 25.55, 25.74, 25.87, and 26.13 °C in the 1970s, 1980s, 1990s, and 2000s, respectively (Fig. 2.2a). As a result, the interdecadal changes in temperature show that in the 1980s, the mean temperature increased by 0.19 °C in comparison with the 1970s. The largest increase in the mean temperature—0.26 °C—was observed during the decade of 2001–2010 (the 2000s). A total mean temperature increase of 0.58 °C was found from the 1970s to the 2000s (Table 2.3).

During the period of 1971–2010, the decadal mean minimum temperatures in the country were 20.97, 21.17, 21.25, and 21.47 °C in the 1970s, 1980s, 1990s, and 2000s, respectively (Fig. 2.2b). Hence, the decadal changes indicate that the mean minimum temperature increased by 0.20, 0.08, and 0.22 °C in the 1980s, 1990s, and 2000s, respectively, in comparison with the previous decade. The total increase in the mean minimum temperature was 0.50 °C from the 1970s to the 2000s (Table 2.3).

In the 1970s, 1980s, 1990s, and 2000s, the mean maximum temperatures were 30.13, 30.32, 30.47, and 30.78 °C, respectively (Fig. 2.2c), indicating a remarkable

Table 2.3 Decadal trends and changes in temperature in Bangladesh

Temperature	Trends (°C/decade) in 1971–2010	Decadal changes in temperature (°C)					
		Observed				Predicted	
		1970s–1980s	1980s–1990s	1990s–2000s	1970s–2000s	2000s–2010s	1970s–2010s
Mean	+0.19 ($p = 0.008$)	+0.19	+0.13	+0.26	+0.58	+0.18	+0.76
Mean minimum	+0.17 ($p = 0.009$)	+0.20	+0.08	+0.22	+0.50	+0.19	+0.69
Mean maximum	+0.21 ($p = 0.011$)	+0.19	+0.15	+0.31	+0.65	+0.16	+0.81

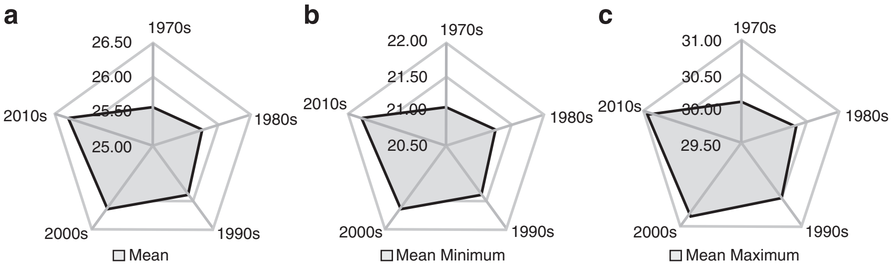

Fig. 2.2 Decadal average temperature (°C) distribution in Bangladesh (1971–2020). (**a**) Mean. (**b**) Mean minimum. (**c**) Mean maximum. The 2010s (2011–2020) values are predicted values

increase in the maximum temperature during the period. The mean maximum temperature increased by 0.19, 0.15, and 0.31 °C in the 1980s, 1990s, and 2000s, respectively, in comparison with the previous decade. A total mean maximum temperature increase of 0.65 °C occurred in the 30 years period of 1981–2010 (Table 2.3).

Therefore, the decadal trends and change analysis denote that the climate of Bangladesh is indeed warming (at a rate of 0.19 °C per decade) and the increase in the maximum temperature was more prominent than the increase in the minimum temperature during these decades. Moreover, from the interdecadal change analysis, it is clear that the greatest warming was observed in the decade of 2001–2010 (Table 2.3). This is broadly consistent with the global warmest periods; the ten warmest years on record all have occurred since 1998 (Trenberth et al. 2007; Hansen et al. 2013; Hartmann et al. 2013; WMO 2014). Again, from the station-wise decadal temperature distribution pattern (Fig. 2.3), it is clear that the mean, mean minimum, and mean maximum temperatures increased at almost all of the observation stations, and that rapid warming—particularly in the mean maximum temperature has been in progress during the decades 1981–2010 (Figs. 2.2 and 2.3).

2.4.2 Temperature: Spatial Patterns of Decadal Changes

The temperature is the most important and dynamic climatic component, which varies spatially and temporally. Hence, the distribution and spatiotemporal pattern of the temperature can be helpful to study the change in temperature over space and time. Here, we analyze and discuss the decadal changes in temperature spatially in order to find out the regional change pattern of the temperature in Bangladesh during different decades. Figures 2.4, 2.5, and 2.6 display the spatial patterns of the decadal changes in the mean, mean minimum, and mean maximum temperatures in Bangladesh, respectively. In conjunction with the spatial pattern of the decadal mean temperature change, Fig. 2.4 shows that the increase in the decadal mean temperature had large geographical variations and was also temporally not uniform

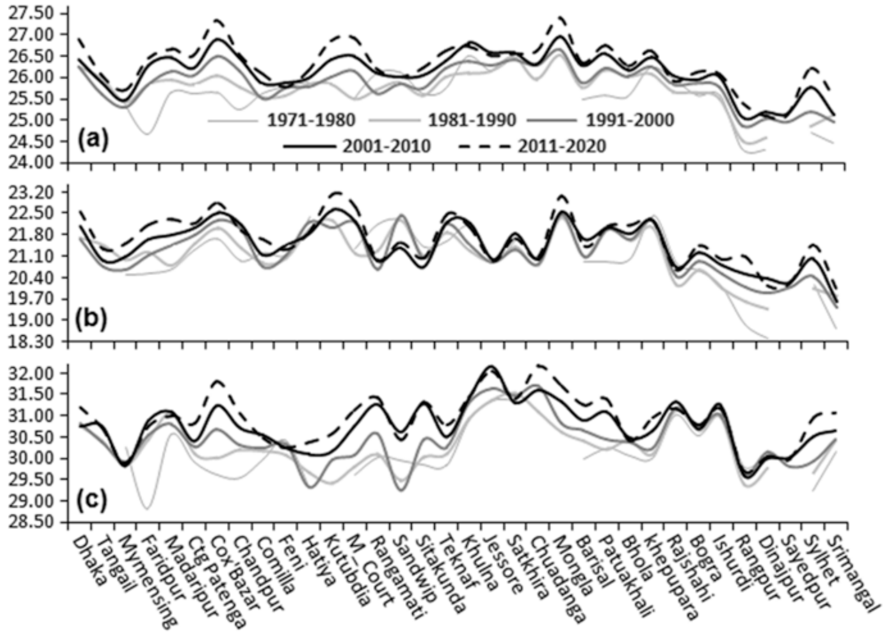

Fig. 2.3 Station-wise decadal temperatures (°C) in Bangladesh. (**a**) Mean. (**b**) Mean minimum. (**c**) Mean maximum

over the last three decades (1981–2010). During the 1980s (1981–1990), greater increases (ranging from 0.51 to 1.17 °C) in the mean temperature were noticed in the northeastern, central and, to some extent, central southern parts of the country (Fig. 2.4a), while in the 1990s (1991–2000), the greatest increase (of 0.26–0.64 °C) was marked mainly in the extreme northwestern part of the country (Fig. 2.4b). In the 2000s (2001–2010), the mean temperature increased more (by 0.34–0.58 °C) in the northeastern and southeastern parts of the country (Fig. 2.4c). However, from the 1970s (1971–1980) to the 2000s (2001–2010), the greatest warming (0.51–1.59 °C) in the mean temperature was observed in the northwestern, northeastern, central, central southern, and southeastern parts of the country, with maximum increases of 1.59, 1.25, 1.18, 1.08, and 0.89 °C in Faridpur, Cox's Bazar, Chandpur, Sylhet, and Dinajpur, respectively (Fig. 2.4d).

With regard to interdecadal change, the spatial pattern of the mean minimum temperature changes highlighted that except in a few locations, the minimum temperatures in Bangladesh increased gradually over space and time, and a greater increase in the minimum temperature occurred mainly in the northern part of the country (Fig. 2.5), where the mean minimum temperature increased by 0.51–1.18 °C in the 1980s (Fig. 2.5a) and by 0.45–1.02 and 0.31–0.73 °C in the 1990s and 2000s, respectively (Fig. 2.5b, c). From the 1970s to the 2000s, remarkable increases (of 0.46–1.97 °C) in the mean minimum temperature occurred in the northwestern, northeastern, central, and central southern parts of the country (Fig. 2.5d). The max-

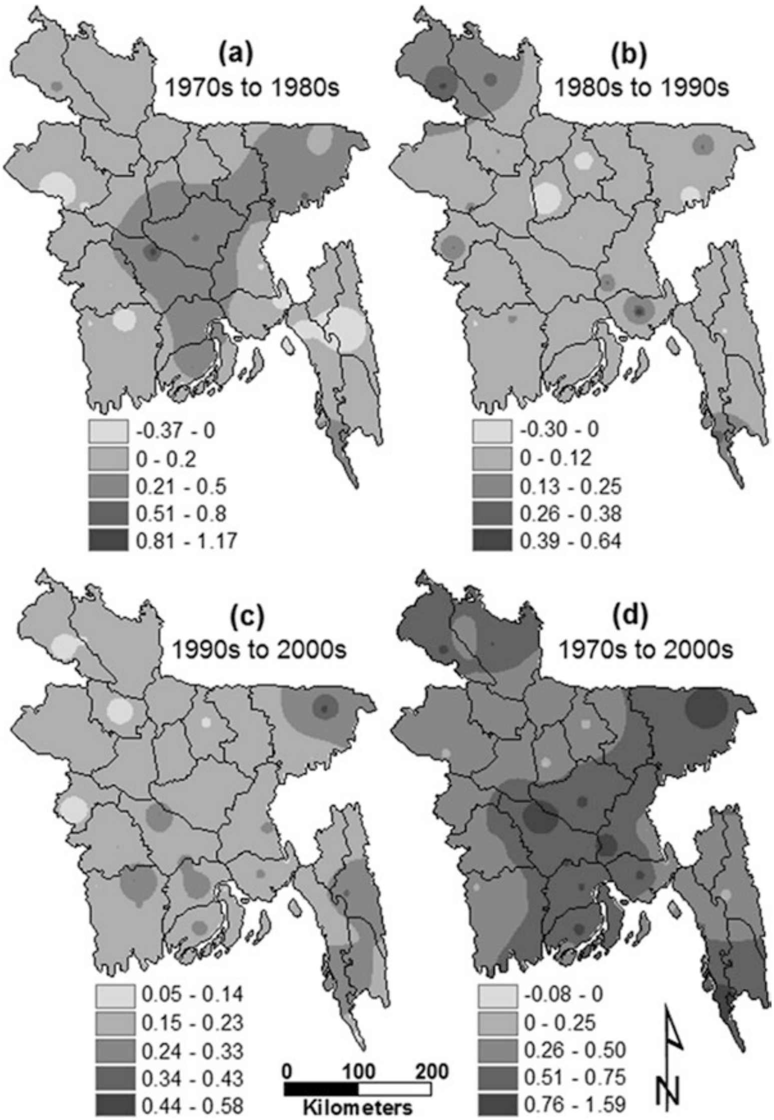

Fig. 2.4 Decadal changes in the mean temperature (°C) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

imum increase in the mean minimum temperature were noticed in Dinajpur (1.97 °C) and Rangpur (1.68 °C), located in the northwestern part of Bangladesh. However, remarkable decreases (of 1.09 and 0.89 °C) in minimum temperatures were detected in Rangamati and Sandwip, respectively, located in the southeastern part of the country.

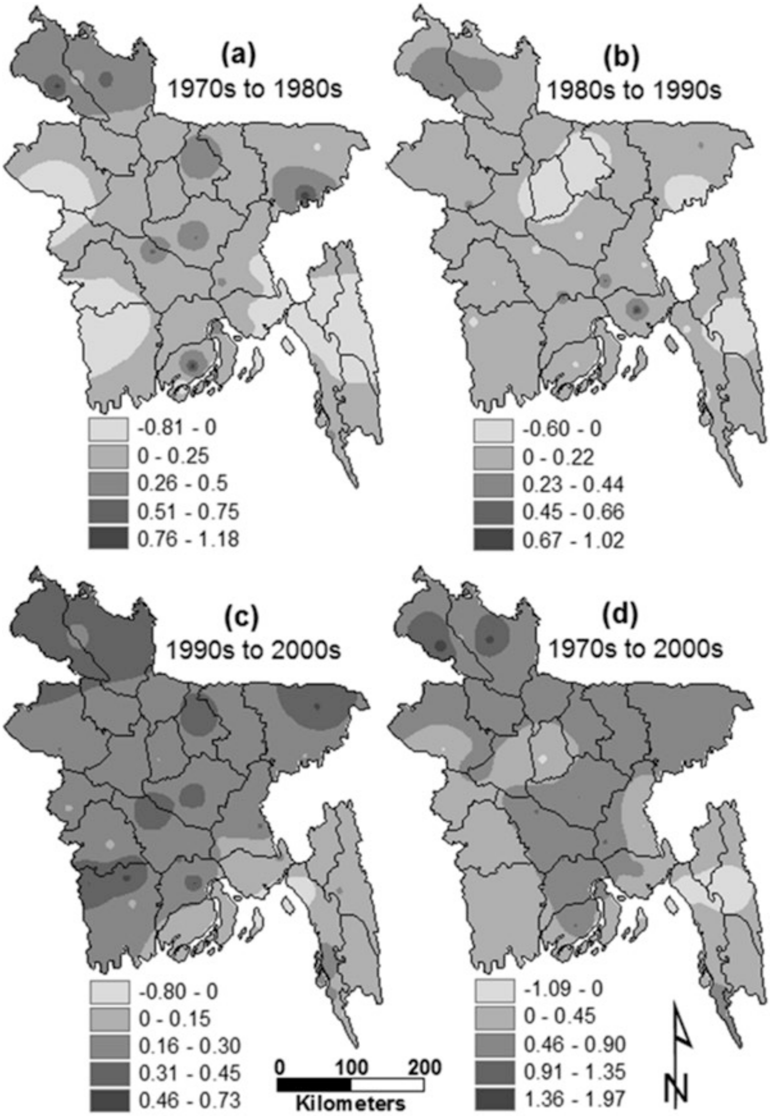

Fig. 2.5 Decadal changes in the mean minimum temperature (°C) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

With regard to the interdecadal spatial pattern of the changes in the mean maximum temperature, distinct spatial variability was also observed, and greater increases in the maximum temperature occurred mainly in the southern, southeastern, and northeastern parts of the country than in other parts. However, Fig. 2.6 illustrates that in the period of 1981–1990 (the 1980s), the central part of the country warmed more, by 0.77–1.63 °C (Fig. 2.6a), while the extreme northwestern,

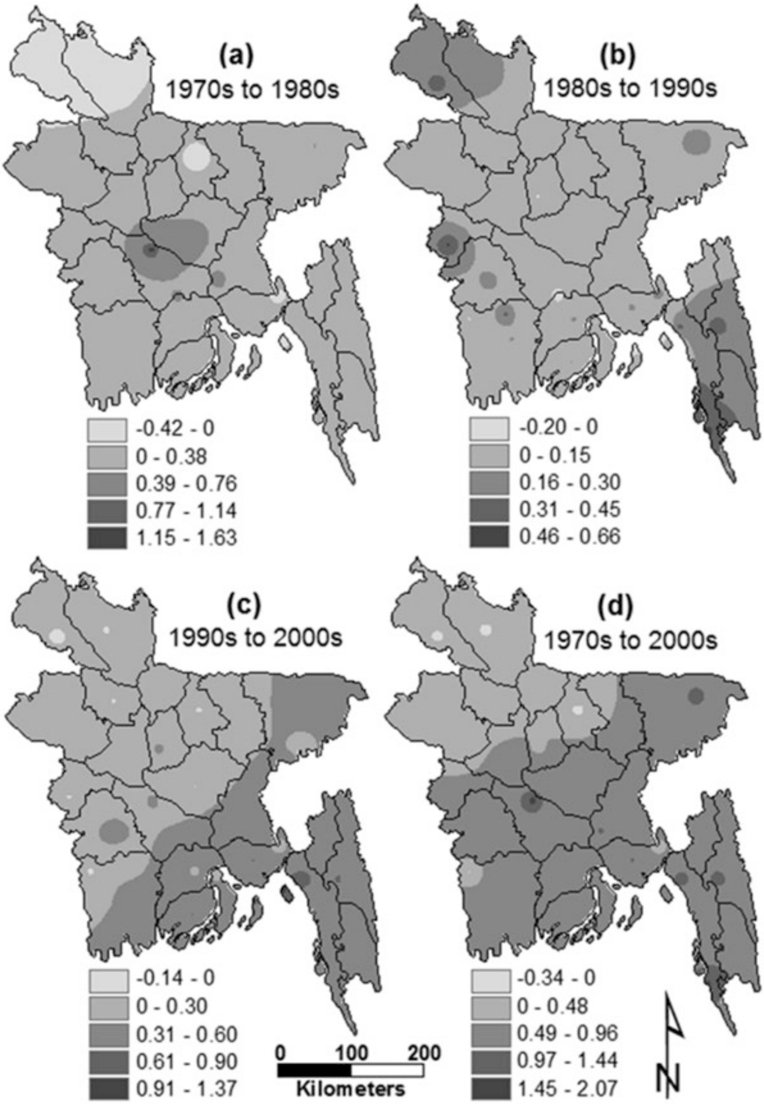

Fig. 2.6 Decadal changes in the mean maximum temperature (°C) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

southeastern and, to some extent, western parts warmed more (by 0.31–0.66 °C) during 1991–2000 (Fig. 2.6c). In the decade of 2001–2010, a notable increase (of 0.61–1.37 °C) in the mean maximum temperature occurred in the southern, southeastern, and northeastern parts of the country (Fig. 2.6c). The spatial pattern of the interdecadal changes in the mean maximum temperature further reveals that in Bangladesh from the 1970s to 2000s (a 30-year time period), greater increases (of

0.49–2.07 °C) in the mean maximum temperature occurred in the southern and northeastern parts of the country (Fig. 2.6d). During this period, the greatest temperature rises occurred in Faridpur (2.07 °C), Cox's Bazar (1.63 °C), Sitakunda (1.46 °C), Sylhet (1.28 °C), and Rangamati (1.24 °C). Conversely, minimal increases (of up to 0.48 °C) in the mean maximum temperature happened in the northwestern and northern parts of the country in comparison with other parts, and in some places the maximum temperatures decreased—notably in Mymensing (by 0.45 °C), Rangpur (by 0.19 °C), and Dinajpur (by 0.18 °C)—during the 30-year time period of the 1970s–2000s. Thus, the spatial pattern of the decadal changes in temperature showed that the warming in Bangladesh varied over space and time, and that the northwestern, northeastern, southeastern, and central southern parts were more vulnerable to rises in temperature.

2.5 Changes in Rainfall (1971–2010)

2.5.1 Rainfall: Decadal Trends and Changes

In a country such as Bangladesh, where agriculture is the mainstay of the country and production in agriculture is mainly dependent on rainwater, the rainfall and its distribution over the country are of vital importance. Because of global warming and its impacts, changes in rainfall patterns—with anomalies, variability, and extremes in rainfall—have been observed globally and regionally. Across all time and space scales, rainfall has been characterized by higher variability (Kim et al. 2011). In fact, in recent decades in Bangladesh we have observed heavy rainfall, causing devastating floods—e.g., in 1987, 1988, 1998, 2004, 2007, and 2010—inundating about 40–60% of the total area (GOB 2012). Conversely, in that same period, we also faced sparse or no rainfall at times, causing severe droughts—e.g., in 1981, 1982, 1989, 1994, and 1995—which affected about 45–50% of the total area of the country (GOB 2012). There was also high variability in rainfall over the country, which may have been linked to the impact of global warming on the regional or local scales. Thus, study of rainfall trends and changes over time, and the spatial patterns of the changes, are very important for the agricultural environment and for planning.

In this section, we analyze and discuss the trends and magnitude of the changes in the decadal and decadal seasonal rainfall in Bangladesh during 1971–2010, during which time the average rainfall increased by 76 mm (3.5%) per decade (Table 2.4). On a seasonal scale, the average monsoon rainfall rose by 57 mm (3.2%) per decade, while the premonsoon and postmonsoon rainfall declined by 8 mm (2%) and 4 mm (6%) per decade, respectively. However, we found that these trends were not statistically significant (Table 2.4); therefore, it may be said that there were increasing and decreasing tendencies in the rainfall in Bangladesh, exhibiting high variability in rainfall over that time period.

Table 2.4 Decadal trends and changes in rainfall in Bangladesh during 1971–2020

Rainfall	Trends (mm/decade) in 1971–2010	Decadal changes in rainfall (mm)					
		Observed				Predicted	
		1970s–1980s	1980s–1990s	1990s–2000s	1970s–2000s	2000s–2010s	1970s–2010s
Average rainfall	+76 ($p = 0.342$)	332	−55	−5	+272	−153	+119
Premonsoon	−8 ($p = 0.724$)	68	−38	−43	−13	+8	−5
Postmonsoon	−4 ($p = 0.762$)	12	+16	−45	−17	+8	−9
Monsoon	+57 ($p = 0.175$)	174	−18	+40	+196	−175	+21

The decadal analysis of rainfall shows that in the 1970s, 1980s, 1990s, and 2000s, the average rainfall in Bangladesh was 2171, 2503, 2448, and 2443 mm, respectively (Fig. 2.7a). Hence, the interdecadal change in the average rainfall between the 1970s and the 1980s was an increase of 332 mm (Table 2.4). Although the trends in the average rainfall between the 1970s and 1980s showed an increase, the rainfall declined by 55and 5 mm in the 1990s and 2000s, respectively, in comparison with the previous decade. Table 2.4 shows a total increase in rainfall of 272 mm from the 1970s (1971–1980) to the 2000s (2001–2010). Seasonally, the average premonsoon rainfall in the country was 422, 490, 452, and 409 mm during the 1970s, 1980s, 1990s, and 2000s, respectively, denoting a sharp decrease since 1980s (Fig. 2.7b). The premonsoon rainfall decreased by 38 mm from the 1980s to the 1990s and by 43 mm from the 1990s to the 2000s. Overall, a 13 mm decrease in the premonsoon rainfall in Bangladesh was observed during the three decades of 1981–2010 (Table 2.4).

The postmonsoon season in Bangladesh is mainly a dry season, with much less rainfall than in the other seasons. The average postmonsoon rainfall was only 70, 82, 98, and 53 mm during the 1970s, 1980s, 1990s, and 2000s, respectively (Fig. 2.7c). A notable decline of 45 mm in the postmonsoon rainfall was observed in the decade of 2001–2010, in comparison with the previous decade, and an overall 17 mm shortfall of rain occurred in this season during the 1970s–2000s (Table 2.4).

In the monsoon, which is the wettest season in Bangladesh, the average rainfall was 1796, 1970, 1952, and 1992 mm in the 1970s, 1980s, 1990s, and 2000s, respectively (Fig. 2.7d). Although there were large amounts of rainfall in this season, the interdecadal change analysis showed that the monsoon rainfall declined by 18 mm from the 1980s to the 1990s, whereas a 40 mm increase in rainfall from the 1990s to 2000s was noted. Table 2.4 further shows a total rainfall increase of 196 mm between the 1970s (1971–1980) and the 2000s (2001–2010). Therefore, in the pattern of rainfall in Bangladesh, overall upward trends in the decadal average and monsoon rainfall and downward trends in the pre- and postmonsoon rainfall were perceived during the period of 1971–2010. However, the interdecadal changes indicated high variability in rainfall, and the rainfall was erratic in the pre- and postmonsoon seasons. The greatest decrease in rainfall over the decades occurred in the postmonsoon season (Table 2.4 and Fig. 2.7).

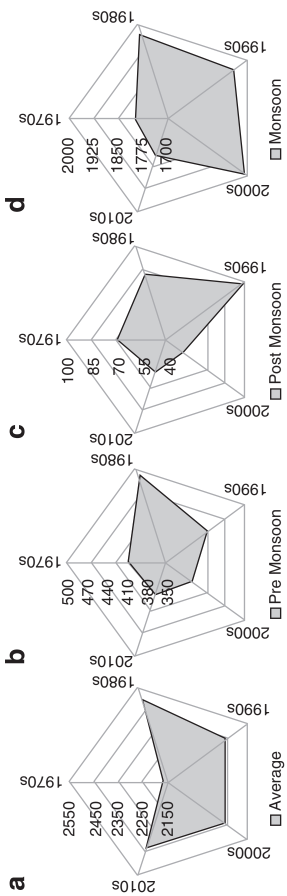

Fig. 2.7 Decadal average rainfall (mm) distribution in Bangladesh (1971–2020). (**a**) Decadal average. (**b**) Premonsoon. (**c**) Postmonsoon. (**d**) Monsoon. The 2010s (2011–2020) values are predicted values

2.5.2 Rainfall: Spatial Patterns of Decadal Changes

In Sect. 2.5.1, we discussed the decadal trends and changes in rainfall in Bangladesh for the period of 1971–2010. However, it is also necessary to identify the spatiotemporal patterns of the rainfall changes, as the spatial and temporal behavior of the changes may be linked to regional agriculture, water, and environmental planning and management. The spatial patterns of the decadal average rainfall and decadal seasonal rainfall changes are shown in Figs. 2.8, 2.9, 2.10, and 2.11, which depict the high spatial and temporal variability in the average, premonsoon, postmonsoon, and monsoon rainfall in Bangladesh. The decadal comparison of the spatial patterns of the average rainfall changes shows that from the 1980s (1981–1990) to the 1990s (1991–2000), except in the southeastern part and in some small areas in the southern and western parts of the country, the average rainfall declined over the country and the maximum decreases (of 75–603 mm) were noticed in the northwestern, northeastern, and central southern districts (Fig. 2.8b). In the 2000s (2001–2010), notable declines in the average rainfall were observed in the central, northeastern, western, and southeastern districts of the country (Fig. 2.8c), in comparison with the previous decade. In contrast, the average rainfall increased significantly (by 300–1086 mm) in the southern, southwestern, and extreme northwestern districts of the country during this period (Fig. 2.8c). Figure 2.8d further reveals that from the 1970s (1971–1980) to the 2000s (2001–2010), small increases in average rainfall were noticed in the northwestern, western, and central parts of the country. Thus, the decadal spatial change analysis of average rainfall shows that the northwestern, western, central, and central southern parts of the country are susceptible to declines in average rainfall.

Seasonally, the spatial pattern of the decadal average rainfall in the premonsoon highlighted the distinct spatial rainfall variability and a greater decrease in premonsoon rainfall over the two decades of 1991–2010 (Fig. 2.9). In the premonsoon season, except in the southeastern hill district, all parts of Bangladesh experienced shortfalls of rain from the 1980s (1981–1990) to the 1990s (1991–2000), and the maximum decreases in rainfall, ranging from 32 to 247 mm, were observed in the whole northern, central, eastern, and southwestern parts of the country (Fig. 2.9b). Again, in this season, the decreases in rainfall continued up to the 2000s (2001–2010), and the maximum shortfalls (of 40–222 mm) were marked in the central, southern, and southeastern parts of the country (Fig. 2.9c). However, during this period, the premonsoon rainfall increased (by 40–144 mm) in the extreme northwestern part. As a whole, from the 1970s to the 2000s, the premonsoon rainfall declined markedly in the northern, northwestern, western, southwestern, southern, eastern, and central parts of the country. Greater decreases (of 30–252 mm) in premonsoon rainfall occurred in the western part of the country and, to some extent, in the northwestern, southwestern, and southern parts (Fig. 2.9d). Consequently, though there was a large spatial variation in premonsoon rainfall, these parts of the country were more vulnerable to decreases in premonsoon rainfall.

Looking at the interdecadal spatial analysis of the postmonsoon rainfall, it is apparent that apart from a few areas, the postmonsoon rainfall increased all over Bangladesh from the 1970s (1971–1980) to the 1990s (1991–2000) (Fig. 2.10a, b)

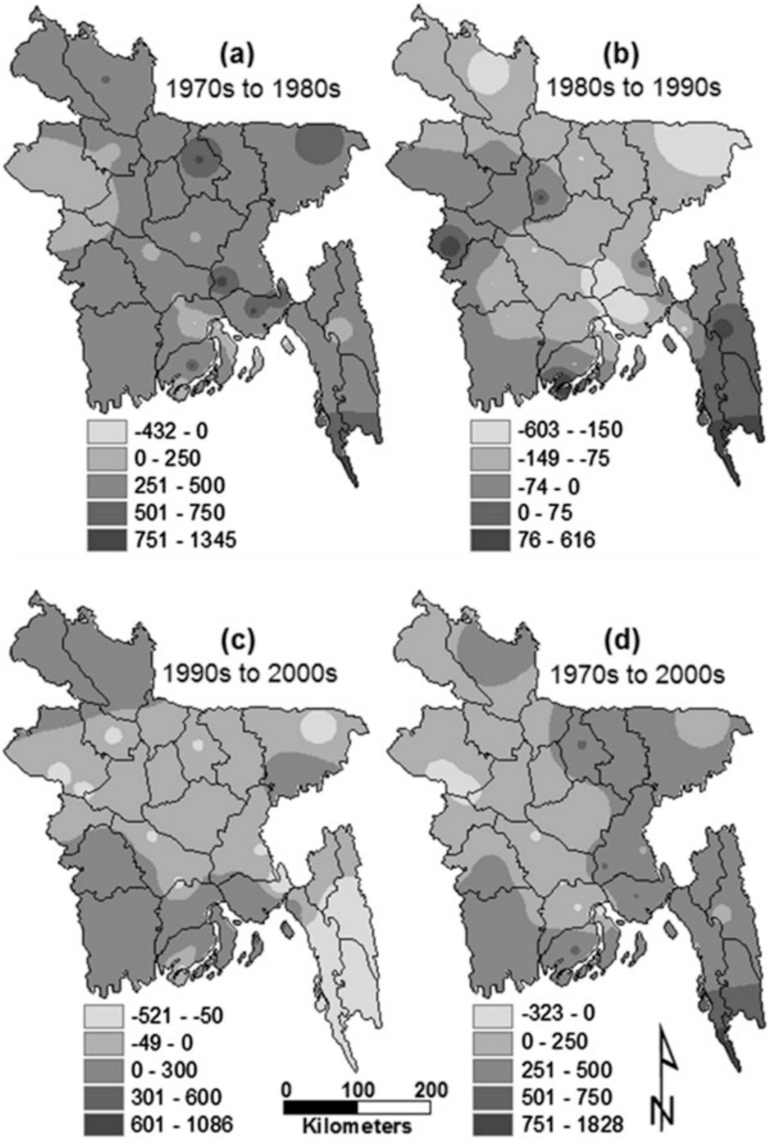

Fig. 2.8 Decadal changes in the average rainfall (mm) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

and a greater increase was observed in the southern part of the country. However, there were big changes in postmonsoon rainfall from the 1990s (1991–2000) to the 2000s (2001–2010); the whole country experienced decline in postmonsoon rainfall during this period, and the greatest declines (of 45–86 mm) were noted in the southwestern, southern, and southeastern parts of the country (Fig. 2.10c). Moreover, Fig. 2.10d shows that in comparison with the 1970s (1971–1980), the postmonsoon

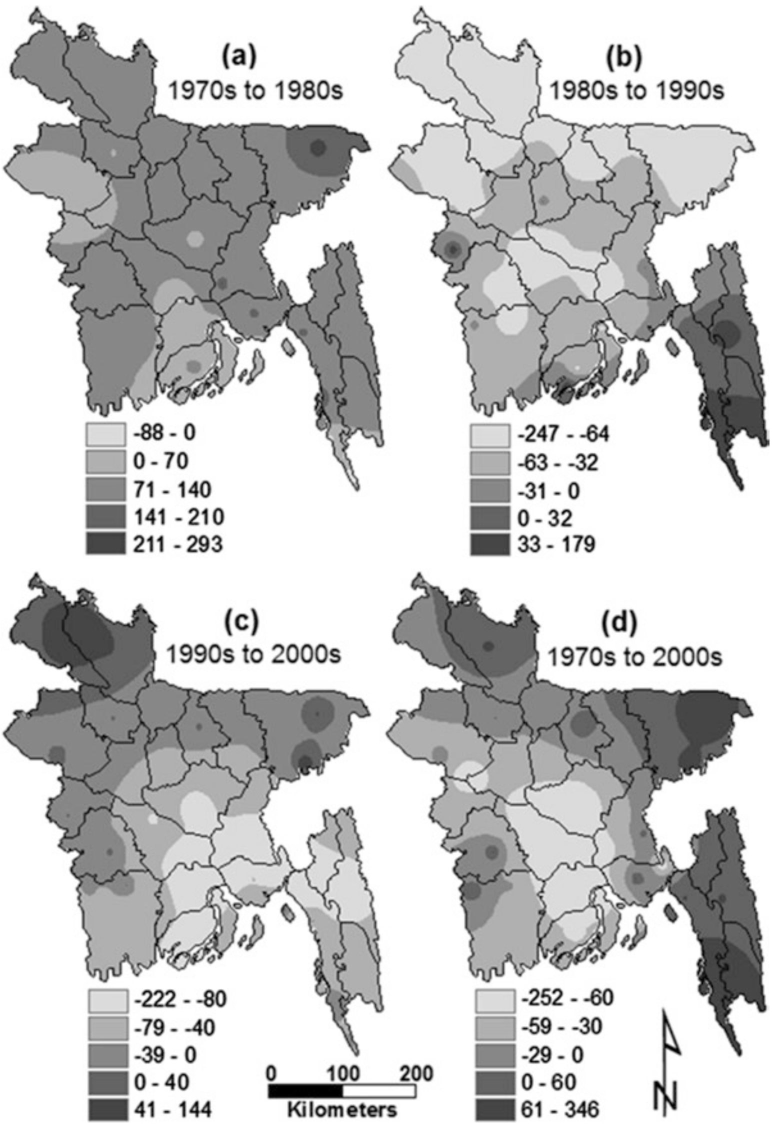

Fig. 2.9 Decadal changes in the average premonsoon rainfall (mm) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

rainfall in the 2000s (2001–2010) decreased all over the country, except in a few locations. During this period the greatest decreases (18–75 mm) were observed in some areas in the northwestern part and in the southern, southeastern, and eastern parts of the country, mainly because of the remarkable decline in the postmonsoon rainfall in the decade of 2001–2010 (Fig. 2.10c). Therefore, it may be noted that changes in seasonal rainfall patterns in Bangladesh are impacts of global climate

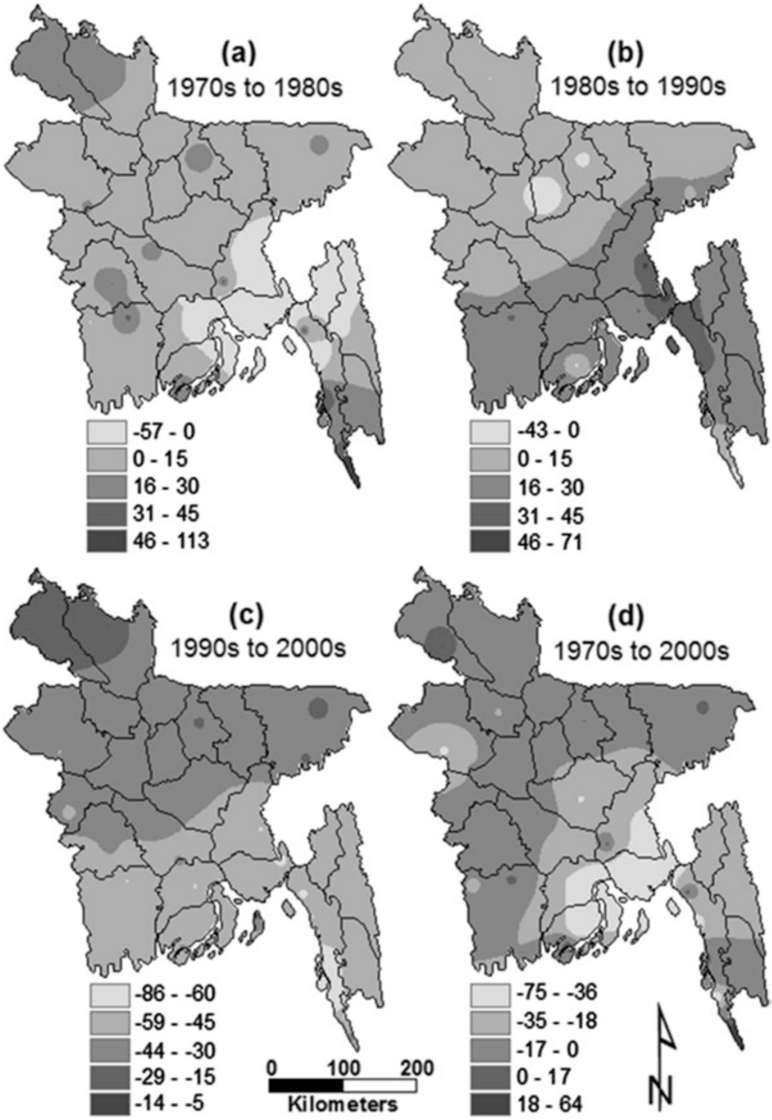

Fig. 2.10 Decadal changes in the average postmonsoon rainfall (mm) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

change at regional or local levels, since major changes have been noted in recent decades.

With regard to the spatial distribution of the decadal changes in average monsoon rainfall, regional disparities were observed during the period of 1971–2010 (Fig. 2.11). Though the monsoon season is the wettest season and the maximum rainfall (75%) occurred in this season, a notable decline in monsoon rainfall has

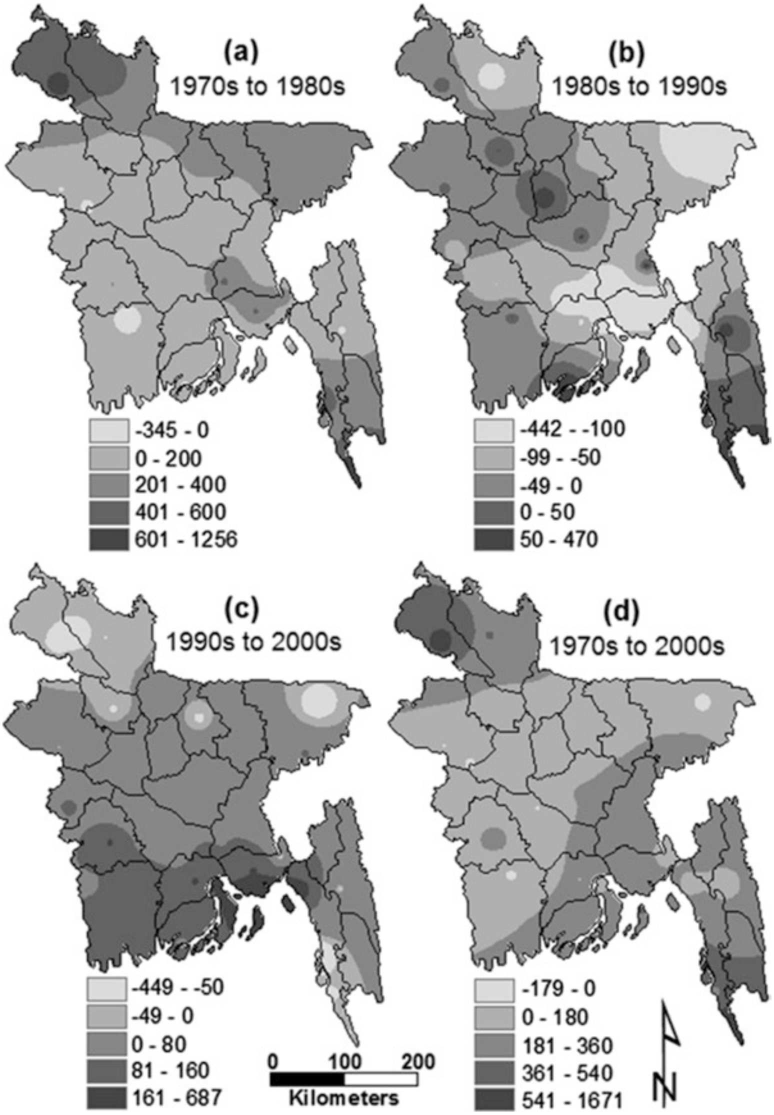

Fig. 2.11 Decadal changes in the average monsoon rainfall (mm) in Bangladesh. (**a**) 1970s–1980s. (**b**) 1980s–1990s. (**c**) 1990s–2000s. (**d**) 1970s–2000s

been observed since the 1990s (1991–2000). In comparison with the 1980s (1981–1990), monsoon rainfall declined almost all over Bangladesh, except in the south-eastern part and in some areas in the central part of the country in the 1990s (1991–2000). The maximum decreases of 50–442 mm were observed in the north-eastern and southern parts and in some areas in the northwestern part of the country during this decade (Fig. 2.11b). In the 2000s (2001–2010), the monsoon rainfall declined (by 49–449 mm) in the northwestern, northeastern, and extreme southeastern parts of the country (Fig. 2.11c). However, in this decade, the monsoon rainfall increased markedly (by 81–687 mm) in the southern part of Bangladesh. The changing pattern of the monsoon rainfall from the 1970s to the 2000s represents an overall increase in rainfall in this season, and greater increases (181–1671 mm) were observed in the southern, southeastern, and northwestern parts of the country (Fig. 2.11d). Nevertheless, during this period, minimal increases (of up to 180 mm) in monsoon rainfall were found in the western, central, and northwestern parts of the country (Fig. 2.11d).

2.6 Future Changes: Forecasting of Temperature and Rainfall

Forecasting of climatic parameters, especially temperature and rainfall, is a critical aspect in climate change and hydrological studies, since these are complex phenomena that vary both in time and in space, and they play a major role in climate risk management, preparedness, and mitigation. As the literature shows, numerous studies have been done worldwide on modeling of temperature and rainfall data for future predictions (Rahmstorf et al. 2007; Diomede et al. 2008; Marengo et al. 2009; Lin et al. 2009; Afshin et al. 2011; Karmalkar et al. 2011; IPCC 2007; Esfahani and Friedel 2014). However, accurate forecasting of temperature and rainfall in an area is still a major research challenge. To manage climate change impacts effectively, availability of accurate and cost-effective forecasts of the parameters is needed. In the forecasting models, an input vector is introduced into the model and then an output is determined by the mathematical rule that has been developed for the model. This model, using only previously recorded data (e.g., on temperature or rainfall) in the input vector, includes calculations for the future, based on mathematical rules. Modern forecasting of climate parameters involves a combination of computer models, observations, and knowledge of trends and patterns. With use of these methods, reasonably accurate forecasts can be made. Many efforts have also been made in statistical modeling of temperature and rainfall data, using historical records (Hansen et al. 2006; Rahmstorf et al. 2007). Time series models, such as the ARIMA model (Box and Jenkins 1976), are popularly used to predict the future condition of time series data (Romilly 2005; Yurekli et al. 2007). Time series models have become quite popular because of their trend-detecting capability and have a large degree of flexibility for application to seasonal as well as nonstationary time series (Lee and Sohn 2007). We predicted temperature and rainfall for the decade of the 2010s (2011–2020), using the ARIMA time series model, and calculated the changes relative to the 1970s (1971–1980), as discussed in Sects. 2.6.1 and 2.6.2. It may be noted here that between the observed data and the data fitted using the ARIMA model, we achieved highly positive coefficient of determination (R^2) values ranging from +0.88 to +0.97, denoting adequate accuracy of the model.

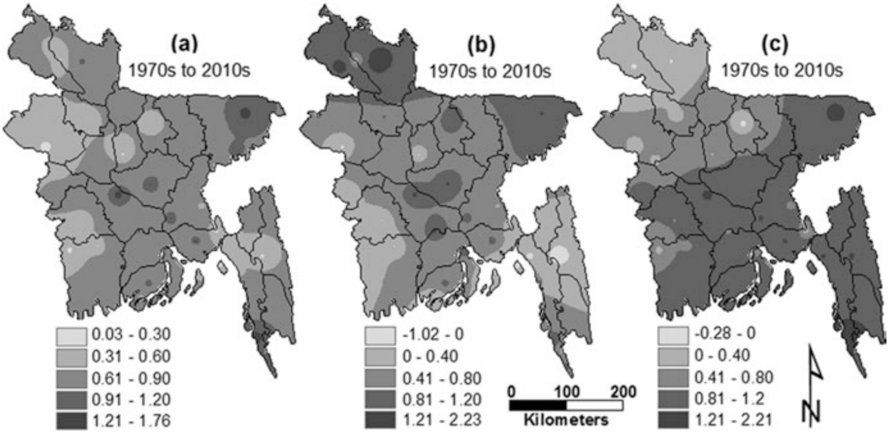

Fig. 2.12 Predicted changes in temperature in Bangladesh for the decade of 2011–2020 (the 2010s) relative to the decade of 1971–1980 (the 1970s). (**a**) Mean. (**b**) Mean minimum. (**c**) Mean maximum

2.6.1 Predicted Temperature Changes: 2010s (2011–2020)

Using the ARIMA time series model and 40 years of monthly temperature data from the 34 observation stations, it was projected that in Bangladesh the mean temperature would increase further by 0.18 °C in the 2010s (2011–2020), and that a total temperature increase of 0.76 °C would occur in this decade compared with the 1970s (Table 2.3). Moreover, in the 2010s, the mean minimum and mean maximum temperatures would increase further by 0.19 and 0.16 °C, respectively, in comparison with the 2000s (2001–2010). Therefore, it was expected that the mean minimum temperature would increase more than the mean maximum temperature in the 2010s. Moreover, mean minimum and mean maximum temperature increases of 0.69 and 0.81 °C, respectively, would be observed in the country, in comparison with the 1970s (Table 2.3). Moreover, the spatial pattern of the temperature change highlighted that during the decade of 2011–2020, the changes in the mean temperature would vary spatially (ranging from 0.03 to 1.76 °C), and the greatest increase in the mean temperature would be observed in the northwestern part and in some areas in the central part of the country (Fig. 2.13a). In these areas, the mean temperature was predicted to rise by 0.91–1.76 °C in comparison with the 1970s (Fig. 2.12a). In contrast, the spatial pattern of the predicted decadal mean minimum temperature change showed that in 2011–2020, the maximum increase in the mean minimum temperature (0.81–2.23 °C) would be observed in the northwestern, northeastern and, to some extent, central parts of the country, in comparison with 1971–1980 (Fig. 2.12b). Hence, mean minimum temperature rises of more than 2 °C would be expected in some places in these parts of the country in 2011–2020 compared with 1971–1980 (Fig. 2.13b). A mean minimum temperature increase of up to 0.40 °C would be expected in the southeastern district and, to some extent, in the western and southwestern parts of the country. On the other hand, in Fig. 2.12c,

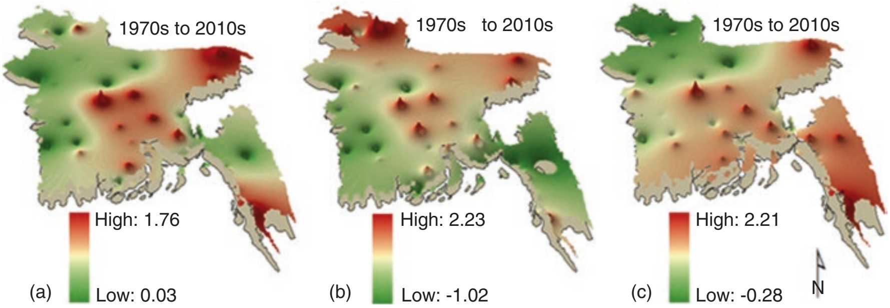

Fig. 2.13 Three-dimensional visualization of predicted changes in temperature in Bangladesh for the decade of 2011–2020 (the 2010s) relative to the decade of 1971–1980 (the 1970s). (**a**) Mean. (**b**) Mean minimum. (**c**) Mean maximum. The vertical scale is exaggerated

it is apparent that in the decade of 2011–2020 (the 2010s), the greatest increase in the mean maximum temperature (range 0.81–2.21 °C) was predicted to occur in the whole southern, eastern, and northeastern parts of the country, in comparison with 1971–1980 (the 1970s). Therefore, as with the mean minimum temperature, in some places in these areas, the mean maximum temperature increase would exceed 2 °C, in comparison with the 1971–1980 mean maximum temperature (Fig. 2.13c). Hence, these areas are the most vulnerable hot spots for warming of the country with respect to future temperature rises.

2.6.2 Predicted Rainfall Changes: 2010s (2011–2020)

Like the temperature, the rainfall in Bangladesh was simulated for the decade of 2011–2020. This simulation showed that during the period of 2011–2020 (the 2010s), the average rainfall would decrease by about 153 mm, in comparison with the previous decade (2001–2010). However, it was predicted that 119 mm more rainfall would occur in 2011–2020 (the 2010s) in comparison with the average rainfall in the decade of 1971–1980 (Table 2.4). It was also predicted that there would be small increases of about 8 mm in the premonsoon and postmonsoon rainfall in the decade of 2011–2020 compared with 2001–2010, but that the average rainfall in the pre- and postmonsoon seasons would be about 5 and 9 mm less, respectively, than the corresponding 1971–1980 (the 1970s) seasonal average rainfall (Table 2.4).

Furthermore, the rainfall predictions showed that in the monsoon season, the rainfall would decrease by about 175 mm in the decade of 2011–2020 compared with the previous decade (2001–2010). However, the predicted monsoon rainfall would be about 21 mm more than in the 1970s (Table 2.4). Hence, though there is high variability in rainfall, the predicted rainfall overall would show a huge shortfall of rain in Bangladesh, even in the monsoon season during 2011–2020, in comparison with the previous decade. Conversely, the spatial pattern of the decadal rainfall change demonstrated that in comparison with the 1970s (1971–1980), the average rainfall would decrease in the northwestern, western, and central districts, with the

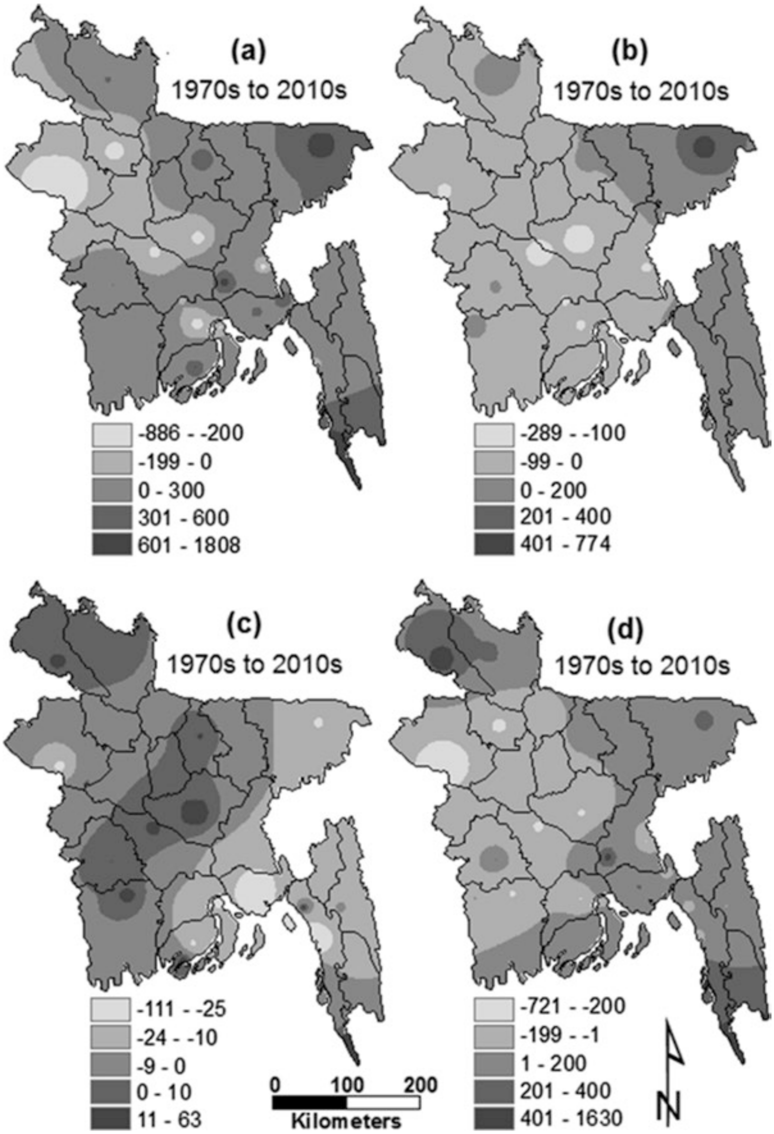

Fig. 2.14 Predicted changes in the average rainfall in Bangladesh for the decade of 2011–2020 (the 2010s) relative to the decade of 1971–1980 (the 1970s). (**a**) Decadal average. (**b**) Premonsoon (March–May). (**c**) Postmonsoon (November–February). (**d**) Monsoon (June–October)

greatest decrease of 200–886 mm being predicted to occur in the northwestern district (Rajshahi) (Fig. 2.14a). However, the average rainfall would increase markedly by 301–1808 mm in the northeastern and southeastern parts of the country, in comparison with the 1970s (Fig. 2.14a).

With regard to the decadal changes in seasonal rainfall, it was predicted that excluding the northeastern and southeastern parts of the country, the average

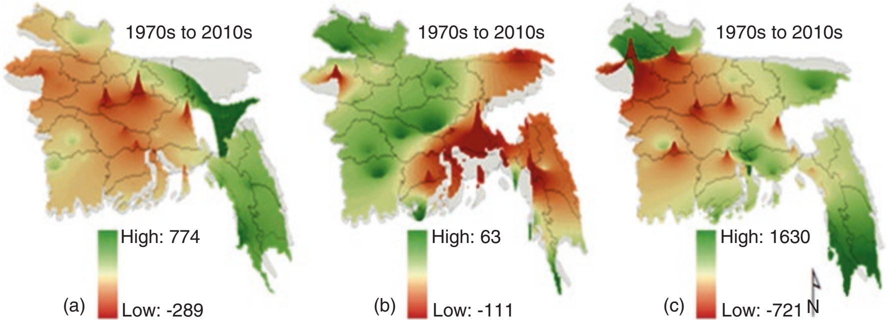

Fig. 2.15 Three-dimensional visualization of predicted changes in the seasonal average rainfall in Bangladesh for the decade of 2011–2020 (the 2010s), relative to the decade of 1971–1980 (the 1970s). (**a**) Premonsoon (March–May). (**b**) Postmonsoon (November–February). (**c**) Monsoon (June–October). The vertical scale is exaggerated

premonsoon rainfall would decline all over the country during 2011–2020, relative to the decade of 1971–1980, and that greater decreases of 100–289 mm would be observed in Rajshahi (in the northwestern part of the country) and in Dhaka and Faridpur (in the central part of the country) (Figs. 2.14b and 2.15a). Furthermore, it was predicted that during 2011–2020, the postmonsoon rainfall would decrease in almost all of the country except in some areas in the extreme northwestern, central, central northern, and western parts of the country. Increases of about 10–111 mm in postmonsoon rainfall would be observed in the southern and southeastern coastal districts, the southeastern hill district, and the northeastern part of the country (Figs. 2.14c and 2.15b). A greater decrease in the average postmonsoon rainfall would also be observed in the Rajshahi district in the northwestern part of the country (Fig. 2.15b). On the other hand, Fig. 2.14d shows that in comparison with 1971–1980 (the 1970s), the average monsoon rainfall would decline in the western, southwestern, central and, to some extent, northwestern parts of the country during 2011–2020. Greater decreases in monsoon rainfall would be observed in the Rajshahi and Bogra districts (in the northwestern part of the country) and in the Dhaka and Faridpur districts (in the central part of the country) (Fig. 2.15c). However, the average monsoon rainfall would increase in the extreme northwestern, northeastern, eastern, southeastern, and southern parts of the country, and greater increases of about 201–1630 mm would be observed in the extreme northwestern and southeastern districts during 2011–2020 compared with 1971–1980 (Fig. 2.14d).

Therefore, on the basis of the above findings and discussion, at a glance, it can be pointed out that the climate of Bangladesh is warming up, and the warming rate is much greater than the global average warming rate. Bangladesh is warming at a rate of 0.19 °C per decade, while the global average warming rate has been 0.13 °C per decade for the last 50 years (IPCC 2007). According to a Global Historical Climatology Network (GHCN) database analysis, the world has been warming at a rate of 0.16 °C per decade since 1950 (IPCC 2007). In Bangladesh, greater warming was observed in the decade of 2001–2010, and the increase in the maximum temperature was greater than the increase in the minimum temperature. Furthermore, the model predicted that the temperature would likely continue to rise in the decade of 2011–2020 and, as a result, warming would continue in the country and the mean temperature would increase by about 0.18 °C more than in 2001–2010, indicating that Bangladesh would be about 0.76 °C warmer in the decade of 2011–2020 than in 1971–1980. Moreover, the increases in temperature have varied geographically and inconsistently during 1981–2010. The northern parts of the country—particularly the northwestern and northeastern parts—are more susceptible to rises in the minimum temperature, while the southern parts of the country—particularly the southeastern and central southern parts—are more vulnerable to rises in the maximum temperature. It was anticipated that the rises in temperature in 2011–2020 would continue predominantly in these parts of the country where, in some areas, it was estimated that both the mean minimum and mean maximum temperature rises would exceed 2.0 °C (with rises of up to 2.23 and 2.21 °C in the mean minimum and mean maximum temperatures, respectively) in comparison with 1971–1980, indicating that these would be the hot spots in the country with respect to temperature rises. The prospect of such warming and its potential effects on the agricultural sector and groundwater resources in Bangladesh are alarming.

With regard to rainfall, as a whole, an uptrend in the rainfall in Bangladesh has been observed; it increased at a rate of 76 mm per decade during 1971–2010. Seasonally, the pre- and postmonsoon rainfall in Bangladesh declined sharply during the two decades of 1991–2010, and the seasonal rainfall exhibited decreasing trends in the pre- and postmonsoon seasons at rates of 8 and 4 mm per decade, respectively. However, the monsoon rainfall has increased in the country by 57 mm per decade. On the other hand, though the model predictions for 2011–2020 showed decreases in the average and monsoon rainfall and increases in the pre- and postmonsoon rainfall in comparison with the previous decade, surpluses of 119 mm in average rainfall and 21 mm in monsoon rainfall and, in contrast, shortfalls of 5 mm in premonsoon rainfall and 9 mm in postmonsoon rainfall would be observed in the decade of 2011–2020 compared with 1971–1980. Thus, it could be said that drier conditions would intensify in the pre- and postmonsoon seasons and the greatest decrease in rainfall would occur in the postmonsoon season in the decade of 2011–2020. Geographically, the rainfall in Bangladesh predominantly varies both in space and in time. The western, southwestern, southern and, to some extent, northwestern parts of the country are more vulnerable to decreases in premonsoon rainfall, which would persist in these parts of the country in 2011–2020. The southern, southeastern, eastern, and northwestern parts are susceptible to declines in postmonsoon rainfall, which would persist in these parts of the country in 2011–2020. Moreover, it was also projected that monsoon rainfall would decrease in the western, southwestern, central, and northwestern parts of the country in 2011–2020 compared with 1971–1980. Greater decreases (of 200–221 mm) in monsoon rainfall were projected for Rajshahi, Bogra, Dhaka, Faridpur, and Khulna in 2011–2020. Hence, these parts of the country would experience great impacts of global climate change in terms of the seasonal rainfall response to global warming. As a result, Bangladesh faces tremendous environmental problems such as flooding and droughts, caused by high variability in seasonal rainfall and seasonal scarcity of rainfall.

2.7 Impacts of Temperature and Rainfall Changes on Agriculture and Groundwater

At the time of the 2011 census, Bangladesh was a country of 144 million inhabitants and was the most densely populated country in the world, with about 976 persons per km^2 (BBS 2012). The population was projected to grow to 242.9 million by the year 2050 (UN 2012). Thus, there is immense pressure on land resources to provide more housing and more food production for the huge population. In Bangladesh, where agriculture is the largest sector of the economy, agricultural production is under pressure from increasing demands for food. Moreover, the recent climate variability and changes, particularly the warming and the high variability and seasonal scarcity of rainfall, make the situation even harsher. In spite of high-yielding inputs (seed, water, and fertilizer), crop production in Bangladesh mainly depends on temperature, rainfall, and normal flooding. The physical agro-environment in an area is a complex combination of the climate (mainly temperature and rainfall), soil, and physiographic environment in that area. In an agro-environment, because of temperature changes (mainly rises) and shifting of temperature zones, reductions in rainfall or heavy rainfall, and declines in soil moisture and nutrients, crop yields may change and agricultural productivity may be reduced because changes in temperature and rainfall have major impacts on soil moisture and fertility, and irrigation and water management are largely dependent on rainfall patterns. Low rainfall and high temperatures may reduce soil moisture and fertility in an area. In an agro-environment, groundwater storage is the most common source of water for use in dry areas; however, it must also be fed by rainfall. Higher evaporation–transpiration due to increased temperatures will mean that more water is required for irrigation. At the same time, higher temperatures will change the crop physiology and phenology, changing the total demand for and production of irrigation water. Therefore, marginal significant changes in temperature and rainfall can have extensive impacts on agriculture and water, and can consequently threaten food security and the overall socioeconomic environment of the country. According to an IPCC estimation, climate change and its impacts could cause Bangladesh to lose 17% of its land and 30% of its food production by 2050 (IPCC 2007). The pathways of the impacts of temperature and rainfall changes on agriculture and groundwater are illustrated in Fig. 2.16.

Bangladesh is warming at a greater rate than expected, and the rising temperatures at present and in the future will affect existing agricultural crops and could reduce the total production of the country. Several studies have indicated that a rise of 1–2 °C in temperature can cause sterility in rice spikelets and reduce yields of various types of high-yielding rice such as *aus*, *aman*, and *boro* in Bangladesh (NAPA 2005). International Rice Research Institute (IRRI) research findings show that there will be about a 20% decrease in the rice yield for every 1 °C increase in the growing season minimum temperature (Peng et al. 2004). Karim et al. (1998) stated that a 2 °C increase in temperature will reduce wheat production by about 61% and the yield of boro rice by 55–62% in Bangladesh. Moreover, according to a

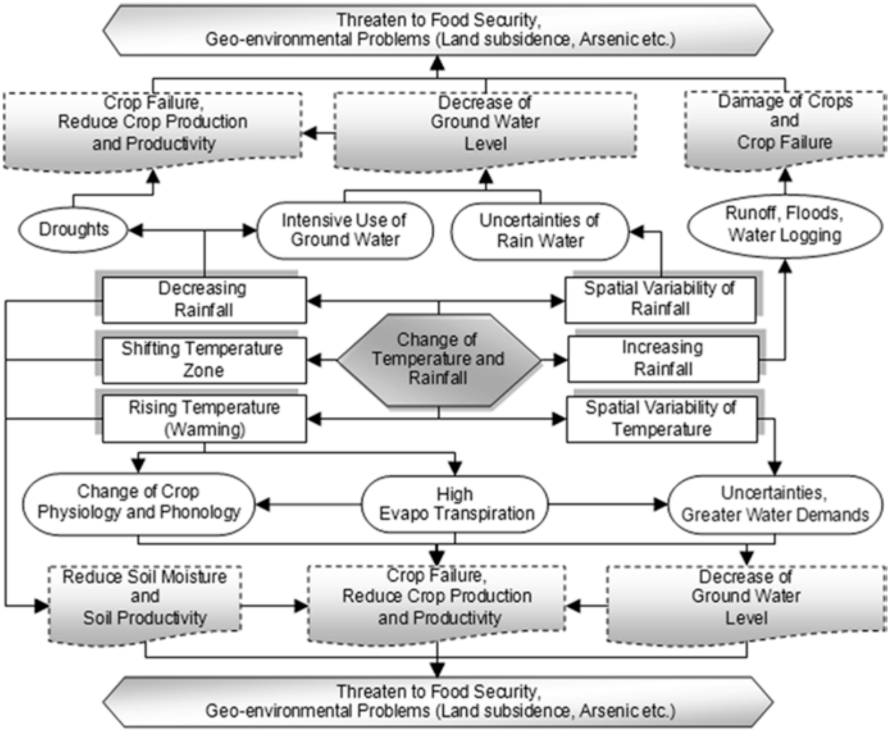

Fig. 2.16 Flowchart showing the pathways of the impacts of temperature and rainfall changes on agriculture and groundwater

statement from the National Adaptation Programme of Action (NAPA), 60% moisture stress could reduce the boro yield by 32%, and moisture stress would be more intense during the dry season, which could cause a great fall in the boro area under cultivation in the future (NAPA 2005). In these contexts, the cultivation and productivity of the crops that are grown in the northwestern, northeastern, southeastern, and central parts of the country will be affected seriously by 2020 and subsequently, since the minimum or maximum temperature rises in these areas either already exceed 2 °C or are on course to exceed 2 °C by 2020 (Figs. 2.5d, 2.6d, 2.12b, c, and 2.13b, c). Meanwhile, climate change is projected to exacerbate the water scarcity in Bangladesh, particularly in the pre- and postmonsoon seasons. Water stress is one of the constraints for sustainable development. This is particularly important in agricultural areas, where rainfall is the main water resource. Bangladesh has a distinct dry season (from November to May, in the pre- and postmonsoon seasons), and less rainfall during this period, due to climate change, leads to a decrease in the moisture content of the topsoil, as well as less recharging of the groundwater. The country will be highly susceptible to increases in moisture stress during dry periods, leading to increases in drought susceptibility in terms of both intensity and frequency (Rahman and Lateh 2016). High rainfall variability is an indicator of drought; therefore, areas with very high variability and low rainfall are prone to

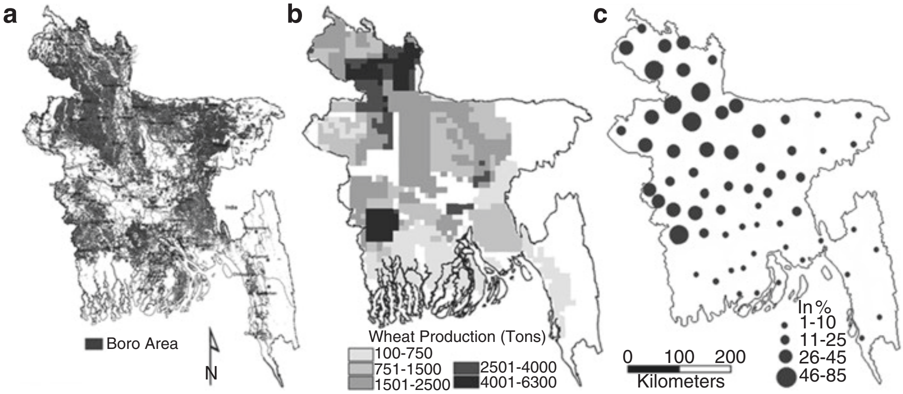

Fig. 2.17 (**a**) Boro rice area distribution (data source: CEGIS (Centre for Environment and Geographic Information Services), Dhaka, 2013). (**b**) Wheat area and production distribution (data source: CEGIS (Centre for Environment and Geographic Information Services), Dhaka, 2013). (**c**) Groundwater-fed irrigation (percentage of the total cultivated land in the district) (BBS 2010)

drought hazards. The shorter dry spells within the season have larger significance with respect to yield loss and livelihood patterns. The droughts of 1994–1995 in the northwestern part of Bangladesh led to a shortfall of rice and wheat production of about 3.5 million tons (Ahmed 2000), thus an additional 0.34 million tons of food grain was required to be imported at that time to meet the national demand (Biswas 1995). Thus, rice (boro) and wheat—which are grown with high intensity in the northwestern, western, southwestern, and southern parts of the country—will be affected seriously, and productivity may fall significantly, since in these parts of the country the pre- and postmonsoon rainfall has already declined significantly and this decline will continue further in the future; thus, drought-like conditions will persist (Figs. 2.9d; 2.10d; 2.14b, c; and 2.15a, b). Moreover, high variability and declines in the monsoon rainfall will also threaten the rain-fed agriculture of the country. Because of the high spatial variability in rainfall, in the monsoon season some parts of the country will suffer from sudden heavy floods, which will damage growing crops; on the other hand, declines in monsoon rain may increase the uncertainties of rain-fed crop growth and reduce crop productivity.

Bangladesh, which is predominantly an agrarian country, produces important seasonal crops such as boro rice and wheat during November to May; these crops are mainly grown in the northern, northwestern, western, central, and eastern parts of the country with high intensity (Fig. 2.17a, b). About 71% of the total rice production of the country is boro rice, which is mainly cultivated with irrigation support. It is estimated that about 4.5 million tons of extra rice will be needed for the increased population by 2020, and a large portion of this additional rice will come from expansion of irrigation-based boro rice cultivation (Shahid 2011). The northwestern part of Bangladesh is known as the “grain storage” of the country, and plays an important role in the country’s food security. However, the northern, northwestern, western, central, and eastern parts of the country are more vulnerable to rising temperatures and declining pre- and postmonsoon rain (in November–May), along with high spatial variability in seasonal rain. Groundwater is the major source of irrigation in these areas because of the lack of sufficient rainwater in the pre- and postmonsoon seasons. Consequently, the rate of groundwater use for irrigation in the northwestern, western, and northern parts is much higher than that in other parts of the country (Fig. 2.17c). About 61% of the cultivated area in Bangladesh is under irrigation (BBS 2010), and this is expected to increase in the future. Climate change will increase the irrigation rate or daily use of water for irrigation in the northwestern part of the country (Shahid 2011). Climate change scenarios (rising temperatures, high rainfall variability, and shortfalls in seasonal rain) will amplify the extraction of more groundwater during the dry season, which may cause a further decline in the groundwater level in the area. Rainfall is the single most important factor for success of crops in the farming areas, and increases in temperature result in greater water demands. During periods of water shortages, exploitation of more groundwater has already created an alarming situation in the Barind Tract (a Pleistocene terrace), located in the northwestern part of the country. The groundwater table has declined by at least 10 m in some areas in the Barind Tract during the last 14 years. In the Barind region on average, the groundwater table is going down by 2 feet per year (BADC 2012). The groundwater level depletion will hamper groundwater-based irrigation in the future. Moreover, the declining groundwater level may cause an increase in irrigation costs and economic losses for farmers. In irrigated areas, groundwater is exploited to meet dry season water requirements. However, groundwater levels are also associated with rainfall. Seasonal rainfall helps to recharge the groundwater. Thus, declines in the groundwater table due to overexploitation of groundwater and highly variable rainfall patterns could lead to crop damage and reduce winter crop coverage in the future, which may threaten the country's future food security.

2.8 Conclusions and Recommendations

Understanding climate change—particularly temperature and rainfall changes, and the impacts of these two most important climatic phenomena—is essential for building effective management policies and adaptation strategies to combat the adverse effects of climate change. This chapter has demonstrated how the temperature and rainfall in Bangladesh have already changed, and has illustrated the changes expected in the near future and the potential impacts of these changes on agriculture and groundwater in the country. Bangladesh's geographical location; high spatial, temporal, and seasonal variability in temperature and rainfall; high population pressure on the land; high level of poverty; inadequate infrastructural and institutional capacity; low economic strength; and lack of literacy have made the country highly vulnerable to climate change. Climate change is an important issue, and potential response measures for reducing the impacts of climate change need to be incorporated into the overall development planning process. As a whole, the climate of

Bangladesh is warming at an alarming rate; it was predicted that in the decade of 2011–2020, the climate would warm by about 0.18 °C in comparison with the preceding decade and by about 0.76 °C in comparison with the base decade of 1971–1980. The most alarming findings from this research were related to dry conditions and marked decreases in pre- and postmonsoon rainfall, which would persist and cause drought-like conditions in 2011–2020. In addition to these decreases in pre- and postmonsoon rainfall, it was projected that the monsoon rainfall would also decrease markedly in the southwestern, central, and northwestern parts of the country in 2011–2020. Overall, the northwestern, western, southwestern, central, and central southern parts of the country are more susceptible to climate change with respect to rising temperatures and high variability and shortfalls of rain, particularly pre- and postmonsoon rain. Therefore, the country would be highly susceptible to increased moisture stress during dry periods, leading to increased drought susceptibility in terms of both intensity and frequency; hence the country could be exposed to moderate to high water stress with climate change. The agricultural sector will face significant yield reductions and, given the country's increasing population and high demand for food, this will have an extremely adverse effect on food grain self-sufficiency and food security in the future. The impacts of climate change upon agricultural production could result in great hardship for the affected communities, with severe effects on the economy and the geo-environment of the country.

Therefore, the climate change mitigation policy, especially adaptation, will be an important part of the development policies of the country. To increase the resilience of agriculture and protect the groundwater from the effects of climate change, some effective recommendations can be made for Bangladesh, particularly for the vulnerable parts of the country. First and foremost, Bangladesh needs to prepare a policy for long-term adaptation to manage and mitigate the climate change impacts on agriculture and groundwater. It also needs to invest in capacity building to manage its agro-environment in a scientific way in response to climate change. Specifically, Bangladesh needs to focus on identifying climate change risk areas and initiate appropriate plans to cope with future agricultural problems caused by climate change; introduce and preferentially choose different crop varieties and species resistant to drought, flood, salinity, and heat; change the crop calendar with adjusted timing of crops; reduce groundwater irrigation and operate surface water–based irrigation systems; prepare sustainable land use plans based on land suitability and climate change; popularize cropping diversity efforts in drought-prone areas by encouraging cultivation of different heat-tolerant crops; introduce improved cropping patterns with promotion of alternative crops that can be harvested after a shorter duration; raise awareness of climate change; implement local adaptation action plans considering climate and disaster risks for agriculture; and build capacity within farming communities, research institutes, and agricultural extension services. These initiatives need to be incorporated into adaptation and mitigation policies and programs to combat the effects of future climate change.

In conclusion, the country of Bangladesh is highly vulnerable to climate change and urgently needs to develop climate-resilient agriculture, since agriculture is the determining factor for the food security of the country and for economic development as well. Things will get worse if we fail to initiate appropriate measures and programs right now to overcome the climate change problem. Therefore, actions must be taken locally, regionally, and globally, since climate change is a global issue. As part of the Rio+20 conference outcomes, it has been acknowledged that people are at the center of sustainable development, and an urgent commitment is needed to work toward environmental protection (UNCSD 2012).

References

Afshin S, Fahmi H, Alizadeh A, Sedghi H, Kaveh F (2011) Long term rainfall forecasting by integrated artificial neural network-fuzzy logic-wavelet model in Karoon basin. Sci Res Essays 6(6):1200–1208

Ahmad QK, Warrick RA (1996) The implications of climate and sea level change for Bangladesh. Kluwer Academic Publisher, Dordrecht

Ahmed AU (2000) Adaptability of Bangladesh's crop agriculture to climate change: possibilities and limitations. Asia Pac J Environ Dev 7(1):71–93

BADC (Bangladesh Agricultural Development Corporation) (2012) Annual report 2011–2012. BADC, Dhaka, Bangladesh

BBS (Bangladesh Bureau of Statistics) (2010) Statistical year book of Bangladesh. Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh

BBS (Bangladesh Bureau of Statistics) (2012) Population & housing census 2011: preliminary results. Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh, Dhaka

BBS (Bangladesh Bureau of Statistics) (2013) Statistical year book of Bangladesh. Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh

Biswas PR (1995) Food: stock, import and price. Dhaka Courier 11(34):9

Box GEP, Jenkins GM (1976) Time series analysis: forecasting and control. Holden-Day, Boca Raton

Boyle SJ, Tsanis IK, Kanaroglou PS (1998) Developing geographic information systems for land use impact assessment in flooding condition. J Water Resour Plan Manag ASCE 124(2):89–98

Dai FC, Lee CF, Zhang XH (2001) GIS based geo-environmental evaluation of urban land use planning: a case study. Eng Geol 91:257–271

Dash SK, Shekhar MS, Singh GP (2006) Simulation of Indian summer monsoon circulation and rainfall using RegCM3. Theor Appl Climatol 86(1–4):161–172

Diomede T, Davolio S, Marsigli C, Miglietta MM, Moscatello A, Papetti P, Paccagnella T, Buzzi A, Malguzzi P (2008) Discharge prediction based on multi model precipitation forecasts. Meteorog Atmos Phys 101(3–4):245–265

Divya MR (1995) Climate change and hydrology with emphasis on the Indian subcontinent. Hydrol Sci J 40:231–241

Esfahani AA, Friedel MJ (2014) Forecasting conditional climate-change using a hybrid approach. Environ Model Softw 52:83–97

GOB (Government of the People's Republic of Bangladesh) (2012) Sixth five year plan. Department of Disaster Management, Ministry of Disaster Management and Relief, Government of the People's Republic of Bangladesh

Hansen J, Sato M, Ruedy R, Lo K, Lea DW, Medina-Elizade M (2006) Global temperature change. Proc Natl Acad Sci USA 103:14288–14293

Hansen J, Sato M, Ruedy R (2013) Global temperature update through 2012. http://www.columbia.edu/~jeh1/mailings/2014/20140121_Temperature2013.pdf

Hartmann DL, KT AMG, Rusticucci M, Alexander LV, Brönnimann S, Charabi Y, Dentener FJ, Dlugokencky EJ, Easterling DR, Kaplan A, Soden BJ, Thorne PW, Wild M, Zhai PM (2013) Observations: atmosphere and surface. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis, contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

Hasan Z, Akhter S, Islam M (2014) Climate change and trend of rainfall in the south-east part of the coastal Bangladesh. Eur Sci J 10(2)

Hegerl GC, Zwiers FW et al (2007) Understanding and attributing climate change. In: Solomon S et al (eds) Climate change 2007: the physical science basis. Cambridge University Press, Cambridge, pp 663–745

Hulme M, Osborn TJ, Johns TC (1998) Precipitation sensitivity to global warming: comparison of observations with HADCM2 simulations. Geophys Res Lett 25:3379–3382

ILWIS (Integrated Land and Water Information System), version 3.3 (2005) Faculty of Geo-Information Science and Earth Observation of the University of Twente (ITC), Enschede

IPCC (Intergovernmental Panel on Climate Change) (2007) Technical summary of climate change 2007: the physical science basis, contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC (Intergovernmental Panel on Climate Change) (2014) Climate change 2014 impacts, adaptation and vulnerability. Fifth assessment report. Cambridge University Press, Cambridge

Jones PD (1995) Maximum and minimum temperature trends in Ireland, Italy, Thailand, Turkey and Bangladesh. Atmos Res 37(1–3):67–78

Karim Z, Hussain SG, Ahmed AU (1998) Climate change vulnerability of crop agriculture. In: Huq S, Karim Z, Asaduzzaman M, Mahtab F (eds) Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht, pp 39–54

Karmakar S, Shrestha ML (2000) Recent climate change in Bangladesh, SMRC No.4, SAARC Meteorological Research Centre (SMRC), Dhaka

Karmalkar AV, Bradley RS, Diaz HF (2011) Climate change in Central America and Mexico: regional climate model validation and climate change projections. Clim Dyn 37:605–629. https://doi.org/10.1007/s00382-011-1099-9

Kim BS, Hossein SZ, Choi G (2011) Evaluation of temporal-spatial precipitation variability and prediction using seasonal ARIMA model in Mongolia. KSCE J Civ Eng 15(5):917–925

Krivtsov V (2004) Investigations of indirect relationships in ecology and environmental sciences: a review and the implications for comparative theoretical ecosystem analysis. Ecol Model 174:37–54

Landscheidt T (2000) Solar wind near earth: indicator of variations in global temperature. In: Proceedings of the 1st solar and space weather European conference on the solar cycle and terrestrial climate, pp 497–500

Lee JH, Sohn KT (2007) Prediction of monthly mean surface air temperature in a region of China. Adv Atmos Sci 24:503–508. https://doi.org/10.1007/s00376-007-0503-1

Li J, Huang JF, Wang XZ (2006) A GIS based approach for estimating spatial distribution of seasonal temperature in Zhejiang Province, China. J Zhejiang Univ Sci A 7(4):647–656

Lin GF, Chen GR, Wu MC, Chou YC (2009) Effective forecasting of hourly typhoon rainfall using support vector machines. Water Resour Res 45:W08440

Marengo JA, Jones R, Alvesa LM, Valverde MC (2009) Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. Int J Climatol 29(15). https://doi.org/10.1002/joc.1863

Mia NM (2003) Variations of temperature of Bangladesh. In: Proceedings, SAARC seminars on climate variability in the south asian region and its impacts. SAARC Meteorological Research Centre (SMRC), Dhaka

Moore D, McCabe G (2003) Introduction to the practice of statistics. WH Freeman and Co., London
NAPA (National Adaptation Programme of Action) (2005) National Adaptation Programme of Action (NAPA): final report November 2005. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh
Paudyal GN (1996) An integrated GIS-numerical modelling system for advanced flood management. In: Proceedings of the international conference on water resources & environment research: towards the 21st century. Water Resources Research Centre, Kyoto University, Kyoto, Japan, pp 555–562
Peng S, Huang J, Sheehy JE, Laza RE, Visperas RM, Zhong X, Centeno GS, Khush GS, Cassman KG (2004) Rice yields decline with higher night temperature from global warming. Proc Natl Acad Sci USA 101:9971–9975
Rahman MR (2012) Cropping pattern planning for a flood prone area—a study using remote sensing and GIS to reduce the losses of climate change impact. In: Proceedings, Asia–Pacific Economic Cooperation (APEC) climate symposium, October 2012. St. Petersburg, Russia
Rahman MR, Lateh H (2016) Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. Environ Earth Sci 75:1026. https://doi.org/10.1007/s12665-016-5829-5
Rahman MR, Saha SK (2007) Flood hazard zonation—a GIS aided multicriteria evaluation approach (MCE) with remotely sensed data. Int J Geoinf 3(3):25–37
Rahman MR, Saha SK (2008) Remote sensing, spatial multi criteria evaluation (SMCE) and analytical hierarchy process (AHP) in optimal cropping pattern planning for a flood prone area. J Spat Sci 53(2):161–177
Rahman MR, Saha SK (2009) Spatial dynamics of cropland and cropping pattern change analysis using Landsat TM and IRS P6 LISS III satellite images with GIS. Geo-Spat Inf Sci 12(2)
Rahman MR, Shi ZH, Cai C (2009) Soil erosion hazard evaluation—an integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies. Ecol Model 220(13–14):1724–1734
Rahman MR, Shi ZH, Cai C (2014) Assessing regional environmental quality by integrated use of remote sensing, GIS, and spatial multi-criteria evaluation for prioritization of environmental restoration. Environ Monit Assess 186(8). https://doi.org/10.1007/s10661-014-3905-4
Rahmstorf SA, Cazenave JA, Church JE, Hansen RF, Keeling DE, Parker RC, Somerville J (2007) Recent climate observations compared to projections. Science 316. https://doi.org/10.1126/science.1136843
Rashid HE (1991) Geography of Bangladesh. University Press Ltd, Dhaka
Rodríguez-Puebla C, Encinas AH, Nieto S, Garmendia J (1998) Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula. Int J Climatol 18:299–316
Romilly P (2005) Time series modelling of global mean temperature for managerial decision-making. J Environ Manag 76:61–70
Shahid S (2010) Recent trends in the climate of Bangladesh. Clim Res 42(3):185–193
Shahid S (2011) Impact of climate change on irrigation water demand of dry season boro rice in northwest Bangladesh. Clim Chang 105:433–453. https://doi.org/10.1007/s10584-010-9895-5
Soon W, Baliunas S, Posmentier ES, Okeke P (2000) Variations of solar coronal hole area and terrestrial lower tropospheric air temperature from 1979 to mid-1998: astronomical forcing of change in earth's climate? New Astron 4(8):563–579
SPSS software, version 16 (2007) IBM Corporation, New York
Trenberth KE, Jones PD, Ambenje P, Bojariu R, Easterling D, Klein TA, Parker D, Rahimzadeh F, Renwick JA, Rusticucci M, Soden B, Zhai P (2007) Observations: surface and atmospheric climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Cambridge University Press, Cambridge/New York

UN (United Nations) (2012) World population prospects: the 2012 revision, population division of the Department of the Economic and Social Affairs of the United Nations Secretariat http://esa.un.org/unpd/wpp/index.htm

UNCSD (United Nations Commission on Sustainable Development) (2012). Rio+20 United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil, 20–22 June 2012

UNFCCC (United Nations Framework Convention on Climate Change) (2009) The Copenhagen accord of 18 December 2009, 2/CP.15, Bonn, Germany

WMO (2014) Press release No. 983. World Meteorological Organization, Geneva, Switzerland

Yu B, Neil DT (1993) Long-term variations in regional rainfall in the south-west of Western Australia and the difference between average and high intensity rainfalls. Int J Climatol 13:77–88

Yurekli K, Simsek H, Cemek B, Karaman S (2007) Simulating climatic variables by using stochastic approach. Build Environ 42:3493–3499

Chapter 3
Vulnerability of Aquaculture-Based Fish Production Systems to the Impacts of Climate Change: Insights from Inland Waters in Bangladesh

Md. Sirajul Islam and Md. Enamul Hoq

Abstract Aquaculture plays a vital role in the agro-based economy of Bangladesh through its contributions to employment and income generation, and through provision of food and nutrition for the people of the country. In addition to 1.32 million full-time fisherfolk, 14.7 million people are involved in aquaculture in Bangladesh. Though all of Bangladesh is more or less prone to adverse impacts of climate change, the northern and northwestern drought-prone areas and coastal regions are particularly sensitive because of specific hydrometeorological, climatic, and human-induced hazards. Erratic rain, irregular rainfall, and temperature changes affect the readiness of fish for breeding. In 2009–2010, extreme weather caused late maturity of fish for breeding in the Mymensingh region—the largest aquaculture zone in the country. Fish farmers are struggling with higher production costs due to water scarcity, higher and lower temperatures, day–night temperature fluctuations, and lower productivity of ponds. Hatchery production has also declined because of such causes. The Bangladesh Climate Change Strategy and Action Plan have considered the fisheries sector as one of the potentially most threatened areas to be targeted. The fisheries sector differs from mainstream agriculture and has distinct interactions and needs with respect to climate change. Capture fisheries have unique features of natural resource harvesting linked with ecosystem production processes. Aquaculture complements and increasingly adds to the supply and, though it is more similar to agriculture in its interactions, it has important links with capture fisheries. Most indigenous fish are migratory and rely on seasonal flooding for spawning cues and access to larval rearing habitats (floodplains). Habitat destruction also has a significant impact, as does lack of flooding/rain—an obvious impact of climate change in the last few decades. Since the economic impacts of climate

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change will have to be borne by individuals, communities, and the government, there is a need to evolve a climate-resilient development strategy involving all of the relevant sectors, including aquaculture. Only eco-friendly, improved, and innovative management practices with insights into technological, environmental, and socioeconomic concerns can mitigate the impact of climate change on aquaculture in Bangladesh and ensure sustainable fish diversity and production.

3.1 Introduction

Bangladesh is located between the latitudes of 20° 34′ and 26° 38′ N and between the longitudes of 88° 01′ and 92° 41′ E. The country is bordered by India to the west, north, and northeast; Myanmar to the southeast; and the Bay of Bengal to the south. The area of the country is 147,570 km^2, 7% of which is permanently underwater (CIA 2008). The country enjoys a generally warm and humid subtropical environment with a mild winter from October to March, a hot and humid summer from March to June, and a warm and humid rainy monsoon from June to October. Fish play an important role for the population of Bangladesh, as indicated by the proverb "*machte bhate Bangali*" ("fish and rice make a Bengali"). Situated in the delta of the Brahmaputra, Meghna, and Ganges Rivers, Bangladesh has favorable climatic, water, and soil conditions for inland fisheries and aquaculture. In 2012, the fisheries sector (including aquaculture and capture fisheries) contributed 4.4% to the country's gross domestic product (GDP) and aquaculture alone contributed about 55% of total fish production. Several aquaculture systems have been attempted in Bangladesh, but not all have been of equal intensity, and not all ponds are suitable for all types of aquaculture. The fisheries in Bangladesh are highly diverse in terms of resource types and species. In inland fisheries, Bangladesh ranks third among the top ten fish-producing countries in the world. China is the top producer with 2.4 million metric tons of fish production, India is second with 0.81 million metric tons, and Bangladesh is third with 0.73 million metric tons (FAO 2007). Considering the resources of China and India, Bangladesh's fish production is remarkable.

Of the major long-term environmental concerns, global climate change is the most serious issue likely to affect Bangladesh over the coming decades. Although the impacts of global warming are still far from precisely predictable, the prospect is sufficiently probable and alarming to warrant precautionary action at both the national and international levels. The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) (BCCSAP 2009) has considered the fisheries sector as potentially one of the most promising ones to stimulate, and the National Plan for Disaster Management (NPDM) (NPDM 2010–2015) has suggested taking appropriate actions and measures to protect the fisheries against disasters. Climate change in Bangladesh has shown its impact on three major subsectors of the fisheries: the closed water, open water, and marine subsectors. Obviously, the climate change impacts will be different for these three different fisheries subsectors and thus a wide range of livelihoods in different situations. The sector will be affected by several issues: ecosystem change, population change, and organism reactions.

This chapter outlines the main climate change impacts that are of concern to inland fisheries in Bangladesh. These impacts are then discussed in relation to their adverse effects on different aspects of inland fisheries. Finally, actions that mitigate the impacts of climate variability in general are outlined, as well as those that target climate change specifically.

3.1.1 Fisheries of Bangladesh

As in many other Asian countries, aquaculture production in Bangladesh has rapidly increased in recent years because of adoption of various improved aquaculture technologies. So, aquaculture is now one of the dominant subsectors, which alone contributed 54% of the total fish production in 2012–2013 (Table 3.1). Hence, aquaculture is a subsector making a major impact on production, economic development, and the livelihood of the people of the country. The gross national product (GNP) of fish (in 2011 values) was BDT 269.928 billion in 2010–2011. The resources are broadly divided into inland water and marine water subsectors. Inland waters are further divided into openwater fisheries (which include rivers, the Sundarbans, *beels*, Kaptai Lake, and floodplains) and closed water fisheries (which

Table 3.1 Water resources and fish production in 2012–2013

Water resources	Area (ha)	Production (metric tons)
1. Inland fisheries		
(a) Open water bodies		
Floodplains	2,702,304	701,000
Rivers and estuaries	853,863	147,000
Sundarbans	177,700	16,000
*Beels*and *baors*	114,161	88,000
Kaptai Lake	68,800	9000
Total open water	3,916,828	961,000
(b) Closed water bodies		
Ponds	371,309	1,447,000
Seasonal water bodies	130,488	201,000
Oxbow lakes	5488	6000
Shrimp farms	275,274	206,000
Total closed water	782,559	1,860,000
Inland totals (a + b)	4,699,387	2,821,000
2. Marine fisheries		
Industrial (trawling)		73,000
Artisanal		516,000
Marine totals	16,606,600	589,000
Country totals	21,305,987	3,410,000

Source: DoF 2014

include ponds, seasonal water bodies, *baors*, and shrimp farms). In 2012–2013 the total fish production of Bangladesh was 3,410,254 metric tons (DoF 2014), of which 82.73% was from the inland fisheries sector and the rest (17.3%) was from the marine fisheries sector. Of the inland fisheries sector, 28.2% was from open water fisheries and 54.5% was from closed water fisheries—mainly aquaculture.

In the past decade a wide range of changes affecting fisheries have taken place, including very large increases in fish production from all forms of pond aquaculture, declines in most capture fisheries, encroachment and degradation of natural assets, rapid urbanization, infrastructure investments that have negatively impacted fisheries, and increased pollution. A major constraint to fish production is reduced dry season surface water flows in the Ganges and other rivers, related to the operation of the Farakka Barrage, unregulated water extraction for irrigation, and the impacts of a large number of flood control, drainage, and irrigation (FCDI) projects. Drought and siltation together are reducing overwintering habitats for fish species, resulting in less recruitment in grazing fields for growth out in open water inland fisheries. Moreover, reduced water flow in the Ganges River basin has resulted in severe depletion of fisheries. Because of the decreases in groundwater and surface water, tremendous pressure has been exerted on wetlands to convert them to agricultural land, resulting in a serious decline in the number of fish species and fish production as a whole. Indeed, there may be nowhere in the world where the effects of climate change and other activities on fisheries and aquaculture are more apparent than in Bangladesh.

3.1.2 Aquaculture Potential and Opportunities

The manifold increase in aquaculture production over recent years can be attributed to (1) the generation of new technologies by various national research institutes such as the Bangladesh Fisheries Research Institute (BFRI) and Consultative Group on International Agricultural Research (CGIAR) institutes such as WorldFish; (2) the dissemination efforts of the Department of Fisheries (DoF), BFRI, and nongovernmental organizations (NGOs); and (3) special projects such as the Mymensingh Aquaculture Extension Project, Northwest Fisheries Project, Development of Sustainable Aquaculture Project, and other aquaculture projects coordinated by WorldFish; and (4) numerous technology dissemination projects conducted by various NGOs (Fig. 3.1). Freshwater pond aquaculture is the dominant fisheries subsector in Bangladesh, contributing about 48% of total fish production and about 89% of total aquaculture production in 2012–2013 (DoF 2014). The yield from cultured ponds increased marginally from an average of 3.0 metric tons per hectare during the mid-1990s to 3.9 metric tons per hectare a decade later. Although freshwater aquaculture has contributed substantially to the growth in total fish production, its full potential has not yet been explored, as indicated by the extensive area of derelict ponds and the dominance of semi-intensive pond culture. The objective of the development of the fisheries sector is to rehabilitate and bring underutilized pond resources (including cultivable and derelict ponds and untapped rice fields) under

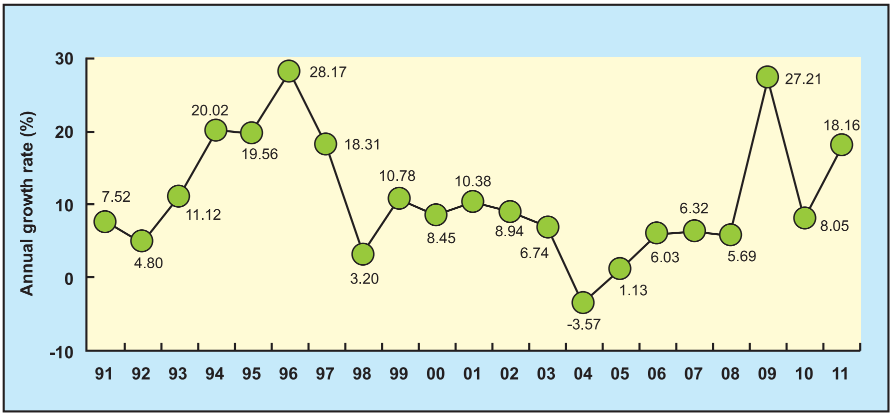

Fig. 3.1 Annual growth rate (%) of aquaculture during 1991–2011. (Source: DoF 2014)

fish culture at an intensity similar to that found in cultured ponds (DoF-BARC 2001). It is believed that the area of ponds is much greater than has been estimated; land is taken out of agricultural production every day for residential construction, with ponds being created to supply soil. At the same time, rice paddies are being converted into permanent ponds for the more profitable activity of fish culture (Karim et al. 2006). In 2001 the Department of Fisheries–Bangladesh Agricultural Research Council (DoF-BARC) (2001) estimated the total pond area to be 320,000 hectares and projected that it would increase to 411,488 hectares by 2010–2011. Interestingly, a more recent estimate by DoF (2007) put the pond area at 265,500 hectares. Regardless of the discrepancies in the estimates of the pond area, there is no doubt that Bangladesh has the potential to increase aquaculture production through area expansion and intensification. Further potential exists for increasing freshwater aquaculture production by improving productivity. Cultured pond operators adopt only some of the recommended technologies and, in 2005/2006, had an average productivity of 3.24 metric tons per hectare, which is much lower than in other Asian countries (Karim et al. 2006). Aquaculture technology developed through research has the potential to increase productivity above the levels that average farmers currently achieve.

3.1.3 Contribution of Inland Fisheries to Food Security, Nutrition, and Employment

Fish provides food for millions of poor people in Bangladesh, where it is regarded as “poor people’s protein.” In fact, fish has long been the main source of protein in Bangladesh. Fish is also an important source of vitamins and micronutrients for the poor in Bangladesh (Thilsted et al. 1997). Bangladeshis, like most Asians, consume rice as their staple food and supplement it with substantial amounts of vegetables, tubers, and pulses, and reasonable amounts of animal protein, mainly fish and meat.

The fisheries sector provides livelihoods and income for the vast majority of the poor in Bangladesh. It plays a particularly important role among disadvantaged groups as a main or supplementary source of employment, livelihood, and income. Most poor Bangladeshis live in rural areas with very limited employment opportunities. The *Poverty Reduction Strategy Paper* and National Fisheries Strategy have indicated that income-generating opportunities for rural households are most promising in the fisheries sector (PC 2005). Overall, the impacts of aquaculture development in Bangladesh appear to have a positive effect. The changes brought about by the cultivation of fish have been profound. The most significant change has been food security through aquaculture. Before fish culture a large number of farming households lived below the poverty line; after starting aquaculture they have increased their food consumption.

3.1.4 Issues, Strategies, and Challenges of the Inland Fisheries Sector

The topography of Bangladesh is predominantly characterized by the delta—a flat alluvial plain less than 10 m above sea level, which occupies 93% of the land area (some mountains occupy part of the southeast). About 88% of the arable land is floodplain, which receives alluvial deposits every year as some 300 rivers overflow during the wet monsoon (BBS 2006).

The fisheries sector is very vast and is dominated by the natural fisheries. A major part of this subsector is a common property resource managed by many agencies/private individuals, other than fisheries. As a result, these water bodies are not used as a primary source of fish production. Rather, they are used for revenue generation, irrigation, and other secondary purposes. The management of open water fisheries is thus a complex and complicated issue. Presently, inland capture fisheries generate 0.96 million metric tons of fish, representing about 28% of the total production. Hilsa is the largest single fishery in this subsector, with an annual production of about 0.35 million metric tons (DoF 2014). The natural fisheries in the inland open waters have been in decline for a variety of reasons, of which the following are the most important:

- Overexploitation and indiscriminate killing of juveniles, due to unregulated fishing pressure and total capture by complete drying up of water bodies in the dry season
- Reduction, alteration, and degradation of natural habitats, due to human development activities and aquatic pollution, reducing natural populations through retardation of reproduction potential and growth
- Siltation of river basins and floodplains, affecting aquatic habitats, feeding grounds, and migration paths, and leading to loss of biodiversity
- Loss and destruction of breeding and nursery grounds, due to flood control, water management, roads, and river embankments, hampering natural recruitment

- Progressive conversion of silted-up open water bodies into cropland and abstraction of waters for crop irrigation, depriving fish of sufficient water for breeding and feeding
- Lack of alternative livelihoods for fisherfolk, resulting in injudicious fishing and overexploitation
- Pollution of aquatic ecosystems, due to industrial and domestic waste and pesticides, seriously affecting fisheries

The management of inland open waters is very complex, yet this is still the largest source of fish for the common people of Bangladesh. Therefore, even a small increase in growth in this sector is bound to make a major impact. Attempts at protection, rehabilitation, and maintenance of water bodies, and conservation of aquatic biodiversity, have so far not been undertaken seriously. Since there is open access for fishing in open water bodies, increased production from this resource will improve both consumption and livelihoods, particularly for subsistence fisherfolk.

3.2 Inland Fisheries in Relation to Climate Change

Bangladesh is widely recognized as one of the countries that is most vulnerable to climate change. On the basis of deaths, the United Nations Development Program (UNDP) has ranked Bangladesh as the country most vulnerable to tropical cyclones and the sixth most vulnerable to floods (Table 3.2). It experiences frequent natural disasters, which cause loss of life, damage to infrastructure and economic assets, and adverse impacts on the lives and livelihoods of the people. The country's population is projected to grow to over 200 million by 2050 (WB and BCAS 1998). Its high population density implies that more people live in areas vulnerable to climate change; therefore, this could limit the capacity of people to move in response to this situation. Climate change is a long-term phenomenon, and the scenario for Bangladesh developed under the United States Country Study Program and World Bank Study show the potential effects of climate change. They are considered here for the years 2030 and 2050 (Table 3.3).

Table 3.2 Countries most vulnerable to tropical cyclones and floods

Tropical cyclones			Floods		
Rank	Country	Deaths/100,000[a]	Rank	Country	Deaths/100,000[a]
1	Bangladesh	32.1	1	Venezuela	4.9
2	India	20.2	2	Afghanistan	4.3
3	Philippines	8.3	3	Pakistan	2.2
4	Honduras	7.3	4	China	1.4
5	Vietnam	5.5	5	India	1.2
6	China	2.8	6	Bangladesh	1.1

Source: UNDP 2004

[a]Deaths/100,000 people exposed to the event

Table 3.3 Climate change scenarios for Bangladesh in 2030 and 2050

Year	Sea level rise (cm)	Temperature increase (°C)	Precipitation fluctuation in comparison with 1990 (%)	Changes in evaporation (%)
2030	30	+0.7 in monsoon	–3 in winter	+0.9 in winter
		+1.3 in winter	+11 in monsoon	+15.8 in monsoon
2050	50	+1.1 in monsoon	–37 in winter	0 in winter
		+1.8 in winter	+28 in monsoon	16.7 in monsoon

Source: UNFCCC 1997

Table 3.4 Tidal surge trends at three coastal stations

Tidal station	Region	Latitude (N)	Longitude (E)	Datum (m)	Trend (mm/year)
Hiron Point	Western	21°48′	89°28′	3.784	4.0
Char Changa	Central	22°08′	91°06′	4.996	6.0
Cox's Bazar	Eastern	21°26′	91°59′	4.836	7.8

Many of the projected impacts of climate change will reinforce the baseline environmental, socioeconomic, and demographic stresses already faced by Bangladesh. Climate change is likely to result in:

- Increased flooding, in terms of both its extent and frequency, associated with sea level rise, greater monsoon precipitation, and increased glacial melt
- Increased vulnerability to cyclones and storm surges
- Increased moisture stress during dry periods, leading to increased drought
- Increased salinity intrusion
- Greater temperature extremes

In 2009 Bangladesh experienced the lowest rainfall in the past 15 years (since 1994), with experts attributing the erratic pattern to global climatic change. The country recorded 47,447 mm of rainfall in June, July, August, and September in 2009, in comparison with 56,163 mm, 66,520 mm, and 60,551 mm in the same periods in 2008, 2007, and 2008, respectively. Excessive rainfall in several parts of the country affected the standing aman crops, while farmers complained that less rainfall affected major crops in some areas (Karim et al. 2006). The impacts of drought, among many other factors, have included more intense pressure on crop, livestock, and fish since the 1970s in almost all areas, especially in northern Bengal; lower water quality, less availability of water for aquaculture, and reduced production of freshwater fish; loss of wild and cultured fish stocks; conflicts among different water users; and irrigation of paddy fields being prioritized.

A study by the South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre (SMRC) (SMRC 2003) revealed that the rate of sea level rise on the Bangladesh coast during the last 22 years was many times higher than the mean rate of global sea level rise over 100 years, showing the important effect of regional tectonic subsidence (Table 3.4). The IPCC 3rd Assessment Report estimated that the global rise in sea level from 1990 to 2100 would be between 9 and 88 cm. It is important to note that analysis of the impacts of sea level rise in coastal areas needs to incorporate the dynamic nature of its morphology and formation process. Bangladesh is a dynamic delta, and its landmass is still growing by gradual deposition of sediment. The average sediment accumulation rate for the last few hundred years in the coastal areas of Bangladesh has been 5–6 mm/year. Therefore, while the sea level rises by 7 mm/year, the land rises by 5–6 mm/year. From the above figures it may appear that the relative sea level rise in the coastal areas of Bangladesh is 1–2 mm/year, but a significant implication of the sea level rise is loss of productive land that has formed over time (GoB and UNDP 2009).

A sea level rise would change the location of the river estuary, causing great changes in fish habitats and breeding grounds. Penaeid prawns breed and develop in brackish water, where salt water and freshwater mix. A sea level rise would turn this interface backward, changing the natural habitat of the prawn population. There are about 60 shrimp hatcheries and 120 shrimp processing plants in the coastal zone of Bangladesh. As this zone is vulnerable to sea level rise, shrimp hatcheries and shrimp fields are also vulnerable to this phenomenon. However, the sea level rise is helping shrimp farming by introducing salinity in the coastal area, but it is also harmful for other crops. If we consider another sea level rise phenomenon—for instance flooding—it is doing massive harm to the sector by overflowing shrimp ponds and setting the shrimps free into the open water. In addition, the high projected magnitude of the sea level rise will inundate the present shrimp ponds and will destroy this prospective foreign exchange–earning sector of the Bangladesh economy (2% of total exports).

3.2.1 Inland Water Environment and Aquaculture

Flooding is an annual occurrence in Bangladesh and occurs mainly during the monsoon months of July to September, when the rainfall is at its maximum intensity and the rivers are all swollen with water from the melting snow of their Himalayan headwaters. One major consequence of the meandering nature of the rivers is the erosion of riverbanks and also accretion of land either mid-river or at the mouth of the river in the estuarine region. The floods bring with them sediment and silt, which help to increase the fertility of the soil. The farmer's perception of floods as being beneficial or harmful, however, depends mainly on the depth of the water and the duration of the inundation. If standing crops are able to remain above the water level and the inundation does not last more than a critical period, then, in fact, the farmer regards the floods as being beneficial. It is only when the water depth is sufficient to inundate the crops and homesteads and lasts for some time that actual damage to crops, livestock, and cultured fisheries occurs. Thus the widespread construction of flood prevention embankments throughout the country is a mixed blessing, as they prevent not only the damaging effects of the floods but also their beneficial effects. These serve as flood storage in the monsoon season and help contribute water to both the soil and the groundwater aquifers, supporting the ecosystem and maintaining habitats. In the absence of floodplain water storage and corresponding sedimentation, additional siltation may occur in the lower river system. While this may counteract the negative effects of sea level rise, it will also restrict drainage and backup floodwater. Floodplains also sustain postmonsoon river flows through gradual release of stored floodwaters. Floodplains and deltas provide grazing land for livestock and habitats for wildlife, and are important spawning grounds for many species of fish. Inundation of floodplains triggers migration and breeding of *beel*-dwelling fish species.

The floodplains of the country are now among the fastest disappearing of all ecological systems. Fishing pressure from the ever-growing population has increased dramatically and has seriously affected the abundance of nearly half of the inland fish of Bangladesh, particularly small fish such as minor carp, loaches, barbs, minnows, small catfish, parchlets, gobies, featherbacks, snakeheads, and eels (Hossain and Naser 2014). As a whole, degradation of wetlands has caused several problems, including:

- Extinction and reduction of fish and other wildlife
- Loss of many indigenous aquatic plants, herbs, shrubs, and weeds
- Loss of natural water reservoirs and their resultant benefits
- Increase in the occurrence of flooding
- Loss of natural soil nutrients
- Degeneration of ecosystems, occupations, socioeconomic institutions, and cultures

3.2.2 Impact of Water Development Projects

In Bangladesh, since 1960, hundreds of water resource development projects have been implemented, such as flood control and drainage (FCD);flood control, drainage, and irrigation (FCDI); closures of rivers and canals; channel diversions; withdrawal of water from rivers and natural depressions for irrigation in the dry season; etc. (Ali 1999). Through implementation of these projects the entire country has been converted into a series of polders with earthen embankments. The possible impacts of these development projects on fish and aquatic resources were not considered at the time of their planning, design, and implementation. The natural migration and recruitment of fish and other aquatic animals from rivers to floodplains, or vice versa, have been obstructed. As a result, many fish and prawn species in rivers, on floodplains, and in estuaries have become threatened or endangered. At the same time, the overall livelihoods of the people surrounding these water bodies have been affected severely. The Jamuna Multipurpose Bridge, which was constructed recently, has had serious impacts, particularly on the existing ecosystem and capture fisheries production, including fish spawn collection in Jamuna River, both upstream and downstream from the bridge site, and other adjacent rivers and floodplains downstream (Ali 1999). The negative and deleterious impacts of water resource development projects on fish and fisheries in Bangladesh have been studied regionally under the Flood Action Plan (FAP) of the Ministry of Water Resources (MWR). The Northwest Regional Study conducted under FAP-2 (1992) revealed that fisheries have been identified as one of the sectors that are worst affected by flood control developments in Bangladesh. It was estimated that the northwestern region's contribution to national fish production fell from 14% in 1983–1984 to 10% in 1988–1989; in particular, the riverine fish production decreased from 24,500 metric tons in 1983–1984 to 3940 metric tons in 1988–1989. Construction of a large number of flood protection embankments around and within the floodplain areas under FCD and FCDI projects adversely affected the ecosystem and habitats of fish populations. It was estimated that 2.0 million hectares of floodplains would be lost to fisheries because of water development projects by the year 2005, with a loss of production of over 1.0 million metric tons per year (Mazid 2002).

3.2.3 Impacts on Livelihood and Employment of Fisherfolk

In Bangladesh, the fisheries sector once provided full-time employment for an estimated 2.5 million fisherfolk. In addition, it is estimated that over 13 million people were partly dependent on fishing, e.g., part-time fishing for family subsistence. Capture fisheries are relatively open access for poorer and landless people, and become a source of last-resort income. Since 1990, full-time employment in this sector has been reduced because of the reduction of open water areas and declining catch per unit effort. Therefore, the number of full-time fisherfolk has gone down to below 1.5 million, and the number of part-time fisherfolk is increasing day by day in the peak fishing time. The increase in part-time fisherfolk and the declining catch are leading the poor to secure their livelihoods from fishing activities alone.

Innumerable rivers in southwestern Bangladesh form a net-like pattern. The rivers heavily influence the lifestyle of the people in the region. Human settlements here have grown on the riverbanks over the ages. Then again, the major rivers have always shifted their directions, leaving human settlements back on their old banks. Over the years, many rivers in this region have lost their navigability for various reasons. Because of poor flow downstream, the rivers in the upper territory have lost their navigability. Similarly, the rivers flowing down to Khulna and Satkhira have become dry and filledup with sediment. Farmers now grow paddy in the beds of rivers that once used to be fast flowing.

3.2.4 Pollution and Contamination

Aquatic resources in Bangladesh are subject to a range of contaminants, which may adversely impact ecosystems, biodiversity, human use, and productive potential, and may also cause chronic or acute human health problems (Table 3.5). Chemical contamination is the most direct acting; in some cases it may lead to dangerous accumulation and concentration in food chains, and it can disrupt life-cycles and survival opportunities for key species. Other common impacts relate to physical damage (e.g., smothering or reduced light access for photosynthesis)and organic

Table 3.5 Water pollutants and their impact on fish

Source of pollution	Impact
Sewage: flow of rivers and tributaries	Excessive non-treated matter
	Excessive fertilization of water
	Production of poisonous species of plankton
	Toxic concentration in fisheries products for human consumption
Industrial effluent	Accumulation of mercury components in fish
1. Discharge of heavy metals such as mercury, cadmium, and copper	Production of mercury toxicity in fish
	Toxicity for human consumption
	Accumulation in biological food chain of fish
2. Halogenated hydrocarbons	Contamination of the human body from consumption of fish
Microbial contamination	Ulcerative diseases in aquatic animals
	Massive loss of fish
	Degradation of fisheries
Aerial fallout	Production of radioactive and noxious materials
	Danger to aquatic animals and humans who consume aquatic organisms

enrichment, leading to deoxygenation and loss of a range of species. Degraded ecosystems may survive but can be greatly compromised in their ability to provide usable water or support productive fisheries. The decreasing availability of fish from some waters can be ascribed to inadequate levels of dissolved oxygen, caused by agro-industrial effluent.

3.3 Climate Change Vulnerability of Fisheries and Aquaculture

3.3.1 Floodplain Fisheries

The open water fisheries production system is a natural uncultivated production system composed of self-reproducing and self-sustaining populations of some 257 species of finfish and 20 species of prawns. Breeding, multiplication, and sustenance of the populations of fish and prawns in the open inland waters are tightly bound to the annual flooding caused by rains during the monsoon. All open water components—i.e., rivers, canals, *beels*, and floodplains—become connected with each other and turn into an integrated single biological production system during the monsoon months. This integrated single production system lasts for up to 5 months, providing suitable aquatic habitats for reproduction, migration, feeding, and growth of aquatic organisms (Fig. 3.2).

In this integrated single production system, the inundated floodplains during the 5-month inundation play the most significant role in expanding and maintaining the

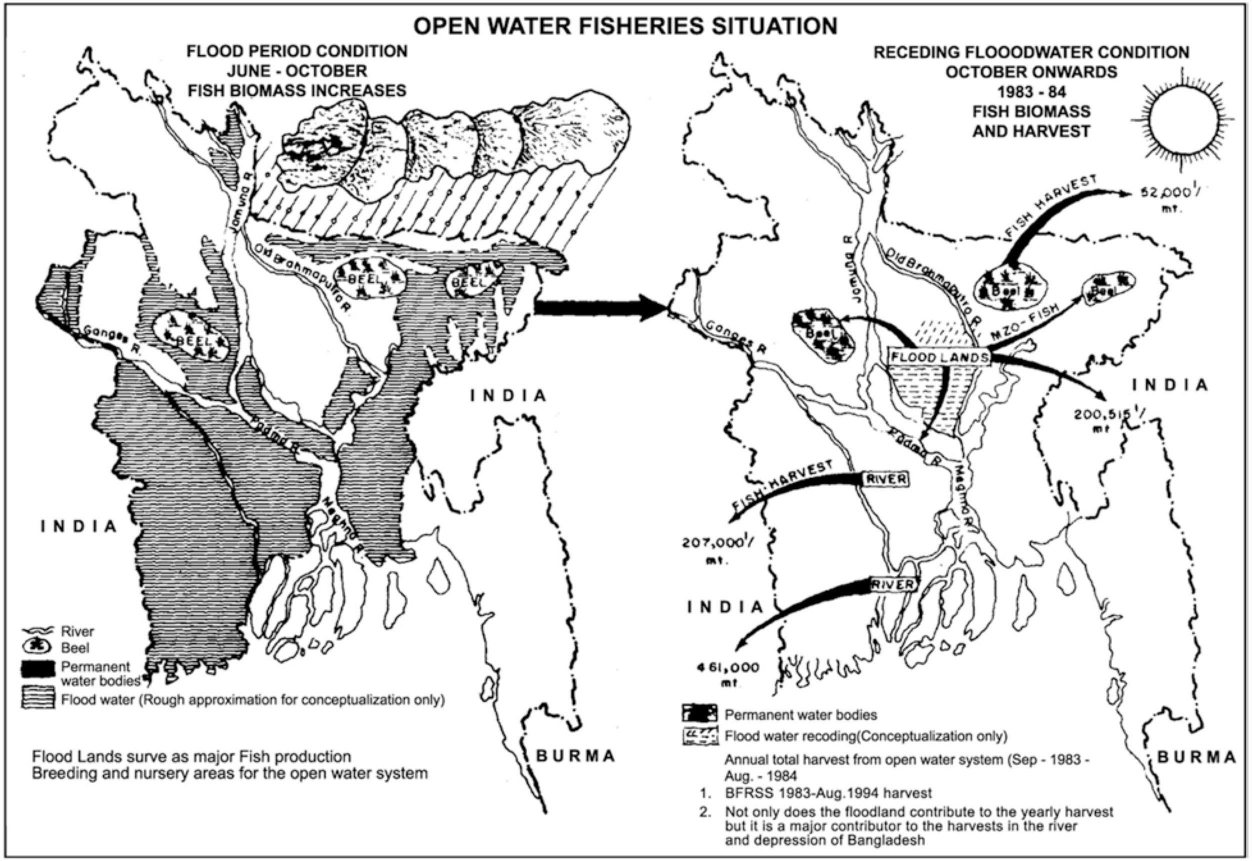

Fig. 3.2 Open water fisheries situation. *BFRSS* Bangladesh Fisheries Resource Survey System, *mt* metric tons. (Adapted from Ali 1997)

open inland water capture fisheries production. Many finfish breed in the favorable habitat conditions on the inundated floodplains, where the newborn juveniles feed and grow in the nutrient-rich flooded lands. Young and juveniles of many finfish and prawns, resulting from breeding in the flowing rivers and/or estuaries, also migrate into the inundated land for feeding and completing early growth. At the end of the monsoon, the fish and prawns return to the rivers and *beels* from the floodplains, with the receding water. Activities occurring in rivers and on floodplains can be seen in Fig. 3.3. The integrity of this production system can be kept intact only if the natural patterns of flooding and water movement are preserved. But such preservation has not been possible, because of the need for FCDI (an area of 50,000 km^2 out of Bangladesh's total area of a little over 88,500 km^2 is flood vulnerable). Flood control and improved drainage are needed primarily for maximizing food grain production. Improved drainage of lowland increases cropping intensity, while flood control is needed to protect the lives and property of rural people.

On the other hand, Bangladesh's open water capture fisheries resources, in terms of both quantity and variety (species diversity), are tightly bound and linked to the cycle of annual flooding. Fisheries resources and future fish production potential in the open waters of Bangladesh are highly reliant on the open floodplains, where flood control and improved drainage have the greatest impact.

3.3.2 Natural Fish Breeding

Small indigenous species (SIS)—such as *sarputi*, *shingi*, *magur*, koi, *bheda*, *puti*, *chanda*, mola, *golsha*, *tengra*, *kholisha*, *along*, *shol*, *gajar*, *lati*, and *cheng*—and fish such as *boaal* and *ghonia* are floodplain breeders. Breeding activities begin during the premonsoon flood, depending on the rain and the volume of water on the floodplains. *Magur*, *shingi*, koi, *tengra*, *pabda*, *aire*, *boaal*, *shol*, and *gazar* start breeding at the end of March and early April. Predator fish such as*boaal*, *shol*, and *gazar* breed earlier than nonpiscivorous species. Flash floods, heavy continuous rain, and thunder together stimulate fish breeding, particularly in *boaal*, *ghonia*, *pabda*, koi, *batashi*, *puti*, and also Indian major carps. It is desirable to undertake investigation in Bangladesh to identify floodplain breeding species, their spawning seasons, and their required environmental conditions.

According to annual flood cycles, there are four seasons for inland open water, which provide different habitats for different species of fish and prawns in Bangladesh:

- *Dry Season (December to March):* During this period, water remains only in the perennial rivers, canals, and *beels*, where fish and prawns congregate to live through the dry winter season. Juveniles grow into adults and mature, and their gonads begin to ripen.
- *Premonsoon Season (April to Early June):* During this period, the water level in rivers rises by inflow of water from the upper reaches and local rainfalls. This is

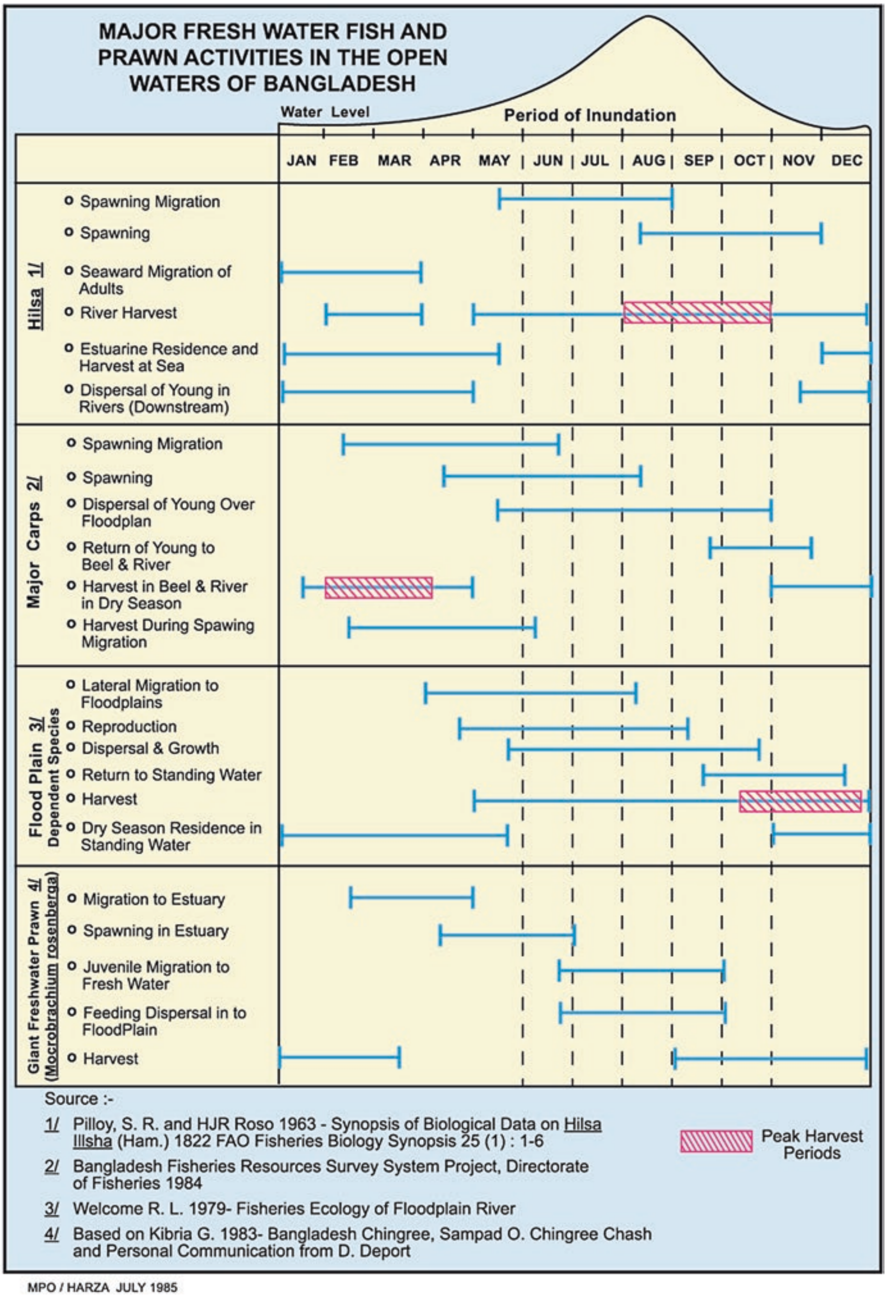

Fig. 3.3 Fish and prawn activities in an open water fishery (Adapted from Ali 1997)

the time when flash floods occur in some parts of the country. Fish move from deep water to shallow water in search of their spawning grounds. Fish adapted to breeding in flowing water migrate from deep *beels* into shallow areas of the rivers, while those living in deep parts of the rivers move to shallow parts of the rivers and then undertake upstream migration to reach their breeding grounds and spawn. This upstream migration can occur over long distances, as in the case of the major carp. For fish and prawns breeding on the floodplains, their breeding migrations usually occur over short distances.

- *Monsoon Flood Season (June to September):*This is the period when the larvae and fry of river breeding fish disperse to the floodplains for feeding and growing. They are swept onto the floodplains usually passively by currents overflowing the riverbanks and/or through *khals.* The larvae and fry of fish breeding on floodplains remain on the floodplains for feeding. Also, the fry and juveniles of estuarine breeding prawns use the floodplains as their nursery grounds until the time when the floodwater starts receding in October. During these months, these fish and prawns on the floodplains are vulnerable to high natural and fishing mortality. They are also easily infected with fish diseases.
- *Postmonsoon Season (October to December):*The floodwater on the floodplains starts receding during this period. The water recession starts in shallow areas, eventually channelizing at the end of the season. As the water surface area shrinks, fish and prawns move with the water flow into deepwater areas in the canals and river channels. Some also move into deep *beels* and ponds (*kua* and ditches) dug on the floodplains by landowners. In the deepwater areas at the end of the season, the fish and prawns aggregate densely, sometimes beyond the carrying capacity of the water areas, leading to the occurrence of fish die-off.

The description of fish migration and movement in the inland open waters from one component to another in different seasons suggests that barriers between those components, if created, would hinder the movement of fish and prawn populations. Figure 3.4 presents the nutrient cycle of events in open waters.

3.3.2.1 Impact on Fish Migration

The Master Plan Organization (MPO) for Water Resources Planning, Bangladesh, presented two broadly conceived schemes for utilization of the main river resources. One is a pair of barrages on the River Brahmaputra to supply water by gravity flow to the northeastern and northwestern regions, and the other is a barrage on the River Ganges to divert water into the southwestern region. From the Ganges barrage, water would be pumped from the river to its distributaries. These barrages, if and when constructed, would eliminate the spawning migrations of anadromous fish (i.e., those migrating from the sea to rivers), such as hilsa, and the migrations of catadromous fish and prawns (i.e., those migrating from rivers to the sea), such as *golda chingree.* This would bring an end to hilsa spawning in the rivers, leading to a decline of hilsa populations in Bangladesh in the Bay of Bengal. Migration of

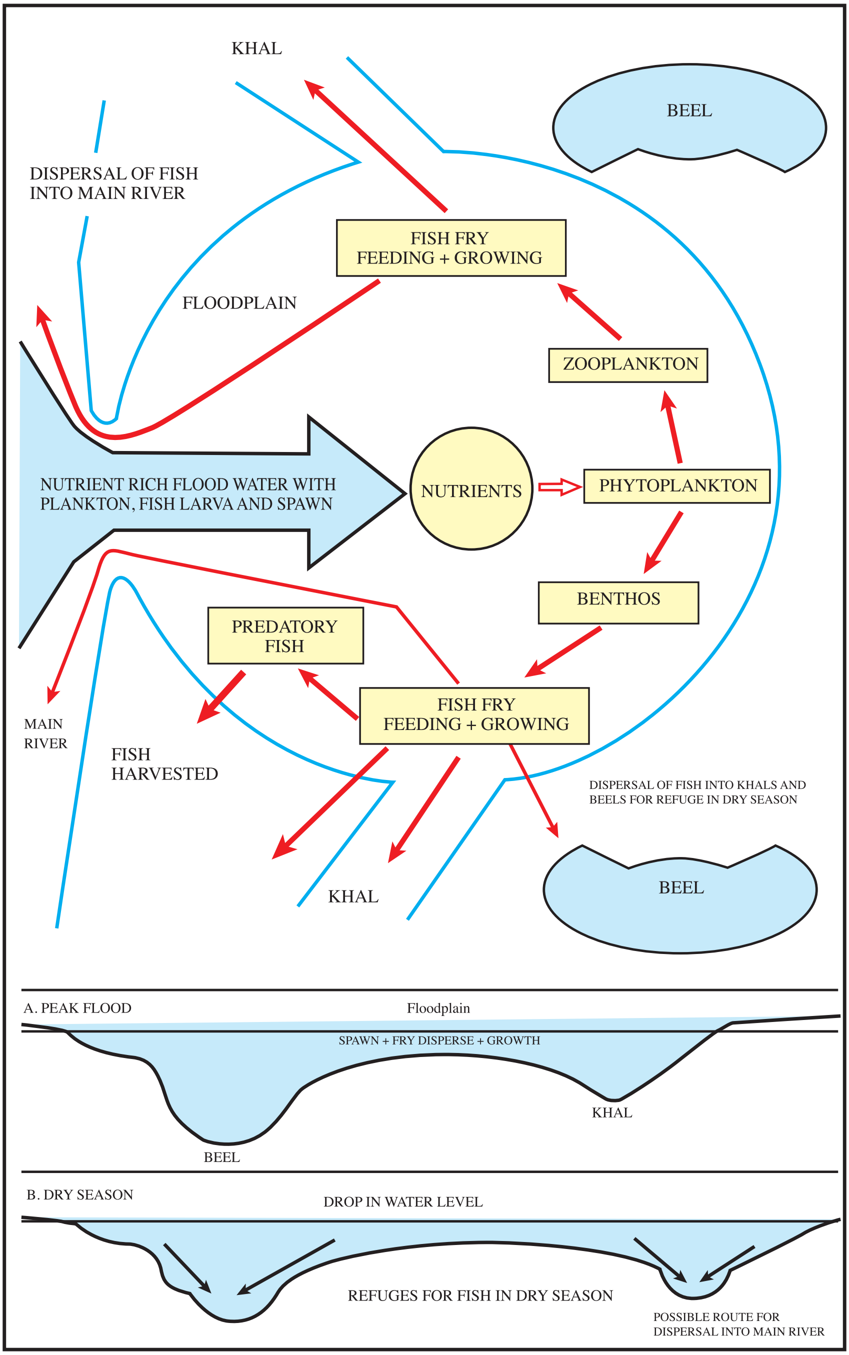

Fig. 3.4 Nutrient cycle in the open waters of Bangladesh. (Adapted from FAP-5 1993)

hilsa juveniles into the rivers between November and April would also be adversely affected because it is during these months that diversion of water for crop irrigation at the barrages would be highest.

Catadromous migration of *golda* and other such species would also be prevented during January to July. Similarly, the return migration of the juveniles and young adults of *golda* to freshwater habitats between June and August would be affected detrimentally by the barrages.

These *beels* remain connected with rivers through small *khals* or channels. These channels usually become dry during the peak of the dry season. During the period from late February to April, when water levels in the rivers slowly rise, these channels receive water and the connections between the *beels* and the rivers become restored. Brood stocks, especially of major carp, then migrate from the *beels* to the rivers for further upstream migration to their breeding grounds. Where these channels are closed by submersible embankments, fish migration from *beels* within embanked *haors* toward the rivers is prevented. Portion of channels outside embankments may receive rising water from the rivers, but the portions inside the embankments remain dry until June, when floodwater overtops the embankments. Thus, broods of carp residing in such *beels* within the submersible embankments would be prevented from breeding. The closure of channels linking the *beels* with the rivers may not only inhibit reproduction of the carp resident in the *beels* but also reduce their overall abundance in other *beels* and associated river systems, both within and outside the region.

Beliefs about the potential impacts of flood control on capture fisheries were based on the general perception that full flood control projects were functional and that natural flooding patterns on floodplains had been radically altered (Fig. 3.5). Outside the northeastern region, the principal objective of flood control was to increase rice production by replacing deepwater broadcast aman (b. aman) with high-yielding variety (HYV) transplanted aman (t. aman), which requires shallow water during the monsoon. Under the scenario of full flood control for HYV t. aman production, some of the more important potential adverse impacts on fisheries are:

- Loss of flooded habitat during the monsoon, resulting in a loss of fish production.
- Blockage of movements of fish (adults, juveniles, and hatchlings) between external rivers and floodplains.
- Loss of high-value migratory species, such as major carp and catfish, by preventing migrations between rivers and floodplains, thereby interfering with their life-cycles.
- Reduced diversity of fish by preventing migratory species entering floodplains.
- Increased fishing pressure on smaller areas of water during the monsoon, threatening the long-term sustainability of fisheries.
- Reduced dry season habitat, resulting in higher fishing pressure and increased catchability of overwintering fish broodstock. The increased abstraction of water from *beels* to irrigate surrounding rice fields is of particular concern.

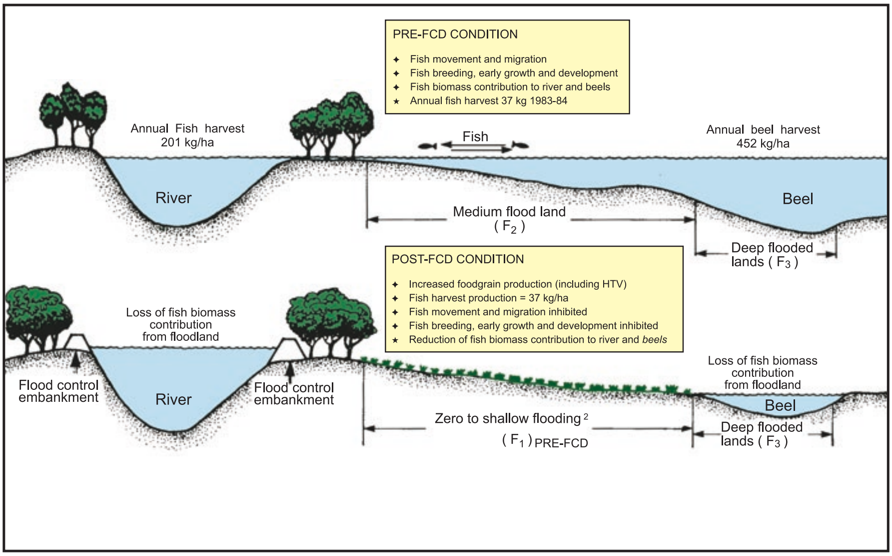

Fig. 3.5 Impact of flood land removal through flood control and drainage (FCD) projects in Bangladesh. The fish harvest refers to 1983–1984. F_1 land type with a flood depth of 0.03 m, F_2 land type with a flood depth of 0.3–1.8 m, F_3 land type with a flood depth of >1.8 m, *HTV* herbicide-tolerant varieties. (Adapted from FAP-5 1993)

- Increased fish disease by creation of adverse environmental conditions such as stagnation of standing waters, which could trigger disease outbreaks in already stressed and modified fish communities.
- Reduced groundwater recharge, resulting in a lower water table in the dry season which, in turn, could lead to a reduction in the area of perennial *beel*. Dry season rice production dependent on tube well irrigation is also thought to be at risk from lowered groundwater levels, which would also create problems for drinking water supplies.

3.3.3 Fish Hatchery Production System

During the flood season, extensive fishing of the fish and prawns feeding and growing on the food-rich inundated floodplains is carried out by the rural population of the country for both home consumption and sale. Fish and prawns resident in their seasonal floodplain habitat become more vulnerable to fishing in the course of their return with the receding waters at the end of the flood season.

Breeding and reproduction of almost all inland water fish and prawn species are tightly bound to the sequence of the annual flooding. The rise in the water level in rivers and streams between February and April triggers physiological changes leading to sexual maturity of fish inhabiting the flowing rivers. Similarly, early monsoon rainfall, in combination with early inundation of floodplains, stimulates fish in *beels* and other similarly static water bodies to become sexually mature. As soon as the connections between the *beels* and flowing rivers are restored by the rising water level in the rivers, sexually mature river breeding fish such as major carp migrate from the *beels* to the rivers through linking canals. In the rivers, the major carp undertake upstream migration, often over a long distance, seeking their spawning grounds.

The spawning (breeding) grounds of the Jamuna–Brahmaputra stock of the major carp are located in the southern tributaries of the Brahmaputra River on the northeastern slopes of the Letha Range and the Assam Hills in Assam, India (Tsai and Ali 1985). The upstream spawning migration of major carp occurs from late February to late April, and the spawning season is in May to June. The resultant stock of newborn fry (spawn) move downstream with the water current and enter Bangladesh. On their downstream movement, the fry move laterally or are swept onto the inundated floodplains. In the course of the downstream movement, the stocks of fry or spawn are also collected by spawn traders in different rivers and streams.

Some species of inland water fish and prawns make a downstream migration to reach their spawning grounds in the estuaries. One such species is the giant freshwater prawn (*Macrobrachium rosenbergii*). Adults of this prawn species make their downstream spawning migration into the estuaries between January and July, and breed there. Their fertilized eggs undergo early development in the saline or brackish water environment. On attaining the juvenile stage, they migrate upstream into the freshwater environment in the rivers and onto the inundated floodplains, where they feed and grow rapidly.

The hilsa—the most popular fish in the country—resides in the coastal waters of the Bay of Bengal and moves into the freshwater habitat of the rivers for the purpose of breeding or spawning. Their biggest spawning migration coincides with the early monsoon. The hilsa appears to spawn almost year round, with the major activity taking place in October and less intense activity occurring in June and March (monsoon, postmonsoon, and premonsoon spawning). The peak spawning run starts at the advent of the monsoon and continues until about September to October, though fishing activities continue almost throughout the year. The maximum riverine harvest occurs between August and October every year, with the lean season being in December to January. Juveniles of hilsa, known as *jatka*, appear in the lower reaches of the river systems in the Patuakhali, Barisal, and Comilla districts between November and April, apparently for feeding. Massive harvests of *jatka* take place during that time.

The seasonality of fish seed production is a very important dimension of aquaculture because production of fish seed and its demands are variable for different types of grow-out farmers in Bangladesh. Different commercially important species have different seasons of seed production and availability that influence aquaculture production. As Indian major and Chinese carp are the main contributors to aquaculture production in Bangladesh, the dependency on hatchery-based seed production of these species is significantly affected by the raising temperature and its steady

Impact of CC on the biology of major carp: Growth and reproductive biology of Indian major carps (i.e. Rui, Catla, Mrigal etc.) has relations with seasons. They breed in rainy day with higher dissolved oxygen contents in water with moderate current. Higher temperature and erratic rainfall could change the reproductive performance of Major carps.

Events	Months												Remarks
	J	F	M	A	M	J	J	A	S	O	N	D	
Fish maturity				■	■	■							1
Reproduction						■	■	■					2
Good growth		■	■	■	■	■	■	■	■	■			3
Poor growth	■										■	■	4
Ambient temp.		▒	▒	▒	▒	▒	▒	▒	▒	▒			5
Rainfall						■	■	■					6

1. Ambient temperature and good growth helps in maturity
2. Rainfall is related to spawning. Rainfall also increase dissolved oxygen in water
3. Ambient temperature is necessary
4. Cold weather restrict body metabolism, food intake and so the growth of fish
5. Water temperature between 24-28°C is necessary for good growth, reproductive maturity, hatching success of eggs and larval survival in water
6. Thunder storm, cloudiness and water current are creating environment for carp mating behavior in river system

Fig. 3.6 Impacts of higher temperature (temp.) and low rainfall on aquaculture. *CC* climate change. (Source: Hossain and Naser 2014)

period. Common carp seed production occurs naturally, and the majority of seed production occurs in the pond-based system, which could be affected negatively by higher water temperatures (Fig. 3.6).

3.3.4 Small-Scale Aquaculture

Sometimes fish farmers collect expensive and good-quality natural eggs and spawn of carp from the Jamuna in the early season. As there is very little and only sporadic rain in April–May, very few eggs and spawn are collected from natural water bodies; accordingly, these are very expensive and precious. However, because of the hot temperature and lack of water, tending to these valuable spawn is very difficult. Even when some of the farmers/hatchery owners are able to tend to them, selling the fry is difficult, as the general fish farmers cannot stock them because there is no water in their ponds. Therefore, even after collecting and tending to the expensive and good-quality spawn, because of lack of customers, the hatchery owners/fish farmers cannot make any profit and instead encounter huge losses. On the other hand, fish hatcheries faces the problems listed below:

- Tilapia stops spawning at temperature slower than 24 °C and at temperatures higher than 34 °C.
- Among the carp, the eggs and spawn of bighead, silver, and bata start to die at high temperatures.

- As the supply of rainwater is insufficient in this area, very uncertain, and mostly absent in the time of need, a huge quantity of water lifted from deep tube wells is needed in the fish hatcheries. That increases the production costs for fish seed significantly.
- As there is not enough rain in this area, brood fish do not mature in time. In normal conditions with sufficient rainwater from the early monsoon, it is possible to produce 1 kg of spawn from 2–3 fish, but nowadays, about 10 brood fish are needed to produce 1 kg of spawn.

3.3.5 Coastal Fisheries

3.3.5.1 Salinity Intrusion

The main impact of sea level rise on water resources is the reduction in freshwater availability, due to salinity intrusion. Both water and soil salinity along the coast will be increased with the rise in sea level, destroying the normal characteristics of the coastal soil and water. A water salinity map for the period of 1967–1997, produced by the Soil Resources Development Institute (SRDI) (SRDI 1998), shows that the problem is already occurring. A 1 m sea level rise would expand the soil and water salinity area at a faster rate (Fig. 3.7).

3.3.5.2 Climate Change and the Sundarbans Ecosystem

Climate change is expected to have a significant effect on the flow regimes of the major rivers in Bangladesh, including the Ganges. Since the viability of the Sundarbans rests on the hydrology of the Ganges and its tributaries, which supply the freshwater influx, climate change is expected to have a significant impact on the Sundarbans. In addition to the altered hydrology, the sea level rise will also have adverse impacts on the forests, directly through enhanced inundation and indirectly by enhancing saline intrusion into river systems. The climate change scenarios indicate that there is general agreement across climate models on increased precipitation during the monsoon season. Greater rainfall runoff would provide increased freshwater discharge in all major distributaries of the Ganges supplying freshwater to the Sundarbans: the Gorai, the Modhumati, and the Bhairab system on the Bangladesh side, and the Hoogly on the Indian side. Simultaneously, however, a rise in sea level would also occur under climate change, which would cause an increased backwater effect in the major distributaries of the Ganges and would tend to push the saline front further inland. The final location of the saline front during the monsoon will, therefore, be the result of two opposing effects: enhanced freshwater flow and an enhanced backwater effect, and is hard to predict precisely. The backwater effect would also reduce the discharge of freshwater flow from the northern reaches

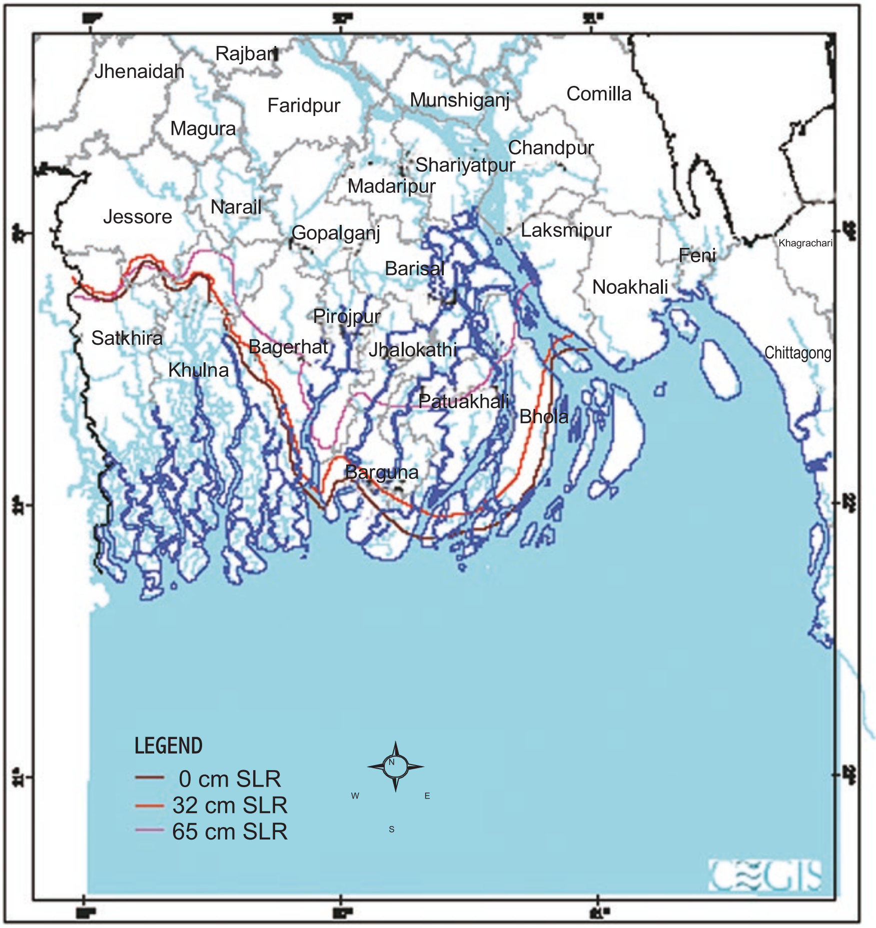

Fig. 3.7 Salinity ingress in southern Bangladesh, due to different magnitudes of sea level rise (SLR)

of the tributaries of the Ganges, resulting in a relatively prolonged inundation of the forestland.

The Sundarbans would be completely lost with a 1 m sea level rise (World Bank 98). Loss of the Sundarbans would mean a great loss of heritage, loss of biodiversity, loss of fisheries resources, loss of life and livelihood and, after all, loss of a very highly productive ecosystem. The impacts on the area of the Sundarbans of inundation by different magnitudes of sea level rise are listed in Table 3.6.

Table 3.6 Impact on the Sundarbans of different magnitudes of sea level rise

Sea level rise (cm)	Potential impact on the Sundarbans
10	Inundation of 15%
25	Inundation of 40%
45	Inundation of 75%
60	Inundation of 100%
100	Complete destruction

Source: Sarwar 2005

3.4 Adaptation of Fisheries to Climate Change

3.4.1 Key Issues, Problems, Impacts, and Adaptation

There are significant interconnections between the natural aquatic resource base of Bangladesh and the livelihoods of its people. It is important, therefore, to address these in a comprehensive manner, as protection of biodiversity, greater subsector production, and more effective fisheries management systems will not in themselves bring about wholesale change in social processes and impacts on the environment. Table 3.7 highlighted the key issues, problems, impacts, and adaptation measures for climate change.

3.4.2 National Plan of Action and Coping Strategies

There is no comprehensive national policy in Bangladesh that specifically targets climate change risks. However, the government of Bangladesh is aware of the importance of climate change, as well as the country's historical sensitivity to climate variability in general, and there are several existing policy response options that relate to climate change. These include indirectly addressing the impacts of climate change through programs that *reduce vulnerability*(e.g., through poverty alleviation, employment generation, and crop diversification); directly addressing *vulnerability to climate variability* and extreme events through disaster risk reduction (DRR) and management schemes; and specifically *targeting climate change* by mainstreaming climate change into sectoral plans and national policies.

Bangladesh has a Participatory Disaster Management Programme (PDMP) with a focus on disaster management and prevention, and also adaptation to climate change. The focus is on "soft" measures to reduce the impacts of disasters, with an emphasis on preparedness, such as awareness raising about practical ways to reduce disaster risks and losses, to strengthen the national capacity for disaster management; enhancement of the knowledge and skills of personnel in handling disasters; establishment of disaster action plans in the most disaster-prone areas; promotion of local-level risk reduction measures; and improvement of early warning systems. In 2003, Bangladesh also established a Comprehensive Disaster Management

Table 3.7 Key issues, problems, impacts, and adaptation measures for climate change

Key issue	Problem	Impact	Adaptation
Abundance of water			
Geographical location and setting (92% of runoff from the Ganges, Brahmaputra, and Meghna Rivers flows through Bangladesh, which is 7% of the catchment area)	Increased flooding	Crop yield reduction and damage	Strengthening of capabilities for flood forecasting and monitoring
Monsoon climate (78% of rainfall occurs in the monsoon)	Increased water-related hazards	Damage to cultured fisheries	Planned development to cater for different sector needs
	Increased riverbank erosion	Early flooding may positively impact fish breeding	
	Drainage congestion due to riverbed siltation	Disruption of livelihood system	
Scarcity of water (dry season)			
Upstream withdrawal for consumption and non-consumption use	Declining river water levels and discharge	Disruption of freshwater fish production	National Water Policy: regional cooperation, augmentation of dry season flow, and use of surface water for irrigation
Low rainfall	Low water flow	Increased conflict among different users and sectors	Re-excavation of channels and ponds in rural areas
Gradual siltation of riverbeds and floodplains	Shrinking dry season water areas	Increased pressure on groundwater	
Dry season irrigation	Disruption of fish habitats	Decline in water quality	
	Decline/fluctuation in groundwater		
Salinization			
Saltwater penetration within embankment for substantial periods	Increased salinity in polder areas	Gradual degradation in quality of land and soil nutrients, resulting in accumulation of sodium chloride, affecting rice production	Development of land use policy and environmental guideline for shrimp culture
			Development of optimal practices for mixed rice–shrimp culture
Pollution			
Industrial effluent	Decreasing inland water quality in dry season	Increased fish mortality, threats to migration and quality of fish	Environmental Conservation Act and regulations

(continued)

Table 3.7 (continued)

Key issue	Problem	Impact	Adaptation
Agrochemicals	Decreasing coastal water quality	Degradation of fish habitats	Setup of environmental quality standards
Fecal pollution	Salinity intrusion into surface water and groundwater	Yield reduction (soil fertility loss)	Industrial environmental impact assessment of effluent treatment plants and reduction of pollutant loads
Ship breaking and lube oil discharge	No primary or secondary measurements of discharge quantities are available	Increased risk of waterborne diseases	National Water Policy: environmental impact assessment for water development projects and increased surface water flow in dry season
Oil and spillage during normal refueling of ships at sea and river ports		Threats to marine aquatic life	
Biodiversity			
Indiscriminate fish fry collection	Destruction of fish biodiversity	Overfishing, reductions in fish populations and fish species	Development of shrimp hatcheries; if required, with provision of adequate fiscal–financial incentives

Programme (CDMP) with the UNDP and other donor assistance, with the aim of refocusing the government toward greater emphasis on disaster preparedness and risk reduction. The CDMP has a number of disaster management components, among which are establishment of an integrated approach to climate change and disaster management, and expansion of risk reduction approaches across a broader range of hazards, with specific reference to climate change. There are three main areas of focus:

- Capacity building for the Ministry of Environment and Forests and the Department of Environment (DoE) to coordinate and mainstream climate change into their existing activities
- Strengthening of existing knowledge and information accessibility on impact predictions and adaptation
- Awareness raising, advocacy, and coordination to promote climate change adaptation in development activities

Capacity building includes assisting the creation of a "climate change cell" within the DOE to build government capacity for coordination and leadership on climate change issues. The cell coordinates awareness raising, advocacy, and mechanisms to promote climate change adaptation and risk reduction in development activities, as well as strengthening existing knowledge and information accessibility on the impacts of climate change and adaptation to it.

Bangladesh therefore has fairly effective mechanisms in place for disaster management and climate risk management (CRM); however, there is room to improve the functional effectiveness of this system. The UNDP has suggested the establishment of an Integrated National Framework for CRM and DRR, for broader understanding of climate change risks and impacts at all levels, as well as capacity building for assessing risks and analyzing them with sectoral and cross-sectoral perspectives and implications.

The government of Bangladesh is integrating climate change into sectoral plans and national policies. For example, recommendations from the World Bank on the impacts of climate change have been incorporated into coastal zone management programs and adopted in the preparation of disaster preparedness plans and a new 25-year water sector plan. Bangladesh's interim *Poverty Reduction Strategy Paper* (PSRP) recognizes the direct link between poverty and vulnerability to natural hazards, and notes that the incidence of disasters is likely to increase rather than decrease as a result of global warming.

Other national policies of relevance to climate change include the National Water Policy (NWP), announced in 1999, which was the first comprehensive look at short, medium, and long-term perspectives for water resources in Bangladesh, followed by the National Water Management Plan (NWMP) in 2001, which looked at the implementation and investment responses to address the priorities identified in the NWP. The NWP does not explicitly mention climate change; however, climate change is recognized by the NWMP as one of the factors determining the future water supply, including the impacts of sea level rise, which guide the implementation of the NWP. Further, many of the NWP and NWMP priorities are synergistic with climate change adaptation, such as the recommendation in the NWP for early warning and flood-proofing systems. Other environmental policies, including the National Environmental Management Plan (NEMAP), the National Land Use Policy, and the National Forest Policy, do not make specific reference to climate change.

A National Climate Change Committee, composed of members from all relevant government and nongovernmental organizations, was constituted in 1994 for policy and guidance and to oversee the implementation of obligations under the United Nations Framework Convention on Climate Change (UNFCCC) process. In addition to the climate change cell, other government institutions that are relevant to climate change include an inter-ministry committee on climate change, headed by the Minister for Environment and Forests and with representation from relevant government ministries as well as NGOs and research institutions; and a National Environment Committee to determine environmental policies, chaired by the Prime Minister, with representation from MPs as well as government and civil society. Through these institutions, as well as independently, the government of Bangladesh, academic institutes, and research organizations have conducted a number of studies on impacts of, adaptation to, and vulnerability to climate change, and have participated in a range of national efforts that seek to address climate change directly. Notable among these efforts in relation to climate change impacts is that Bangladesh was the first country to complete a National Adaptation Programme of Action (NAPA), which is a document produced by the Least Developed Countries for the UNFCCC to identify immediate and urgent needs for adaptation to climate change. Bangladesh successfully completed the NAPA in 2005.

3.4.3 Recommendations

3.4.3.1 General

- Regional and bilateral dialogue on water sharing and watershed management needs to be encouraged, and steps need to be taken to protect watersheds in Bangladesh. Capacity needs to be developed to understand and respond to the longer-term implications of water scarcity and climate change. Effective systems need to be developed for integrated planning and management of water use, and for water conservation for the dry season.
- A much greater capacity to understand and respond to the longer-term implications of water and climate change is required, with conservation of dry season water and protection of water bodies from drainage for protection of fish stocks and other aquatic resources.
- An efficient forecasting and warning system would prove beneficial for all people potentially affected by storm surges and floods, enabling them to take reactive measures such as evacuation. A safe environment is an important condition for industrial development in the coastal zone with optimal utilization of its energy potential.
- Scarce freshwater could be allocated with priority to domestic and industrial users, and used for ecologically sound management of the Sundarbans. Other possible adaptations could include changes in agricultural practices with a shift to paddy with shrimp cultivation (with due consideration of the environmental and social implications of introducing shrimp culture), while proper groundwater management would prevent aquifers from becoming saline.
- National capability to provide systematic quantitative information on geographical variations in the diversity of aquatic resources in Bangladesh should be established. This measure is designed to improve the basic knowledge of the diversity of fish, shrimps, and prawns, and to identify environmental problems (including flood control) linked with reductions in biodiversity.

3.4.3.2 Specific

- The movements of fish and prawns between rivers and floodplains that are free flooding and others on which flooding is controlled should be investigated. Such a study would require continuous intensive monitoring of catches in canals linking rivers with floodplains.
- The migrations of fish along rivers in the north central region should be investigated to identify possible environmental factors that might explain the general scarcity of riverine and migratory species in comparison with some other regions in Bangladesh.
- Possible spawning grounds of major carp should be identified in the Brahmaputra and Padma Rivers in Bangladesh, with investigation of upstream breeding migrations in these rivers.

- Movements by passive downstream drifting of fish and prawn hatchlings between rivers and floodplains should be investigated in relation to seasonal changes in river discharge. Such a study is essential on the big river ecosystem, where the Jamuna River provides an annual supply of hatchings of major carp and many other species of fish.
- *Beels* and connecting canals should be re-excavated for fish habitat restoration, biodiversity conservation, and sound ecosystems. In each of the large floodplains, a certain small area of about 1 hectare should be deep enough to contain water 2–3 m deep year round for fish habitat restoration and fish biodiversity conservation.

However, it is predicted that sea level rise will cause a reduction in fish production by reducing the freshwater fishing area. Decreased rainfall and river runoff, and increased evaporation during winter, will also reduce the winter fishing area. Pond culture in the coastal area will be affected by intrusion of salt water into the ponds, unless embankments are made around them.

3.5 Conclusions

This chapter has discussed some climate change scenarios in inland fisheries in Bangladesh, but still there remain a lot of uncertainties in the assessment, which is understandable in the light of the non-availability of long period data, limitations of models, and lack of full understanding of the climatic parameters and their variations. The process of awareness raising should be geared up. This will assist adaptation and mitigation measures to be undertaken.

The vulnerability of Bangladesh to climate change is well recognized, given its higher level of exposure to both the gradual change phenomenon and extreme events, and its lack of institutional and financial capacity to deal with climate change–related problems as well. Changes in the climatic system and its associated adverse impacts are already visible. Changes in the duration of seasons (i.e., lengthening of the summer season and shortening of the winter season, and shifting of the mango flowering season), increases in the frequency of hazards, and changes in the rainfall pattern are major indicators of climate change in Bangladesh. The relationship between adverse impacts of climate change and poverty is multidimensional and complex. For better understanding of this complex relationship, there is a need for a longitudinal disaggregated poverty database along with information on different income streams for households and their assets. Strengthening of the institutional and human capacity to analyze poverty in the context of climate change is also needed. The relationship between adverse impacts of climate change and GDP growth is complex as well.

The Ministry of Environment and Forests in Bangladesh is the focal point for management of climate change at the national and international levels. The government of Bangladesh has formulated the Bangladesh Climate Change Strategy and

Action Plan 2009 as a living document to address climate change issues. In 2005, the government also formulated the National Adaptation Programme of Action (NAPA) where the immediate and urgent needs or adaptation were identified. The Bangladesh Climate Change Strategy and Action Plan 2009 is built on six pillars, of which five are related to impact management and one is related to mitigation through low-carbon development. These pillars are (a) food security, social protection, and health; (b) comprehensive disaster management; (c) infrastructure; (d) research and knowledge management; (e) mitigation and low-carbon development; and (f) capacity building and institutional strengthening. It has been suggested that the Climate Change Action Plan will be implemented under the overall guidance of the National Environment Committee. It will be coordinated by the Ministry of Environment and Forests. Programs funded under the plan will be implemented by ministries or their agencies, with involvement, as appropriate, from civil society and the private sector.

References

Ali MY (1997) Fish, water and people reflections on inland open water fisheries resources of Bangladesh. University Press Limited, Dhaka

Ali MY (1999) Fish resources vulnerability and adaptation to climate change in Bangladesh. In: Huq S, Karim Z, Asaduzzaman M, Mahtab F (eds) Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht, pp 113–124

BBS (Bangladesh Bureau of Statistics) (2006) Report on labour force survey, 2005. BBS, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka

BCCSAP (Bangladesh Climate Change Strategy and Action Plan) (2009) Bangladesh Climate Change Strategy and Action Plan 2009. Ministry of Environment and Forests. Government of the People's Republic of Bangladesh, Dhaka, 76 p

CIA (Central Intelligence Agency) (2008) The world fact book: Bangladesh. www.cia.gov/library/publications/the-worldfactbook/print/bg.html

DoF (Department of Fisheries) (1997–2007) Fishery statistical yearbook of Bangladesh. DoF, Government of the People's Republic of Bangladesh, Dhaka

DoF (Department of Fisheries) (2014) Fish week compendium 2014 (2–8 July). DoF, Government of the People's Republic of Bangladesh, 144 p

DoF-BARC (Department of Fisheries–Bangladesh Agricultural Research Council) (2001) Fisheries sector review and ten-year (2002–2012) production projection. DoF, Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh, Dhaka

FAO (Food and Agriculture Organization of the United Nations) (2007) The state of world fisheries & aquaculture 2006. FAO, Rome, 162 p

FAP-2 (Flood Action Plan 2) (1992) Agriculture and fisheries north west regional study. In: Flood action plan 2. Flood Plan Coordination Organization, Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka

FAP-5 (Flood Action Plan 5) (1993) Gumti phase II sub project feasibility study—fisheries. In: Flood action plan 2. Flood Plan Coordination Organization, Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka

GoB and UNDP (Government of the People's Republic of Bangladesh and United Nations Development Program) (2009) The probable impacts of climate change on poverty and economic growth and the options of coping with adverse effect of climate change in Bangladesh.

In: Support to monitoring PRS and MDGs in Bangladesh. General Economics Division, Planning Commission, GoB and UNDP, Dhaka, 117 p

Hossain MAR, Naser MN (2014) Assessment of agro-ecological zone specific risks, vulnerabilities of disaster and climate change, and climate change adaptation (CCA) in fisheries sector of Bangladesh—draft report. Disaster and Climate Risks Management in Fisheries Project. Department of Fisheries/Comprehensive Disaster Management Programme-II, Government of the People's Republic of Bangladesh, Dhaka, 97 p

Karim M, Ahmed M, Talukder RK, Taslim MA, Rahman HZ (2006) Dynamic agribusiness focused aquaculture for poverty reduction and economic growth in Bangladesh. WorldFish Center Discussion Series No. 1. 44 p

Mazid MA (2002) Development of fisheries in Bangladesh: plans and strategies for income generation and poverty alleviation. Nasima Mazid, Dhaka

PC (Planning Commission) (2005) Unlocking the potential: national strategy for accelerated poverty reduction. Provisional final draft. Planning Commission, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka

Sarwar MGM (2005) Impacts of sea level rise on the coastal zone of Bangladesh (thesis), Lund University International Masters Programme in Environmental Science. Lund University, Lund, 45 p

SMRC (South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre) (2003) The vulnerability assessment of the SAARC coastal region due to sea level rise: Bangladesh case. SMRC-No. 3, SMRC Publication, Dhaka

SRDI (Soil Resources Development Institute) (1998) Coastal area and water salinity map of Bangladesh (1967 and 1997). SRDI, Dhaka

Thilsted SH, Ross N, Hassan N (1997) The role of small indigenous fish species in food and nutrition security in Bangladesh.NAGA: the ICLARM quarterly(Supplement) July–December, pp 13–15

Tsai Chu-fa, Ali MY (1985) Open water fisheries (carp) management program in Bangladesh. Fish Inf Bull 2(4) Bangladesh Fisheries Resource Survey System, Department of Fisheries, Government of the People's Republic of Bangladesh, Dhaka, 51 p

UNDP (United Nations Development Program) (2004) A global report: reducing disaster risk: a challenge for development. http://www.undp.org/bcpr

UNFCCC (United Nations Framework Convention on Climate Change) (1997, 11 December) Kyoto protocol to the United Nations Framework Convention on Climate Change, Kyoto, Japan

World Bank and BCAS (Bangladesh Centre for Advanced Studies) (1998) Bangladesh 2020: a long-run perspective study, the World Bank and Bangladesh Centre for Advanced Studies (BCAS). The University Press Limited, Dhaka

Chapter 4
Environmental Migrants in Bangladesh: A Case Study on Climatic Change Hazards in the Southwestern Coastal Area

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Abstract Bangladesh has been considered one of the countries most affected by climatic change impacts. Increases in natural hazards, perceived to be due to climate change, have affected the southwestern coastal environments of Bangladesh and people's livelihoods in this area. Remarkably, the numbers of human deaths due to floods, cyclones, and tidal surges have decreased, primarily because of mitigation strategies such as safe houses. However, the number of homeless people has increased sharply, contributing to internal migration in Bangladesh, including migration between neighboring cities. This chapter discusses the influence of climate-induced hazards on the decision to move, and the circumstances that prompt migrants to take decisions to migrate. Semistructured questionnaires were used to collect data in the Gabura union in the Shyamnagar thana in the Satkhira district, and qualitative analysis and case studies were conducted to further elaborate the outcomes. The results showed that along with anthropogenic causes—such as government policy implementation to protect the Sundarbans (the largest mangrove forest in the world) and changes of paddy cultivation fields into saltwater fish and shrimp farms—natural hazards such as periodic cyclones and tidal surges have damaged the territory of poor workers and/or day laborers, leading them to move to places where employment is more readily available. In this regard, climatic hazards have played a fundamental and influential role with other factors in the process of migration.

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4.1 Introduction

Climate change poses a major threat to human habitats. The magnitude of the threat, considered by some researchers to be unparalleled in human history, has made climate change a focus of much current research. The Intergovernmental Panel on Climate Change (IPCC) has identified human migration as the greatest single impact of climate change. Worldwide, 200 million people are expected to relocate by 2050 in response to environmental changes such as rising temperatures and sea levels (Christian Aid 2007). Most of those migrants will be from the coastal areas of poor countries in the Global South—that is, countries in Africa and Asia, whose nations are less responsible for the causes of changes in climate than the countries of the developed world.

Natural hazards are expected to become more frequent and extreme because of climate change (McMichael et al. 2003). Human habitats are impacted by these natural disasters. A large number of people have migrated and are expected to migrate from the affected areas. For example, the Asian Development Bank (ADB) (2012) has suggested that over 30 million people were displaced in Asia in 2010 because of environmental problems such as floods, cyclones, droughts, and riverbank erosion. According to the Norwegian Refugee Council (NRC), natural hazards caused the displacement of more than 15 million individuals in 2011 (NRC 2012).

Bangladesh—a low-lying delta country with a high density of poor people—is one of the most affected countries in the world with respect to climate change. Natural hazards such as floods, riverbank erosion, cyclones, and tidal surges are common in the country, affecting thousands of people almost every year. Migration due to climate change is on the rise in Bangladesh. Around 6.5 million people are said to have been displaced by climate change so far, and another 50 million are expected to be displaced by 2030 (Musa 2011). The objective of this chapter is to address the questions of whether and to what extent climate change impacts this migration in Bangladesh. Under this broad question, this study also investigates what the other push and pull factors are that contribute to the process of migration.

4.2 Major Natural Disasters in Bangladesh

Worldwide emission of CO_2 is the key factor responsible for global warming (Drake 2000). It is believed that the developed world is more liable for producing CO_2 gases than developing countries. In spite of being a minimum CO_2–producing country, Bangladesh is a typical example of the dramatic effects of natural disasters in response to climate change in the world. Floods, droughts, cyclones and storm surges, riverbank erosion, salt water intrusion, and landslides are very common and put stress on peoples' livelihoods in the country every year. Some studies (Lein 2009; Karim 1995; State of Environment Report 2001) have noted that because of its geographical setting, Bangladesh is vulnerable to natural disasters. Examples of

Table 4.1 Numbers of deaths in major cyclones in different years

Year	Deaths
1960	3000
1960	5149
1961	11,466
1963	11,520
1965	19,279
1970	500,000
1985	11,069
1988	2000
1991	140,000
2001	3064
2007	10,000
2009	330

Source: European Community (1998) and MoEF (2009)

Table 4.2 Countries most vulnerable to tropical cyclones and floods

Tropical cyclones			Floods		
Rank	Country	Deaths/100,000[a]	Rank	Country	Deaths/100,000[a]
1	Bangladesh	32.1	1	Venezuela	4.9
2	India	20.2	2	Afghanistan	4.3
3	Philippines	8.3	3	Pakistan	2.2
4	Honduras	7.3	4	China	1.4
5	Vietnam	5.5	5	India	1.2
6	China	2.8	6	Bangladesh	1.1

Source: UNDP 2004

[a]Deaths/100,000 people exposed to the event

this geography are the north and east bordering with ranges of the Himalayan mountains, the funnel-shaped Bay of Bengal in the south, the low gradient from north to south, the thousands of rivers, and the fact that two thirds of the land is covered by alluvial flood plains.

Bangladesh has been experiencing devastating disasters for a long time. Since 1980, 220 natural disasters have been recorded in the country (UNDP 2004). The World Disaster Report (2010) revealed that more than 154 million Bangladeshi were affected by natural disasters between 1990 and 2010. On the basis of deaths in tropical cyclones (Table 4.1) and floods, the United Nations (UN) Development Program (UNDP) has ranked Bangladesh as the country most vulnerable to tropical cyclones and the sixth most vulnerable to floods (Table 4.2). Moreover, riverbank erosion, drought, and waterlogging have gained importance according to their extent and severity.

4.3 Conceptualizing Environmental Migration

Movement is a characteristic of human beings. There are many reasons behind the movement of people, including environmental factors. For example, environmental disturbance has recently been highlighted by environmentalists (Afifi and Jager 2010). However, environmental degradation due to climate change has been threatening human livelihoods and security at an alarming rate since the last half of the twentieth century. Living in a safe place is one of the most fundamental needs of human beings. Therefore, if climate change induced by human activities jeopardizes people's habitats, they need to resettle and/or migrate. The available evidence suggests that anthropogenic climate change has been the hub of human migration in the last decade. This mounting distress has guided scientists and researchers toward extensive arguments on the potential of climate change–engendered population movement (Morrissey 2009). In 2007, the International Organization for Migration (IOM) (2007:1) defined "environmental migration" specifically as:

> persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad. (p. 1)

Subsequently, considering a subset of environmental migrants, the IOM (2007) revised its definition of "climate change migrants" to include a specific reference to climate change, saying that climate change migrants are:

> persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment as a result of climate change that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad. (Kniveton et al. 2008, p. 31)

4.4 Debate on the Term "Environmental Refugee"

The term "environmental refugee" was first formally used by Lester Brown of the World Watch Institute in the 1970s. It became more popular through the work of El-Hinnawi (1985) and later Jacobson (1988) and Black et al. (2001). El-Hinnawi's paper on the topic of environmental refugees has been considered the starting point of the debate on environmental refugees (Morrissey 2009). As El-Hinnawi says:

> Environmental refugees are defined as those people who have been forced to leave their traditional habitat, temporarily or permanently, because of a marked environmental disruption (natural or triggered by people) that jeopardizes their existence and/or seriously affected the quality of their life. (El-Hinnawi 1985; see also Bates 2002 and Westra 2009)

This definition of environmental refugees has generated two major arguments. *Firstly*, it has established a physical relationship between the environment and human migration and, as a result, developing countries that are more concerned about the effects of climate change have been voicing their demand to establish the same rights for environmental refugees as those of other UN-defined refugees. For instance, a delegation from the government of Bangladesh stated at the 2009 Copenhagen Climate Summit:

> Twenty million people could be displaced [in Bangladesh] by the middle of the century. We are asking all our development partners to honor the natural right of persons to migrate. We can't accommodate all these people. (Grant 2009)

All member states that attended the summit supported the appeal of the Bangladeshi delegate (Findlay and Geddes 2011). Since the developed world is more liable to dislocate people by creating climate change—i.e., natural disasters—it is the developed world's responsibility to come forward and show equal concern for environmental refugees. It is, therefore, a matter of concern to all scientists that anthropogenic climate change will force millions of people to leave their homes. Many studies on environmental refugees have been carried out by environmentalists, experts in natural disasters and climate change, geographers, and social scientists. Myers, for example, has estimated that there are nearly 200 million environmental refugees in the world (Myers 1993). Christian Aid (2007) has added that:

> Scientists predict that at the current rate of carbon emissions tens of millions more people will go hungry in the next couple of decades as agricultural yields diminish across the globe. And if nothing is done to stem a rise of 2 °C in global average temperatures by 2050—they say—250 million more people will be forced to leave their homes.

Secondly, some scholars have criticized the fact that environmental refugees are excluded from the UN definition of "refugees." The UN High Commissioner for Refugees (UNHCR) states that a person becomes a refugee:

> owing to a well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion, [and] is outside the country of his nationality, and is unable to, or owing to such fear, is unwilling to avail himself of the protection of that country. (UNCHR:1).

Therefore, migrants due to climate change do not fulfill the *legal* criteria to claim themselves as conventional refugees. Migration due to environmental factors usually takes place within the boundaries of a country. It is mostly seen in developing countries where people are able neither to manage the cost of international migration nor to meet the migration policy of destinations. Moreover, a *methodological* problem arises when researchers only predict the number of migrants induced by potential climate change, while very few empirical studies have so far been done. Environmentalists and policy makers have therefore emphasized the necessity for experimental results to probe the hypothesis that "people have been displacing in response to the adverse effect of climate change." In addition to that, a *theoretical* dispute has been recognized concerning how to distinguish climate change migrants while a number of people are moving as a consequence of other causes. Humanity has always had a tendency to search for a better living place with comfortable working conditions. Along with environmental factors, social, political, economic, geographical, and religious factors also influence people to relocate, which makes it complex to identify only climate-induced refugees (Castles and Rajah 2010).

Considering these problems, Hugo (1996) suggests the use of the term "environmental migrant" instead of "environmental refugee." Some are also influencing victims to stay in their affected homes for as long as possible, receive financial help and protection from developed countries, and adapt to the situation by indigenous means (Findlay and Geddes 2011). For instance, in response to the minister from the government of Bangladesh at the 2009 Copenhagen Climate Summit, the UK's international minister urged greater attention to supporting local climate change adaptation. The reaction carried on:

> It's absolutely legitimate for Bangladesh and the Maldives to make a lot of noise about the very real risk of climate migration—they hope it will make us come to their rescue. But reopening the 1951 Convention [on refugees] would certainly result in tightening of its protections. (Grant 2009)

Drawing upon this phenomenon, this chapter argues that environmental migrants might be more victimized than UN-defined refugees. For example, a coastal settlement submerged by sea level rise can never be recovered. Some argue for a revision of the UN's legal definition of refugees to include environmental refugees, with the aim to assist or provide new living places for victims, as every day the number of environmental migrants is increasing.

4.5 Methodology

4.5.1 Study Area Selection

Various active factors such as cyclones, tidal surges, floods, droughts, saltwater intrusion, waterlogging, floods, riverbank erosion, and drought were considered while selecting the study area. Through extensive review of disaster maps, journal articles, and reports, the top major factors—cyclones and tidal surges—that had contributed (or had the potential to contribute) to migration in Bangladesh were identified. Moreover, previous studies (CEGIS 2010; Khatun 2013) confirmed that Satkhira, in the southwestern part of the country, has been affected by cyclones and tidal surges. On the basis of this analysis, one union in the Shyamnagar thana in this district, named Gabura, was selected as the study area. The selected study area is located in the southwestern coastal part of Khulna Division and borders the Sundarbans—the largest mangrove forest in the world (Fig. 4.1).

The Kapatakh and Kholpetua Rivers surround eight small villages in the Gabura union, making it a small island. Its area is 37.749 km^2, its total population is 32,417, and its literacy rate is 31% (BBS 2012). There are 15 mosques, two temples, nine primary schools, two high schools, and three madrassas in this union. Fishing and agriculture are main sources of livelihoods in Gabura. More than one fourth of the total population is involved either in fish farms (*ghers*) or in fishing in the rivers. Some *ghers* are run by owners from Gabura, while many *ghers* are hired by outsiders. Almost the same proportion of people are involved in agriculture, mostly in

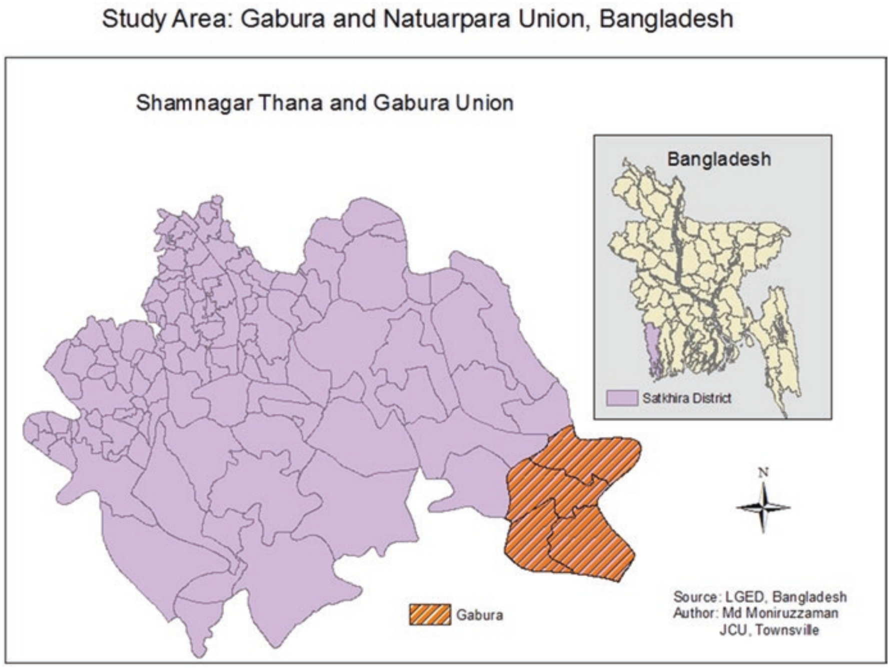

Fig. 4.1 Study area. *JCU* James Cook University, *LGED* Local Government Engineering Department

cultivation of International Rice Research Institute (IRRI) paddy in the winter season (November to February). Women are involved in preparation of the paddy fields. Some people run businesses selling rice, wheat, fish, and daily essentials in the Gabura bazaar. A small number of people work in schools, madrassas, and nongovernmental organizations (NGOs).

4.5.2 Data Collection Method

The study employed qualitative data collection methods, which allowed gathering of descriptive information that illuminated the stories of both migrants from and nonmigrants in the Gabura union. Qualitative methods are particularly appropriate when investigating a sensitive topic in natural settings that cannot be explored in detail through structured quantitative methods (Thomas et al. 2012). In-depth interviews were conducted for this qualitative research (Ulin et al. 2007). The number of participants in a qualitative study is not limited but is often small; it depends on the depth of information and the variation in experiences (Hennink et al. 2010). Hennink et al. (2010) also mentioned that the number of participants to be recruited in qualitative studies is guided by a theoretical principle called *saturation*. The number of nonmigrants in the Gabura union who were selected was 27, and the number of migrants from Gabura who were selected was 26.

Snowball sampling was used to collect the addresses of the migrant respondents, because the target population (migrants) was difficult to locate. Snowball sampling is a method of accumulation in which each position suggests other subjects, and it continues until a satisfactory number of individuals in the target population is interviewed (Babbie 2013). Collection of migrants' addresses was accomplished in three stages. We collected the addresses of individuals who migrated from Gabura throughout the last 25 years or more. Firstly, we collected names and their destination addresses from the villagers; we asked nonmigrant participants, during interviewing, if they knew migrants from either their family, or relatives, or neighbors. Thus we collected 20 addresses, but it was impossible to find all of these migrants by following up these addresses at the destinations. Actually, we found 14 out of 20 migrants from Gabura. As a second step, we collected addresses from migrants of the first stage, who provided nine addresses, of which we physically located seven. Finally, we collected addresses from the migrants we found in the second stage. From there we found five migrants out of seven.

4.6 Factors in Environmental Migration in the Coastal Area of Bangladesh

A number of factors involved in the origin and destination of migrants and the process of migration can broadly be divided into two categories: *push factors* and *pull factors*, which are often used for migration analysis. Push factors are factors or causes that push people away or repel them from certain locations, while pull factors are the conditions that attract people to a particular location (Schoort 1996). Basically all negative factors are termed push factors, such as poverty, lack of jobs, political or religious persecution, and environmental problems. Conversely, all positive factors are termed pull factors, which include higher wages, better living standards, labor demand, political and religious freedom, family reunion, and comfortable weather (Parkins 2010).

4.6.1 Push Factors

4.6.1.1 Loss of Livelihood in the Sundarbans Area

The Sundarbans was one of the main sources of income for locals around the forest. The people of Gabura had to face economic challenges in the 1990s when residents living around the Sundarbans lost their income from this forest. Some respondents who were (at the time of interviewing) more than 40 years old talked about the limitations of entering the forest at that time.

As the respondents said, they used to go to the forest for multiple reasons: collecting wood and *golpata* (nipa palm), hunting deer, gathering honey, and fishing in the rivers. In the southwestern and other parts of Bangladesh, there is a demand for sundri and goran wood for furniture making. Villagers around the Sundarbans used to cut down trees and collect wood illegally from the forest. They even collected fuelwood for selling. Beside this, *golpata* was used as the main material for building houses in coastal areas. Many people of Gabura used to go to the forest and return with a boat full of *golpata*. The *golpata* was sold in the local market and was one of the main sources of their livelihood.

Illegal logging/cutting of wood continued in the Sundarbans for a long time. As a result, big trees disappeared and some parts of this forest were cleared. To protect its biodiversity and to prevent illegal logging, various steps were taken by the government, NGOs, and international agencies such as the UN Educational, Scientific and Cultural Organization (UNESCO) and the World Bank. So, later on it was not that easy to cut trees and collect timber from the forest.

Moreover, many trees are now planted by individuals all over the country for timber production—such as mahogany, rain tree, sal, teak, etc.—so the demand for timber from the Sundarbans has decreased. Moreover, the durability of *golpata*–made houses is very poor. They cannot tolerate even a mild storm. That is why *golpata* collection has decreased.

Timber and honey collection in the Sundarbans is unsafe because the world-famous Royal Bengal tiger lives in this forest. Many people have been killed or injured (and some permanently paralyzed) in attacks by this dangerous animal. Loss of livelihood in the Sundarbans forest has also been blamed by many on robbers. As two migrant respondents (RESP_MIG) said:

> RESP_MIG: Every 3 months we [a team of 5–7 people] used to go to the Sundarbans 3–4 times for gathering honey. One day, one of our members was attacked by a tiger [a Royal Bengal tiger] and he was killed; the other two were seriously injured. We came back immediately. Then my wife did not allow me to go there … I took all my family here [to Khulna].

> RESP_MIG: I was forced to pay to the robbers in the Sundarbans in 2004. My family sold out all belongings and managed 25,000 taka to pay the ransom. I started living like a beggar. Then I came alone to Satkhira city and managed a job as a hodman. After Aila, I brought all my family members here.

A group consisting of 8–10 persons used to go to the Sundarbans with a large boat to collect honey. Many honeycombs can be seen in big trees and bushes in this forest. The honey collectors create smoke by setting a fire and collect honey from these honeycombs. The group would stay in the Sundarbans for 30–40 days and collect up to 100–150 kg of honey. This honey is in high demand all over Bangladesh.

Besides tigers, robbers/pirates are another problem for villagers in the Sundarbans. Their activities are increasing day by day. They kidnap hardworking laborers from the Sundarbans and demand huge money for their release. If the ransom is not paid, they even kill the victim sometimes. Poor families of victims often have to sell their homesteads to rescue the victim. It is one of the major hurdles in earning a livelihood for the people of the Sundarbans.

Moreover, constant honey collection/extraction by the people of Gabura and some other areas has created heavy pressure on this resource. Subsequently, the production of honey has decreased and so they have been unable to collect the quantity they expected. Therefore, they have left this profession and started looking for an alternative.

In 2002, Mofizul Islam came to Khulna from Gabura and took a job doing soil excavation for making buildings. Before this, he used to work in the forest—that is to say, he was part of a team or group. That group used to go to the forest by boat to collect timber and sometimes honey. Because of difficulties in that profession, he came to Khulna in search of a new job. In 2005, he married in Gabura but did not bring his wife to Khulna from Gabura. He used to go to Gabura every fortnight to see his family and used to stay there for 4–5 days. One day, when Cyclone Aila came with a big tidal surge, Mofizul went to Gabura with a hired trolley and took his wife and only child to Khulna. Since then, they have lived in this divisional city. There are many families from Gabura and its surrounding villages who are now living in Mohammad Nagar in Khulna. Some of them came before Aila, and many of them came after Aila. There is a social bond between these families. They help each other and share their happiness and depressions. When Mofizul brought his family to Mohammad Nagar, he rented a house with the help of a family who were also from Gabura. By this time, his second child had been born. This family does not want to go back to Gabura. In response to the question about his return to Gabura, he said:

> There are many types of jobs in Khulna. If I return to Gabura, how will I feed my wife and children?

4.6.1.2 Transformation of Agricultural Land into Fish Farms

Transformation of agricultural land into fish farms is a major cause of unemployment. According to the nonmigrant and migrant respondents, paddy was cultivated heavily in Gabura before 1995. Farmers used to cultivate aman and IRRI rice mostly. Among them, some had their own lands and some were cultivating land leased from others. Many landless farmers worked as laborers in these farms to earn their livelihood. As rice cultivation and processing requires many day laborers, most of the poor were able to get work in paddy fields. Sometimes the landowners experienced labor shortages during the IRRI season in February to April. Women also used to work in the paddy fields alongside the men.

Fish culture started in Gabura—as in other areas of the southwestern region—around 1990. Much of the agricultural land was converted into fish farms. Local influential farmers converted their agricultural land into lowlands and let in salt water from the sea. Fishing being a profitable business, many businessmen took leases for fish farming on agricultural land owned by the local farmers of Gabura. Within 2–3 years, three fourths of the arable land was converted into fish farms and people associated with the paddy fields lost their jobs.

Irrespective of its many environmental problems, fish farming became popular with the people of the coastal areas of Bangladesh (including Gabura) for four reasons. Firstly, rice farming requires much more effort and labor than fish farming. In fact, fishing requires less than one fourth of the labor that agriculture requires. Secondly, it ensures at least five times more profit than rice production. For instance, if the production is good, the profit from rice is 20,000–25,000 taka per acre for rice farming, whereas the net profit from fish farming on the same land can be at least 100,000 taka. Thirdly, in the fish trade the net payment is in cash, unlike the rice trade, in which payment is mostly made via debit. Fourthly, after farming, paddy requires processing, but fish farming involves no such processing. When the fish are ready, dealers catch the fish by themselves and pay the fish farmers.

Many businessmen came to Gabura from the nearby cities, including Satkhira and Khulna. They leased acres of land from the local farmers. Local landowners were also inspired when they received a handsome income without doing any work.

Land prices in Gabura increased by 3–4 times. Poor laborers not only lost their jobs but also any hope of buying a piece of land. Thus they became poorer, and the only option left for them was to migrate.

China Hor is a 36-year-old woman. Her husband is involved in making and selling fishing nets at the local market. She helped her family collect shrimp spawn and sell them to the farms. Her neighbor, Putul, was her helper in shrimp collection. But 7 years ago, Putul left the village with her husband to go to Satkhira. As China said:

> Days are getting more difficult now. We [Putul and herself] used to make up to 80 taka per day each. But her fisherman hubby took her to Satkhira. Now when I go with my 11-year-old boy on some free days for fishing [in the river], we can only earn a maximum of 40 taka per day.

4.6.1.3 Political and Social Instability

Political and social instability in the home place can be a compelling reason to migrate (Parkins 2010). Political and social instability in a country or in a region of a country have dynamic effects on personal and familial behavior, motivating people to find a new and more peaceful destination for the rest of their life (Schoort 1996). Political violence and conflicts were common in Gabura. Local elected chairmen and members of the union council were actively involved in the violence. During the election time, political turmoil became more frequent and was led by local leaders, including union council members and the chairman. A supporter of the leader of the ruling party is in a lucrative position; he can access relief, government land, and resources. Jobless youths join the team of hoodlums. After committing crimes or being involved in incidents, such people used to hide in different areas or were scared, or their opponents forced them to leave the place. Sometimes, parents and other family members would also migrate with them.

The aid provided by the NGOs and other organizations is confined to poor and middle-class families. It has been found that the same persons or families are getting relief/aid from different NGOs or donor organizations in different ways. The elected chairman or members would make up the list with the names of their relatives, known families, and persons who belonged to his/their party. The staff of various organizations would first contact these elected members and the chairman. Then they would provide aid according to the list. As a result, the same families would benefit by receiving aid/relief from different organizations. This relief would sometimes be in the form of cash, sometimes foodstuffs, or sometimes building or construction materials. Using these materials, they were rehoused even better than before. On the other hand, those who did not receive any relief became helpless and migrated. A migrant in Khulna expressed the following:

> RESP_MIG: I had good relations with the chairman. After Aila, when I became jobless, I joined his gangsters. I used to receive money and relief regularly. Soon I realized my involvement was getting more and more dangerous. He gave me a weapon and made me the leader of his gangsters. I even led some lootings of opposition houses. My mother told me to come out from the hoodlums. I said to my mother that they would kill me if I left. One night, I left the village with my family and came to Khulna where my brother lived.

4.6.1.4 Climatic Hazards: Cyclones and Tidal Surges

Climatic hazards are considerable factors contributing to the migration process. In our study area, two significant drivers related to extreme climatic events were considered for migration: cyclones and tidal surges. The following factors were found during interviewing at Gabura.

House Destruction

Destruction of houses and properties was one of the main reasons that led some respondents to leave Gabura. In response to the question “Why did you migrate?” most of the affected interviewees claimed that cyclones (Aila and Sidr) and tidal surges from the southern sea (the Bay of Bengal) destroyed their houses, blew away schools, damaged trees and vegetable gardens, and killed domestic animals (cattle, goats, ducks, and chickens).

> RESP_MIG: Well, just the fact that … it’s hard to explain. We had a well-organized home, a vegetable garden in the yard, and three goats and some hens were part of my family, which helped me to earn additional money. Now I have nothing; everything was swept away with the giant tidal surge.

> RESP_MIG: It is unbelievable. If you go now where we used to live, you will not believe that once there were some houses in that place. There is no trace of our house, which was made with mud and straw. After a lot of trouble, we took shelter at a cyclone center and then managed to come out here [Khulna].

> RESP_MIG: First we took shelter on the roof of our house, then we were two days on a boat. In the meantime, Aila destroyed our house. Then we took the decision to come to Binerpota, Satkhira, where we stayed two months, and then came here to Khulna.

Most of the houses in Gabura were made of mud, straw, or tin, known as *kacha* houses. Cyclones Sidr and Aila destroyed not only these *kacha* houses in Gabura but also schools and many small business shops. Many people and their children had no place to live immediately after Cyclones Sidr and Aila when tin shacks were flattened and mud and straw houses were washed away. After receiving shelter in different places, including cyclone centers and on the roofs of houses, the people came back to see the condition of their houses, where they found them totally unusable or even unable to be rebuilt. Some of the people kept waiting for better conditions, while others found no hope and left for different destinations.

Frightening Situations

Mostly women (wives of interviewees) who had seen dead human bodies, including those of children, got frightened and forced their husbands to leave the place. Cyclone Sidr hit the coastal area in 2007; 2 years later the people of Gabura experienced Cyclone Aila with a tidal surge. Many of them started thinking that this kind of disaster would happen very frequently, which might impact their lives, including those of their children.

Shanewaj is 43 years old. He came to Khulna just a day after Cyclone Aila struck. Seeing the pathetic condition of women and children, he was very frightened. He helped many women and 16 children to traverse by boat as he was working as a member of a rescue team. He said:

> I rescued almost ten dead bodies from river and canals. I had a picture with them on the daily newspapers published at that time. I cannot remember those things again. It has a great impact on my mind and I got sick mentally. For 3 months I did not have a normal life. My wife does not want me to go back again from here [Khulna] to Gabura.

Some women lost their children in the tidal surge that occurred during Cyclone Aila. The tidal surge hit the village during the day when the men had left their homes and were at work. As a result, women were at home with their children. At the time when the wave entered the land from the south, many women became helpless and could not protect their children alone. As Salma explained:

> I could not protect my second daughter. She was 6 years old. Along with my first daughter who was 8, she [the lost daughter] held my neck and I took my 3-year-old son with my hand. The level of water was up to my shoulder. When a big wave of severe current hit us, she was swept off my shoulder and drifted away forever. I held onto a tree for 1 day until a boat found and rescued us.

Loss of Livelihood

Cyclone and tidal surges caused loss of livelihoods in Gabura. Many migrants and nonmigrants lost their jobs after Cyclone Sidr, which brought salt water inland through the tidal surge. Migration was mostly livelihood related. Many migrants argued that they had lost both their occupation and their agricultural territory, and they tried to manage jobs outside the village.

> RESP_MIG: I lost my job when salt water damaged our agriculture field.

> RESP_MIG: Not only rice, trees were lost on saline land. All types of trees and vegetation died because of stagnant water for months, even years in some places.

> RESP_MIG: Fish were washed away from ponds to rivers, which [wasted] millions of taka [money]. All fish farms, agricultural lands, and settlement areas were flooded under a single body of water. For a long time, people had no jobs. Some got help from NGOs and others left the area. But now many people have gone back as there is now water … but I did not go back.

Nonmigrant respondents (RESP_NMIG) said:

> RESP_NMIG: For 2 or 3 years we did not cultivate our land. Salt water made the land unfertile.

> RESP_NMIG: The soil of the whole village has become saline. Therefore we still cannot cultivate rice as before. Fish are affected with unknown viruses. Only a few groups of fish traders are here frequently.

Many people became jobless when a big tidal surge during Cyclone Aila washed everything away. Salt water entered the villages with the big surge and destroyed all croplands and fish farms. Since this salt water was stagnant for 3 years, most of the arable lands became saline, where crops could hardly be grown. Moreover, the water in the fish farms also changed from being mildly saline to being highly saline. Fish that were being cultivated in mildly saline water died in the highly saline water. As a result, many people who were affiliated with the above two sectors lost their jobs. Some of these jobless people at last decided to move to nearby towns where jobs were available to them.

Migration is also related to domestic animals and price hiking of daily essentials. Some respondents claimed that they were now not able to tend to domestic animals. Some also talked about the climbing prices of medicine and other essentials. According to the nonmigrants:

> RESP_NMIG: We have lots of problems in this village. We don't have any goats or cows. People don't drink milk for a long time. Grasses cannot be grown; what will they eat?

> RESP_NMIG: We all have stomach problems. We used to drink pond water, but now it has become polluted with salt water. Still we are drinking this saline water; our kids are too … medicines are expensive here; we need long time to go to the city in case of emergency. Life has become so difficult in this village. The people who have shifted from here did well.

> RESP_NMIG: Living in the town for me [a woman] is boring. In the village I had some goats and hens, from which I could earn some money for my own. Now, every time I ask my husband to give [me] some money.

Most of the people in the village have pet animals at home, such as lambs, goats, cows, and hens. Spending time with those animals provides additional recreation for women and children. Moreover, they are a source of meat and additional income for a family. They use meat from these domestic animals when relatives visit their homes. These animals are the only source of milk in the village; they use cow's milk

Fig. 4.2 Drinking water collection from ponds

for their family members and sometimes they sell it in the local market. This animal feeding tradition was affected in Gabura when salt water damaged grasses in the village. So far, they have been unable to grow grass because the soil has become saline. As a result, few families keep domestic animals now and this minor source of income has also decreased (Fig. 4.2).

In addition to that, the availability of fresh and healthy drinking water has become a problem in the village. There were some selective ponds that they previously used for drinking and domestic purposes only. Salt water polluted all of these ponds during Cyclone Aila in 2009, so the villagers could not use water from those ponds as before. Some obtained alternative rainwater storage systems (discussed in Chap. 8), but they are costly. However, some people are still using polluted saline water from ponds and getting health problems. Both migrants and nonmigrants mentioned the above two issues.

Loans from Nongovernmental Organizations

Taking loans from NGOs is very common in the coastal areas, especially in Gabura. Migrants from Gabura did not acknowledge getting loans from NGOs. However, NGO officials claimed that many people took loans from their organizations between Cyclones Sidr and Aila and left the village after Aila forever. The manager of the Gonomukhi Foundation claimed:

> We distributed loans among 122 families in the Gabura union. Out of them, around 25 families disappeared [migrated] after Aila. Many of them took loans from other NGOs as well.

Poor people from Gabura took loans after Cyclones Sidr and Aila, ranging from around 30,000 to 50,000 taka. Some men used their wives' names to obtain further money from the same NGOs they had used before in their own names. Doing this several times, their liability became a very big amount, which they were unable to pay back, or they simply failed to pay regular installments in different places. When a big cyclone (Aila) came in 2009, they lost their houses and went away to different locations. But the NGOs claimed that they did not go back because of their NGOs loans.

4.6.2 Pull Factors

4.6.2.1 Job Availability

Job opportunities are one of the most significant causes of migration. Respondents from Gabura talked about the availability of work in the places to which they had migrated. The main aim of migrants was to increase their level of income and reduce their poverty. When we asked about the causes of their migration, many of their answers were job related. This clearly showed the difference in family earnings in the host and home places.

> RESP_MIG: I got a job in newspaper distribution in this city and I left Gabura temporarily in 2005, but I brought my family to Satkhira after Aila in 2009 and got settled permanently. I was running a fish farm in Gabura, where I lost all my money and investment.

> RESP_MIG: I pull vans [three-wheelers] in this city [Khulna]. Sometimes I take passengers, and sometimes I bring vegetables on it. I earn every day almost 300 taka … I came here after Aila.

The relation between job availability and migration received special attention from the researchers, as it is important to the economic growth of the migrant families as well as the country. Whether they migrated before or after a cyclone or tidal surge, or for other political or economic reasons, the migrants were in search of new income sources in nearby cities and villages. Once they found some reasonable work, they planned to shift to new places. For instance, people from Gabura migrated to Jessore, Khulna, Jhikorgacha, and Satkhira, and engaged mainly in day labor work.

Easin Dhali is a 26-year-old man from Gabura. Like his elder brother, who was a construction supervisor and left the village for Satkhira a day after Cyclone Aila, he was searching for a job outside the village. First he went to Khulna and got a job as a security man for a house. After 3 months, he lost that job, but he did not go back to Gabura. He shared his friend's slum in that city for some time. Meanwhile, one of his friends in Jhikorgacha helped him to get a job in a vegetable market there. He loads and unloads vegetables between vans and different shops.

4.6.2.2 Land Availability

Becoming an owner of land at the destination has caused migration in certain cases. In this research, we found that three migrants migrated with their family to become owners of a piece of land at their destination.

> RESP_NMIG: We came here [Khagrachari] only to buy a small hill at a cheap price from the Chakma [an aboriginal group]. Now we can grow some crops and fruit.

Migrants felt that becoming an owner of a piece of land is a great achievement in life. It is important to them because firstly the place where they used to live was affected by weather or vulnerable to natural hazards, and secondly they needed a permanent shelter for themselves and for their children.

4.6.2.3 Education and Better Lifestyle

Migration is very often related to better education for children and, broadly speaking, a better life. Middle- and upper-class families from rural areas can decide to move to urban areas to provide better life facilities and quality education for their children. Five respondents who migrated from both of the study areas told me how education was a part of their migration process; three of them said:

> RESP_MIG: Among many reasons, my children's education was one. [You know] schools in villages do not maintain the standard of quality education, even; it is very hard to find a good home tutor. Comparatively, many good-quality schools are here and I can choose any one of them. … I hope they [the children] can make a good base from their present school.

> RESP_MIG: I don't say my son will be a doctor or engineer, but at least we expect a bright future, a better job, and afterward a better life. I don't have money so that he [my son] can do business in future. I have tried my best; I even brought my family here to give him [my son] a better education. Now, it's up to him.

> RESP_MIG: I can go back to my village, but my wife and I have decided to stay here only for our daughter. Schools are better here [in Satkhira] and, being a good student, my daughter is receiving additional attention from her teacher.

Four respondents migrated only for their children's education. Village schools have many problems in terms of quality education and the availability of facilities, but problems in the schools in disaster-affected areas are more acute. For example, schools in these areas remain closed for a long time during disaster periods, and they are even used as shelter centers. Moreover, many schools have disappeared in the rivers or been damaged by either cyclones or floods; many schools were found to have no tables or chairs for students. Although many parents had the capability to endure the stress and shock they experienced from different hazards, and their family condition in terms of their financial means was not that much worse, they were worried about their children's education and their future. As a result, they migrated to city areas where their children could attend better schools.

4.7 Conclusion

This chapter has focused on factors behind migration processes. People evidently migrate because of both push and pull factors, but push factors are more active than pull factors.

For a long period of time (around 30 years), human professions have been impacted badly by a number of factors. Firstly, the people of Gabura used to collect timber (*golpata*) and honey from the Sundarbans for trade, which was subsequently hampered for multiple reasons (e.g., government policy, decreased demand for timber and *golpata*, tiger attacks, and kidnapping for ransom). Secondly, rural people took loans at high interest rates from NGOs working near them and, after becoming poorer, changed their locations and especially moved to big city areas, so that NGOs could not find their addresses to demand that they pay back their loans. Thirdly, when the livelihoods of rural people became vulnerable for the above two reasons, the continuous impact of natural disasters makes their lives more fragile. When residents understand that cyclones and tidal surges are becoming more powerful and frequent, they take the decision to move to comparatively safer places.

Besides push factors, this study also identified three pull factors, which were important in drawing people from Gabura to different cities and villages in Bangladesh. Firstly, people migrate to different city areas or villages because of better job opportunities. Migrants who are not skilled in any specific profession move to city areas. Secondly, some migrants resettle in a place where land is available at a reasonable price. Finally, some families move to city areas for better education of their children.

References

Afifi T, Jager J (2010) Environment, forced migration and social vulnerability. Springer, Berlin

ADB (Asian Development Bank) (2012) Climate induced migration. Retrieved from http://www.adb.org/themes/climate-change/climate-induced-migration

Babbie E (2013) The basics of social research. Wadsworth, Cengage Learning

BBS (Bangladesh Bureau of Statistics) (2012) Population and housing census—2011. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka

Bates D (2002) Environmental refugees? Classifying human migrations caused by environmental change. Popul Environ 23(5):465

Black R, Bennett SRG, Thomas SM, Beddington JR (2001) Climate change: migration as adaptation. Nat Int Weekly J Sci 478:477

Castles S, Rajah C (2010) Environmental degradation, climate change, migration and development: Mexico 2010. Retrieved from http://www.nnirr.org/~nnirrorg/drupal/sites/default/files/pga-paper-on-environment-and-migration-by-castlesrajah.pdf

CEGIS (Centre for Environment and GIS) (2010) Climate change study division. Retrieved from http://www.cegisbd.com/climate_div.htm

Christian Aid (2007) Human tide: the real migration crisis. Retrieved from www.christianaid.org.uk/images/human-tide.pdf

Drake F (2000) Global warming: the science of climate change. Arnold/Copublished in the United States of America by Oxford University Press, London/New York

El-Hinnawi E (1985) Environmental refugees. United Nations Environment Programme, Nairobi

European Community (EC) (1998) Cyclone shelter preparatory study (CPSP) stage I: feasibility study, draft final report; Suppl. Vol. 3, Community development studies, Part A, Suppl. Vol. 8; Environmental analysis, field visits and other notes. EC/Sener Ingenieria Sistemas SA, 1996

Findlay F, Geddes A (2011) Critical views on the relationship between climate change and migration: some insights from the experience of Bangladesh. In: Piguet E, Pecoud A, Guchteneire PD (eds) Migration and climate change. Cambridge University Press, Cambridge

Grant H (2009) UK should open borders to climate refugees, says Bangladeshi minister. The Guardian, 4 December. Retrieved from http://www.guardian.co.uk/environment/2009/nov/30/rich-west-climate-change

Hennink M, Hutter I, Bailey A (2010) Qualitative research methods. SAGE, London

Hugo G (1996) Environmental concerns and international migration. Int Migr Rev 30(1):105

IOM (International Organization for Migration) (2007) Discussion note: migration and the environment. IOM, Geneva. Retrieved from https://www.iom.int/jahia/webdav/shared/shared/mainsite/about_iom/en/council/94/MC_INF_288.pdf

Jacobson J (1988) Environmental refugees: a yardstick of habitability, World Watch paper, no. 86. World Watch Institute, Washington, DC

Karim N (1995) Disasters in Bangladesh. Nat Haz, ISSN 0921-030X, 5/1995 11(3):247258. Kluwer Academic Publishers. Printed in the Netherlands

Khatun M (2013) Climate change and migration in Bangladesh: golden Bengal to land of disasters. Bangladesh Sociological Society, Volume 10 (November 2). Retrieved from http://www. bangladeshsociology.org/Climate%20Change%20BEJS%2010.2%20Final-5.pdf

Kniveton D, Schmidt'Verkerk K, Smith C, Black R (2008) Climate change and migration: improving methodologies to estimate flows. Geneva, International Organization for Migration. (Migration Research Series No. 33)

Lein H (2009) Climate change and forced migration Bangladesh. IOP Conf Ser Earth Environ Sci 6(56):562015

McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL, Githeki A, Scheraga JD, Woodward A (2003) Climate change and human health: risks and responses. World Health Organization, Geneva

MoEF (Ministry of Environment and Forests) (2009) Bangladesh climate change strategy and action plan 2009. MoEF, Government of the People's Republic of Bangladesh, Dhaka

Morrissey J (2009) Environmental change and forced migration: a state of the art review, Refugee studies centre. Oxford Department of International Development/University of Oxford, Oxford

Musa ARMA (2011) Bangladesh—climate displacement. Displacement solutions. Retrieved from http://displacementsolutions.org/ds-initiatives/climate-change-and-displacement-initiative/bangladesh-climate-displacement/

Myers N (1993) Ultimate security: the environmental basis of political stability. WV Norton, New York/London

NRC (Norwegian Refugee Council) (2012) Climate change and disaster induced displacement. Retrieved from http://www.nrc.no/?aid=9407106

Parkins NC (2010) Push and pull factors of migration. Am Rev Polit Econ 8:6–24

Schoort J (1996) Determinants of international migration: theoretical approaches and implications for survey research. In: Vandererf B, Heering L (eds) Causes of international migration: proceedings of a workshop, Luxembourg, 14–16 December 1994. DIANE Publishing

State of Environment Report (2001) Natural disasters. Retrieved from http://www.rrcap.unep.org/pub/soe/bangladesh_disasters.pdf

Thomas J, Nelson J, Silverman S (2012) Research methods in physical activity, 6th edn. Human Kinetics, Champaign

Ulin PR, Robinson ET, Tolley EE (2007) Qualitative methods in public health: a field guide for applied research, 1st edn. Jossey-Bass, San Francisco

UNDP (United Nations Development Program) (2004) Reducing disaster risk: a challenge for development. UNDP Bureau for Crisis Prevention and Recovery, New York

Westra L (2009) Environmental justice and the rights of ecological refugees. Earthscan publishers in association with the international institute for environment and development, London

Chapter 5
Risks and Adaptation Strategies for Climate Change: A Community-Based Assessment Study in the Chittagong Hill Tracts of Bangladesh

Salma Mamtaz, Md. Mahbub Murshed, Mohammod Asaduzzaman, and Md. Nazrul Islam

Abstract The Chittagong Hill Tracts (CHTs) of Bangladesh are the most disadvantaged and vulnerable regions in the country in terms of geographical settings and almost all major development indicators, such as income, employment, poverty, health, water and sanitation, education, and access to infrastructure. The area is mainly inhabited by indigenous communities, who depend on the hill resources for their livelihoods.

5.1 Introduction

The Chittagong Hill Tracts (CHTs) of Bangladesh are the most disadvantaged and vulnerable regions in the country in terms of geographical settings and almost all major development indicators, such as income, employment, poverty, health, water and sanitation, education, and access to infrastructure (UNDP 2009). The area is mainly inhabited by indigenous communities, who depend on the hill resources for their livelihoods.

Indigenous peoples depend on natural resources for their livelihood, and they often inhabit diverse but fragile ecosystems. At the same time, indigenous peoples are among the world's most marginalized, impoverished, and vulnerable peoples. To indigenous peoples, climate change is, however, not simply a matter of physical changes to the environments in which they live. Many consider climate change a

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threat to their livelihoods, and they fear that their economy and resource use will be threatened, followed by an erosion of their social life, traditional knowledge, and culture. Hence, to indigenous peoples, climate change is not only an environmental issue but also a human rights issue (World Bank 2000).

According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), South Asia is the world's most vulnerable region to climate change impacts (McCarthy et al. 2001; Gunter et al. 2008). Land and ecosystems are being degraded, threatening to undermine food security. In addition, water and air quality are deteriorating, while continued increases in consumption and associated waste have contributed to the exponential growth in the region's existing environmental problems. Changes in climate variability are uncertain. The IPCC (Houghton et al. 1999) concluded that higher maximum and minimum temperatures are very likely, more intense precipitation is very likely in most areas, and more intense droughts, increased cyclone wind speeds, and precipitation are likely in some areas.

The international community also recognizes that Bangladesh ranks high in the list of the most vulnerable countries on earth. Bangladesh's high vulnerability to climate change is due to a number of hydrogeological and socioeconomic factors, which include (a) its geographical location in South Asia; (b) its flat deltaic topography with very low elevation; (c) its extreme climate variability, which is governed by the monsoon and results in acute water distribution over space and time; (d) its high population density and high prevalence of poverty; and (e) the fact that the majority of its population are dependent on crop agriculture, which is highly influenced by climate variability and change (Ahmed 2006). The land of Bangladesh is highly subject to natural hazards. There is evidence of prominent increases in the intensity and/or frequency of many extreme weather events such as heat waves, tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, and thunderstorms in the region (Cruz et al. 2007). The impacts of such disasters range from hunger to susceptibility to disease, loss of income, and loss of livelihoods, affecting human survival and well-being. In recent years, enormous pressures have been put on ecosystems to support the ever-growing demand for natural resources. Coastal and marine ecosystems, forests, and mountainous regions—and the flora and fauna within them—are most affected. Climate change will have a profound effect on the future distribution, productivity, and health of forests. Preparedness and actions are needed for a changing climate, and adaptation measures may be slow but must be taken. Capacity and knowledge need to be applied to better manage the present risks, adapt to changing future risks, and integrate climate risk management into development strategies.

This chapter focuses on risks and vulnerabilities to climate change and climate variability—as well as adaptation capacities—in the hilly region of Bangladesh, based on indigenous community perceptions.

5.2 Geographical Description of the Chittagong Hill Tracts

In terms of its ethnic, cultural, and environmental diversity, the CHT region is distinctly different from the rest of Bangladesh (Roy et al. 2000; Rafi and Chowdhury 2001). This region, with an area of 13,294 km^2 (about 10% of the land area of Bangladesh), is located between 21.25° and 23.45° N latitude, and between 91.45° and 92.50° E longitude. Geographically, the CHTs are part of Hill Tripura and the Arakan Yoma range, branching off from the Himalayan range and continuing to the south through Assam and Hill Tripura in India to Arakan in Myanmar (Fig. 5.1) (MCHTA 2012; Rafi and Chowdhury 2001; Roy et al. 2000; UNDP 2008). The topography of the region features mountains and valleys, covered by dense evergreen rain forests. The relief ranges from 60 to 90 m above sea level in the north to 300–600 m in the south (Hassan et al. 1995; Khan 1991 and Rashid 1991). Almost all soils in the region have low inherent fertility. The water-holding capacity of most of the soils is very low. Because of the poor soil condition, only 3.2% of the land in the region is suitable for all-purpose agriculture, about 15% is appropriate for fruit gardening and forestry, and 77% of the land is suitable solely for forestry(Roy et al. 2000; Rafi and Chowdhury 2001).

The temperatures in the region range from 10.2 to 35.1 °C during the year. The higher temperature is usually accompanied by high humidity during the rainy season. The rainfall in the region ranges from 85 to 120 inches (2159 to 3048 mm) a year. The southern part of the region receives more rainfall than the north. About 80% of the total rainfall takes place in May–September, in the form of torrential downpours. Rainfall during the other 7 months (the drought period) is not only very low but also highly unpredictable (Rafi and Chowdhury 2001).

5.3 Communities in the Chittagong Hill Tracts

The CHT region is inhabited by a total of 1,587,000 people (BBS 2012), who are divided into 12 ethnic groups, including 11 hilly ethnic groups and Bengali people. The eleven ethnic multilingual minorities are Bawm, Chak, Chakma, Khyang, Khumi, Lushai, Marma, Mro, Pangkhua, Tangchangya, and Tipra or Tripura. Most of the hilly ethnic groups are of Sino-Tibetan descent and have distinctive Mongoloid features (MCHTA 2012; Rafi and Chowdhury 2001; Roy et al. 2000; UNDP 2008).

Administratively, the CHTs comprise three hill districts: Bandarban (4479 km^2), Khagrachari (2699 km^2), and Rangamati (6116 km^2). Besides the formal administrative structure of the region, the CHTs are traditionally divided into three circles: (i) the Chakma circle; (ii) the Mong circle; and (iii) the Bhomong circle. Each of the circles is headed by a circle chief, traditionally known as the Raja(king). The circle chiefs are entrusted with the collection of taxes and are empowered to resolve conflicts among the people under their respective jurisdictions. The circle chiefs are represented at the *mouza* level by a headman and at the village level by a *karbari* (MCHTA 2012; Rafi and Chowdhury 2001; Roy et al. 2000; UNDP 2008). In terms

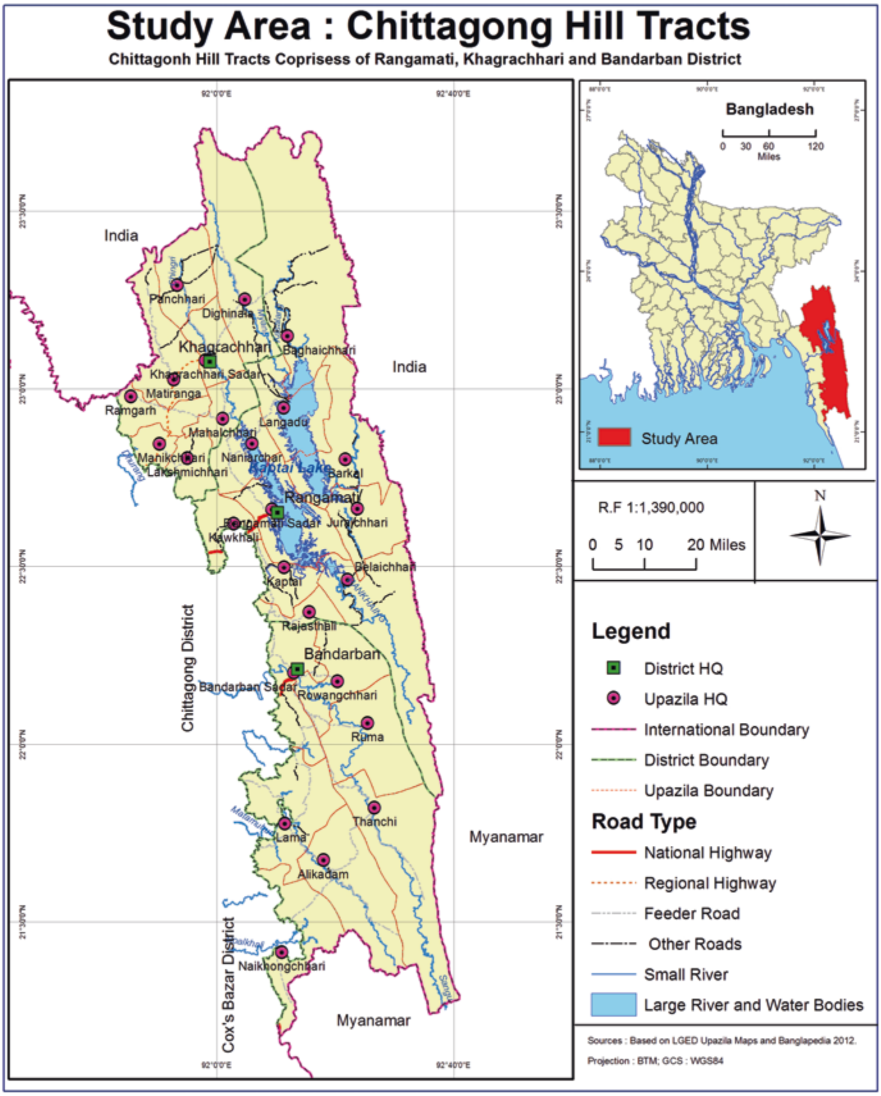

Fig. 5.1 Location of Chittagong Hill Tracts. *BTM* Bangladesh Transverse Mercator,*GCS* geographic coordinate system, *LGED* Local Government Engineering Department

of the ethnographic makeup of the CHTs, 77% of the *paras* (villages) are inhabited by one or more indigenous/tribal communities, 16% *paras* are inhabited by only Bengalis, and the rest are mixed *paras* (UNDP 2009). The population in the CHTs is young, with 58% of the population being below the age of 24 years.

A 2008 United Nations Development Program (UNDP)survey (2008) on ethnic communities found that 7.8% of all CHT people (aged 5 years and above) had completed primary education and 2.4% had completed secondary education. About 54% of the household heads had no education. About 9.4% had completed primary education, 4% had completed secondary education, and only 2% had completed more than secondary education.

The delivery of essential services has produced tangible results. In education the net enrolment in 2011 reached around 90% (as compared with 49% in 2009) and gross enrolment reached 95% (as compared with 82% in 2009). Community-based health services, delivered to an under served population of 500,000, have contributed to reductions in mortality and morbidity associated with preventable causes. In agriculture, a suitable strategy for the CHTs has been developed and the geographical coverage has been increased, with approximately 328 hectares of land, covering 62 communities, benefiting from five irrigation schemes.

Poverty in the CHTs is higher than in rural Bangladesh; 75% of CHT households live below the lower poverty line (<US$12 per person per month) and 86% below the upper poverty line (<US$15 per person per month). On the basis of direct caloric intake (DCI), about 62% of households, irrespective of ethnicity, live below the absolute poverty line (consuming below 2122 kcal per day), while 36% are defined as hard-core poor (consuming below 1850 kcal per day).

5.4 Livelihood Patterns

The impact of climate change can be much greater for indigenous communities living in more remote and ecologically fragile zones and relying directly on their immediate environments for subsistence agriculture (UNFCCC 2004).

Agriculture is one of the major occupational choices in the CHTs. The people depend on it for their livelihood. The major agricultural crops are potato, leafy vegetables, wheat, cabbage, buckwheat, carrot, and beans (white). Regarding the agricultural production sufficiency, 40% have enough food production for 9–12 months, and the rest are suffering from food deficiency. Nearly 70% of the households cultivate crops such as potatoes, leafy vegetables, cabbage, cauliflower, carrots, radish, and beans for the purpose of selling. The people in the CHTs are dependent on the hills and hill resources for their livelihood. Traditional slash-and-burn or *jhum* cultivation is the primary occupation of 46% of the household heads. In January/February, a plot of mountain with a gentle slope is selected and its vegetation coverage is slashed and left there to dry. After sometime the dried vegetation is set ablaze to fertilize the topsoil. Next, small beds are prepared in the plot, and paddy, cotton, watermelon, lady's-finger, bottle gourd, sesame, and a variety of indigenous seeds are sown all together. Harvesting and collection of crops and vegetables from these seeds are done throughout the year, as they become ready for harvesting at different times of the year. Plow cultivation is done on the plains located in the river valleys and the stretches of plains between hills where irrigation is possible. In addition to bullocks, power tillers are also used nowadays in cultivation of floodplains. Livestock rearing is another common income source. People who own livestock—such as cows, oxen, goats, pigs, or tame elephants—have more income than farmers doing all of the work by human labor. Fruit growing, fishing, and hunting are also popular among the hill people in the CHTs. Traditionally, the economy of the people is one of survival or subsistence, with limited production for the market. From this perspective, loss from climate change is likely to be greatest for poor and marginalized people who depend almost exclusively on natural resources. With poverty, poor infrastructure (roads, electricity, water supply, education and health care services, communication, and irrigation), and reliance on subsistence farming and forest products for livelihoods, health indicators are being affected.

5.5 Community Observations and Perceptions on Climate Change

There are hardly any data available to compare past and present climate changes in the CHT region that can be used to identify the vulnerabilities and threats to the local environment, lives, and livelihood of the people,caused by climate change. The reason may be the backward geographical setting and the remoteness of the CHTs. Again, there is an acute research gap with regard to the impact of climate change on the CHT region; that is why relevant scientific literature is not available. Given that fact, community observations and perceptions are the only way, at the moment, to identify the changing pattern of climate and its impacts in the region. As for the people's awareness of and knowledge about climate change in the hill areas, only 10% of the people understand it (Fig. 5.2). Though the local people do not understand climate change, they have experienced changes in terms of temperature and rainfall.

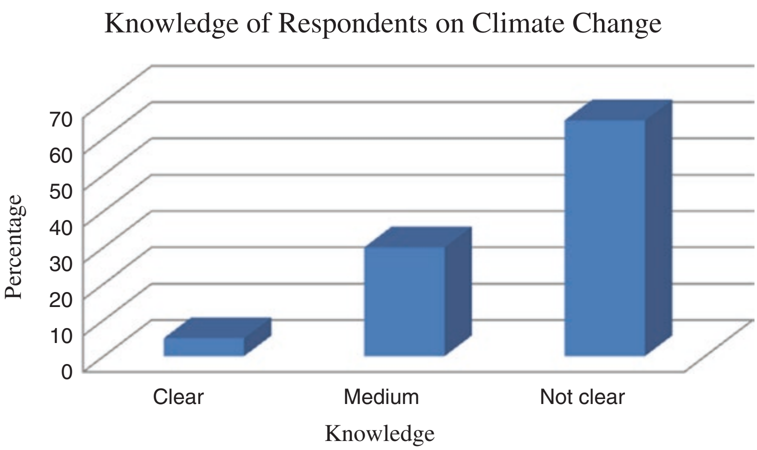

Fig. 5.2 Knowledge of local people about climate change. A field survey was conducted from February to April 2014 to obtain primary data focusing on the present research objectives. Three villages from three hill districts were selected randomly. A total of nine focus group discussions were conducted (three in each village). In three of the discussions the participant types were household heads/aged persons, farmers, and knowledgeable/experienced indigenous persons from the area

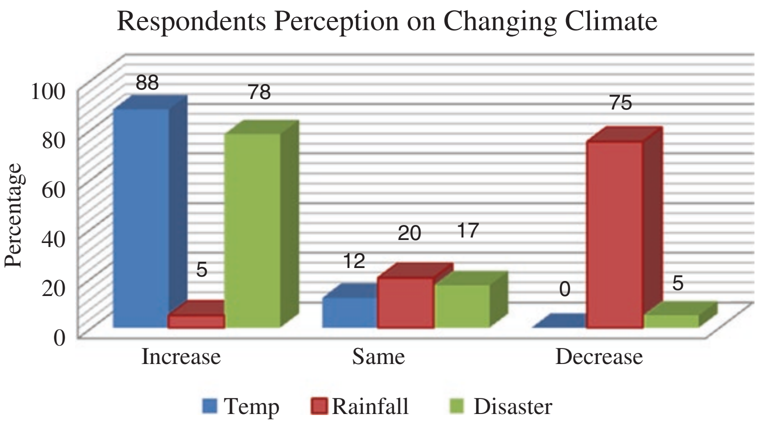

Fig. 5.3 Perceptions of local people about climate change. A field survey was conducted from February to April 2014 to obtain primary data focusing on the present research objectives. Three villages from three hill districts were selected randomly. A total of nine focus group discussions were conducted (three in each village). In three of the discussions the participant types were household heads/aged persons, farmers, and knowledgeable/experienced indigenous persons from the area

In participatory focus group discussions held in the pilot villages of three hill districts (Rangamati, Khagrachhari, and Bandarban), participants stated their perceptions that the current climate in the region is behaving differently than in the past, with more frequent droughts, changes in seasonal rainfall patterns, and unseasonal rainfall. In addition, 88% of respondents perceived that the average temperature has increased in the summer over the years and that the duration of winter has shortened; 78% claimed that the incidence of different disasters has increased (Fig. 5.3).

They perceived that because of higher temperatures and changes in precipitation, the intensity of climate change impacts has increased, thus posing a threat to their survival. The sectoral impact of climate change has ranked highly in view of people addressing this issue in several focus group discussions. Among them, the agricultural sector has been prioritized as the sector with the greatest impacts perceived by local people.

Temperatures are likely to increase more in mountain areas than elsewhere. Global climate change will also likely shift monsoon precipitation patterns in ways that will threaten the CHTs' current agricultural practices and biodiversity where migration of species is physically restricted.

With respect to people's perceptions of climate change in the area, they marked its impacts indifferent categories as high, medium, low, and negligible (Table 5.1). The rankings for categories in which high impacts were perceived were led by agriculture, followed by forestry, biodiversity, water and hydrology, ecology and the environment, and health and sanitation. The rankings for categories in which medium impacts were perceived were led by biodiversity, followed by forestry, agriculture, water and hydrology, health and sanitation, and ecology and the environment. The rankings for

Table 5.1 Rankings of survey respondents' perceptions of climate change impacts

Category	Likely impact of climate change (as judged by survey respondents)			
	High	Medium	Low	Negligible
Agriculture	25	15	3	2
Forestry	24	16	2	3
Health and sanitation	10	12	20	8
Water and hydrology	22	15	3	4
Ecology and the environment	16	2	5	8
Biodiversity	23	20	6	1

A field survey was conducted from February to April 2014 to obtain primary data focusing on the present research objectives. Three villages from three hill districts were selected randomly. A total of nine focus group discussions were conducted (three in each village). In three of the discussions the participant types were household heads/aged persons, farmers, and knowledgeable/experienced indigenous persons from the area

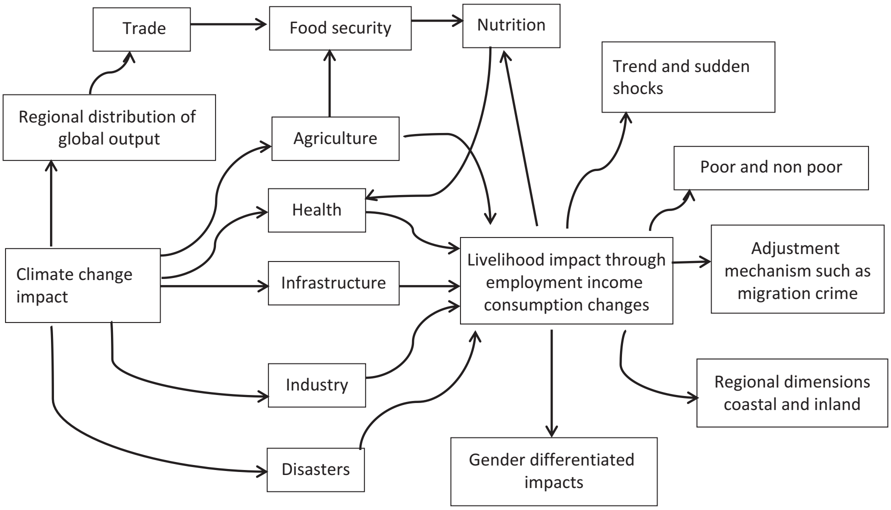

Fig. 5.4 Intensity of climate change impacts on different sectors. (Source: NAPA 2005)

categories in which low impacts were perceived were led by health and sanitation, followed by biodiversity, ecology and the environment, agriculture, water and hydrology, and forestry. The rankings for categories in which negligible impacts were perceived were led equally by health and sanitation, and ecology and the environment.

In a nutshell, the local people considered agriculture, forestry, and sources of water as priorities requiring action, as they have a lot of concern about how to sustain and improve their livelihoods.

At the grassroots level, people in this area have organized and implemented practices to combat climate change by minimizing consumption of energy, promotion of renewable energy, and river course protection and watershed management through a plantation program (Fig. 5.4).

5.6 Identification and Assessment of Risks/Threats Due to Climate Change (Based on Community Perceptions)

The CHTs support sub ecosystems that are rich in species and biodiversity. These give livelihood support to the hill people in the region. The hill sub ecosystems in the CHTs are likely to be affected by climate change stresses such as temperature rise, erratic rainfall, and increased drought spells (Rahman 2014). The key threats of abnormal climatic behavior, as perceived by the local people, are likely to result in an imbalanced environment through deforestation, loss of biodiversity, loss of water sources, less food production and increased food insecurity, increased diseases, significant intensification of flash floods and landslides, and ultimately loss of livelihood and loss of traditional culture.

While flash floods and landslides in the CHTs are related to mostly man-made soil erosion and deforestation, the frequency and severity of such disasters are likely to increase sharply because of climate change–induced increases in precipitation (Gunter et al. 2008).

Thus a negative scenario could be triggered because of increasing population pressure and nonsustainable human use of hills and hill resources. The whole scenario is represented in Fig. 5.5.

5.6.1 Seasonal Calendar Change

The people in the CHTs historically follow a seasonal calendar for their traditional *jhum* and floodplain land cultivation and other livelihood activities (Table 5.2). But in recent years the schedules of the seasonal calendar have been disturbed by abnormal climatic behavior, as perceived by the CHT communities. During the focus group discussions it was evident that the main change in the seasonal calendar has occurred in the timing of the *jhum* plantation and harvest period. The ethnic household heads mentioned that in previous years (15 or 20 years before) they sowed *jhum* seeds with the season's first rain in the first half of May, but in recent years rain had become uncertain, with droughts being more frequent, along with increased temperatures, resulting in dry soil conditions. This has caused delays of 1 month or more until the rainfall occurs, affecting the *jhum* cultivation period with an uneven rainfall pattern. Delayed *jhum* cultivation shortens the *jhum* cycle, putting *jhum* production and the food security of the CHT people at great risk.

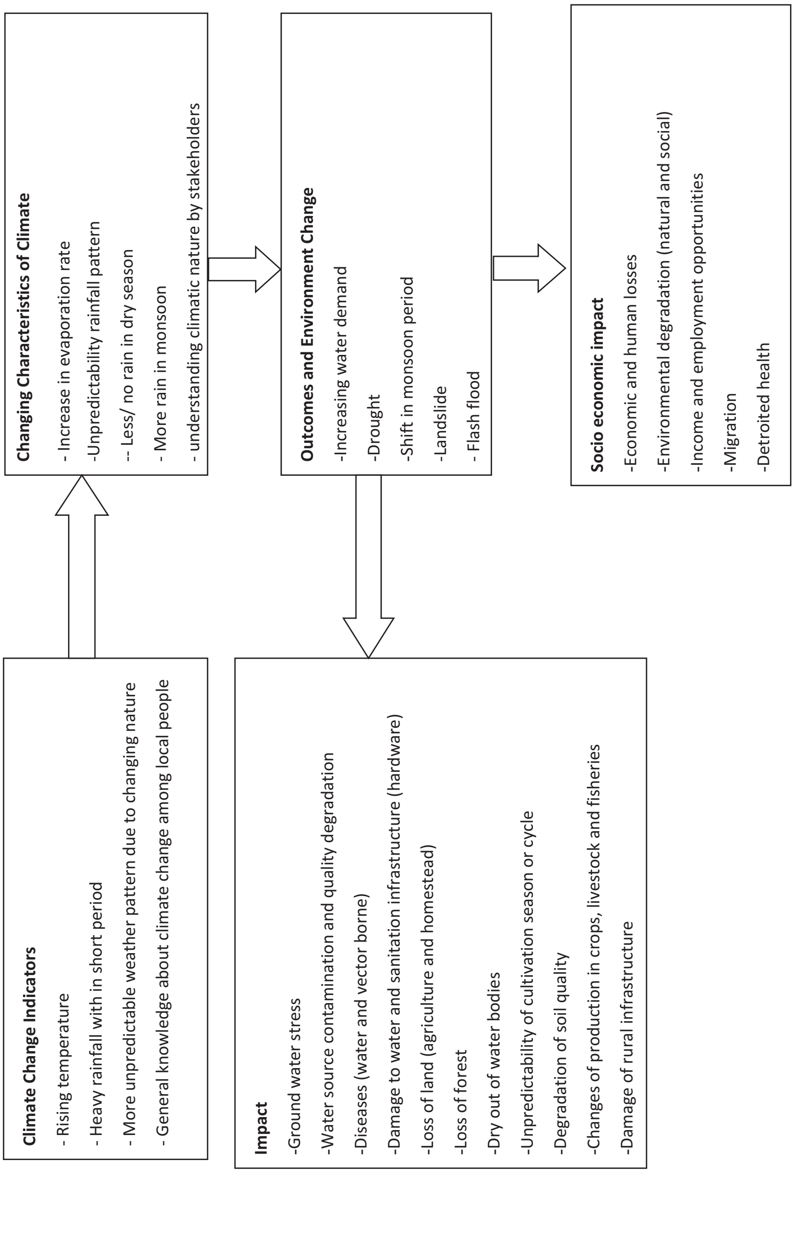

Fig. 5.5 Climate change risk scenario. (Adapted from AWRRI 2010)

Table 5.2 Seasonal calendar for agricultural activities in the Chittagong Hill Tracts

Month	Agricultural activities	Other activities
January	Prepare hill slopes for *jhum* by clearing jungles	Construct and renovate houses
		(Women) collect firewood, gin and spin cotton, die threads and cloths, make baskets
February	Harvest tobacco, mustard, chili, potato, and vegetables on plain lands	
March	Sow *aush* paddy	
	Plow land for winter crops on plain lands	
April	Burn *jhum* land to clear jungles	Construct *jhumiya* huts
May	Sow a man paddy seeds in the beds prepared for them	Conduct all works related to sowing and planting
	Start planting *jhum* land with the first rain	
June	Harvest *aush*, plow and harrow fields for aman paddy	
	Jhum farmers do the same as in May	
July	Collect *jhum* vegetables	
August	Collect vegetables, harvest early rice and sesame, and pluck cotton from *jhum*	
September/ October	Prepare plain lands for mustard, onion, chili, radish, peas, cucumber, brinjal, tobacco (etc.) cultivation	Cut bamboo and sun grass for sale
	Jhum farmers harvest the last rice for the year	
November/ December	Harvest a man and prepare plain lands for *aush*	Weave cloths
	The *jhum* cycle ends	

A field survey was conducted from February to April 2014 to obtain primary data focusing on the present research objectives. Three villages from three hill districts were selected randomly. A total of nine focus group discussions were conducted (three in each village). In three of the discussions the participant types were household heads/aged persons, farmers, and knowledgeable/experienced indigenous persons from the area

5.6.2 *Impact on Production*

The people in the region perceive that the climatic patterns have changed, on the basis of observation and personal experiences; farmers are perceived as being most affected by such changes, of which they have little knowledge. The local people in the CHTs feel that their production of *jhum* has decreased, which is affected by increased rainfall, dry spells, high temperatures, and occurrence of drought. They also perceived that today's climate is different from the past; the seasonal cycle and rainfall pattern have changed, dry spells have become prolonged, pests and diseases have increased, and the average temperature has increased in the summer, while the winter has shortened.

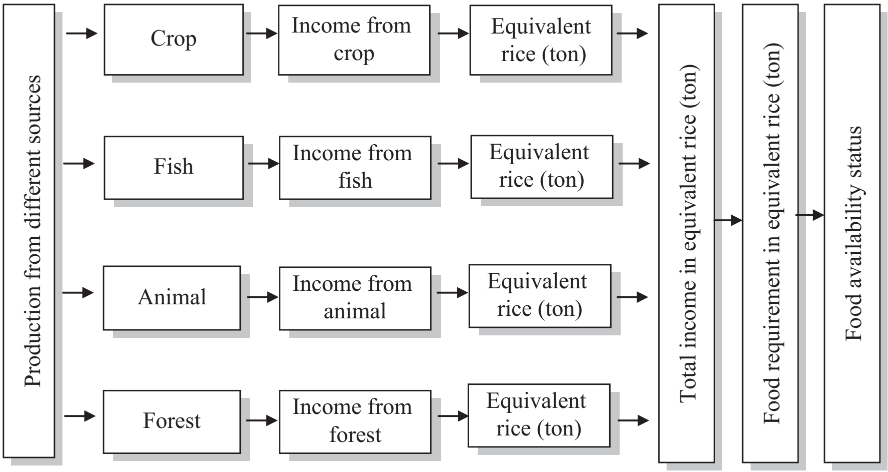

Fig. 5.6 Structure of food availability status. (Source: Bala et al. 2010)

Local perceptions of climate change and its impacts—including emerging alien plant species, warmer and precipitated monsoons, dry winters, increased frequency of extreme events, and increased vector-borne diseases—are serious in the area. Adaptation responses—such as use of metal sheeting to build houses to prevent rainwater leakage, use of alternative storage tanks or irrigation canals for rainwater collection, temporary migration, and cultivation of shorter-span crops—show that the local people have responded to climate change impacts in the area. The fact that less *jhum* is being produced may also be due to intensive cultivation on the same hills and failure to follow a crop rotation system. During the focus group discussions, the people reported that they have had to apply more pesticides lately, as pest attacks on *jhum* have increased, and their perception is that the extreme temperatures in summer and the drought periods are responsible for the pest attacks. Thus the main livelihood of the people in the CHTs—*jhum* production—is in a vulnerable condition because of climate change, as perceived by the local people (Fig. 5.6).

5.6.3 Agriculture and Food Security

Agriculture is the largest sector of the Bangladesh economy, accounting for some 35% of the gross domestic product (GDP) and 63% of the labor force. Agricultural production is already under pressure from increasing demand for food and the parallel problem of depletion of land and water resources caused by overuse and contamination. The impacts of climate variability and change cause an additional risk for agriculture. The population depends on agriculture for its livelihood. Farmers follow a traditional set planting pattern, relying on rainwater and the seasons. Now the old rhythms are upset by unpredictable rains or prolonged droughts. Monsoon precipitation could lead to more floods during the rainy season, damaging not only agriculture and livestock but also the livelihoods of many people. All of this would decrease crop yield and lower livestock productivity, which could threaten food security (Alan and Regmi 2005).

Agricultural productivity can be affected by climate change in two ways: first, directly, because of changes in temperature, precipitation, and/or CO_2 levels; and second, indirectly, through changes in the soil and in the distribution and frequency of infestation by pests, insects, diseases, or weeds. Climatic change has brought about extreme events each year, such as floods, droughts, and hailstorms, affecting agriculture drastically in the area. Rising temperatures and increasing rainfall have led to more pests and weeds, resulting in reduced productivity.

Increased climate variability poses additional threats to the environment and is considered a major crop production risk factor. It forces farmers to depend on low-input and low-risk technologies, leaving them unable to adopt new technologies that would allow them to derive maximum gains during favorable seasons, and leaving them less able to recover quickly after disasters.

The focus group discussions with the CHT household heads attempted to explore the food security status of the people, and found that the indigenous farming system and dependency on the forest resources are unable to ensure food security all year round, thus the hill people face more or less 2–3 food-unsecured months (May–June, June–July, and July–August (in Bengali:*Jaistha*, *Ashar*, and *Sravan*)). During the months of food shortages the people face their hardship by hunting, collecting bamboo shoots and other dry vegetables, or other means. According to the community perception, as the amount of forest is decreasing as a result of population pressure, illegal deforestation, and new *jhum* land creation, the forest resources are declining, and they feel that climate change may greatly reduce the food security of the CHT region.

5.6.4 Water Scarcity

Water is the key to human survival, good health, sanitation, and hygiene. Available water sources in good quantity and quality are a must for a good environment and safe health. Geographically, the people in the CHT region are dependent on surface water such as streams, springs, dug wells, and rainwater. In the floodplain lands or where a groundwater table is available, tubewells are an important source of water, and about 36% of hill people depend on such sources. But the common water sources are hill springs and dug wells, on which about 28% and 27% of the people, respectively, must depend (UNDP 2008). These sources suffer with seasonality, as the hill springs are almost dry during the dry season, and the people face water scarcity in that season. However, the hill community mentioned that a large number of hill springs have already dried up permanently because of the extensive drought period that has prevailed in recent years, and the water scarcity scenario has become more severe, particularly for those tribes who are living in remote mountainous regions.

5.6.5 Health Impacts

Climate change is the biggest global health threat of the twenty-first century. The indirect effects of climate change on water, food security, and extreme climate events are likely to have the biggest effects on global health. Vector-borne diseases will expand their reach and death tolls will increase because of heat waves (Rahman 2012). In Asia, the principal impacts of climate change on health will be on epidemics of malaria, dengue, and other vector-borne diseases (Martens et al. 1999). With a rise in surface temperatures and changes in rainfall patterns, the distribution of vector mosquito species may change (Patz and Martens 1996; Reiter 1998). Temperature can directly influence the breeding of malaria protozoa, and suitable climate conditions can intensify the invasiveness of mosquitoes (Tong and Ying 2000). Another concern is that changes in climate may allow more virulent strains of disease or more efficient vectors to emerge or be introduced into new areas. In 2015, it was reported that the world's largest burdens of climate change–attributable diarrhea and malnutrition were in Southeast Asian countries, including Bangladesh, Bhutan, India, the Maldives, Myanmar, and Nepal. Illness and death are expected to increase from diarrheal diseases such as cholera. Increases in the frequency and duration of severe heat waves and humid conditions during the summer are likely to increase the risk of mortality and morbidity (Epstein et al. 1995).

Changes in temperature and precipitation could also expand vector-borne diseases into previously uninfected high-altitude locations. Expansion of the geographic ranges of vectors and pathogens into new areas, increases in suitable habitats and numbers of disease vectors in already endemic areas, and lengthening of the transmission seasons could potentially expose more people to vector-borne diseases.

An increase in malaria has been attributed to climate change. Malaria is one of the major public health problems in Bangladesh. It is one of the Asian countries where malaria has become one of the biggest health concerns. Out of 64 districts, 13 border districts in the east and northeast—facing the Indian states of Assam, Tripura, and Meghalaya, and part of Myanmar—are in the high-risk malaria zone. Water is a breeding ground for mosquitoes, and warmer temperatures mean that these disease-carrying pests now breed in previously cool areas.

Malaria, diarrhea, and acute respiratory tract infections are the most common diseases in the CHT area, and malaria is a major health issue. In Bangladesh a study of the CHTs has indicated that increased temperatures and high rainfall have increased the number of cases of malaria. In 2007 it was reported that the annual death rate from malaria was expected to become much higher because of temperature rises as a result of climate change(Alam et al. 2007). The incidence of malaria gradually decreased from 12.8% in 2006 to just 2.1% in 2011, reflecting a positive decline in the incidence of malaria in the CHTs.

Both maternal and child mortality are higher than the national average. Access to safe drinking water is a key problem for communities in the CHTs. The people depend mainly on the mountain springs for drinking water. In the dry season almost all of the springs become dry or diminished, and become polluted. As a result, people fall sick frequently after using polluted water. Again, the community feels that the consequences of a long dry season with increasing temperatures increase disease in the region. Infants and the aged are the worst affected. The hot summer and the extreme heat waves increase the incidence rates of malaria and other virus-related fevers.

In the CHTs, community-based health services are delivered by mobile medical teams, satellite clinics, and a referral system for emergency patients.

5.7 Community Capacities and Adaptation Strategies

Adaptation to climate change is one of the approaches considered likely to reduce the impacts of long-term changes in climate variables. Adaptation is a process by which strategies to moderate and cope with the consequences of climate change—including climate variability—can be developed, enhanced, and implemented (UNDP 2004). Obviously, many countries are already adapting to current climatic events at national, provincial, state, district, and local levels in short, medium, and long-term time frames (Fig. 5.7).

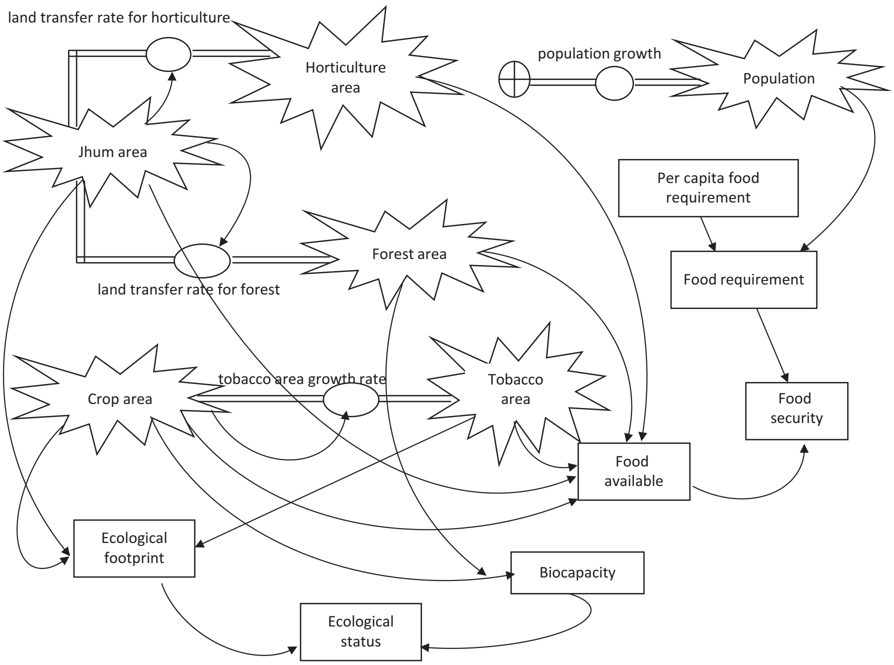

Fig. 5.7 Simplified flow diagram of the management system of the upland agricultural systems in the Chittagong Hill Tracts. (Source: Adapted from Bala et al. 2010)

Climate change is considered to be one of the most serious threats to sustainable development, with adverse impacts expected on the environment, human health, food security, economic activity, natural resources, and physical infrastructure. The global climate varies naturally, but scientists agree that rising concentrations of greenhouse gases in the earth's atmosphere are leading to changes in the climate. According to the IPCC (IPCC 2014), the effects of climate change have already been observed, and scientific findings indicate that precautionary and prompt action is necessary.

Adaptation to the effects of climate change is now acknowledged as necessary for responding effectively and equitably to the impacts of both climate change and climate variability. In recent years, adaptation has become a key focus of the scientific and policy-making communities and is now a major area of discussion in the multilateral climate change process. Particular attention will need to be paid to the management of water and other natural resources, agricultural activities, and the sources and generation of energy.

Successful adaptation reduces vulnerability to an extent that depends greatly on adaptive capacity: the ability of an affected system, region, or community to cope with the impacts and risks of climate change. Enhancement of adaptive capacity can reduce vulnerability and promote sustainable development across many dimensions (IPCC 2003).

In order to cope with the adverse effects of climate change, CHT households practice various adjustments at the household and community levels, and also receive support from both formal and informal sources, including local/national institutions. Local people have initiated tree planting on riverbanks, enhanced bamboo plantations, developed infrastructure (road repairs, gabion wall construction, embankments, and bioengineering methods), changed cropping patterns, used hybrid seeds, and initiated community-based disaster management in order to cope with the adverse situation of climate and climate change. Awareness raising, capacity building, and small-scale mitigation works are gradually being conducted at the community level, with input from various nongovernmental organizations(NGOs) and international NGOs (INGOs) to implement disaster risk reduction in the district and help the local people to deal with climate change. Considering those matters, a development framework has been designed where a consolidated scenario of risk and adaptation are seen, which could be functional in the CHTs as well (Fig. 5.8).

5.7.1 Agriculture Sector

Agriculture is the main source of livelihood of these populations. Nonfarm income opportunities are very limited and in some areas nonexistent. The tribal populations here are the most disadvantaged populations in Bangladesh. Shifting agriculture, locally known as *jhum*, is still the cultivation system in this region, with little impact of different government plans and programs to promote agricultural land use patterns. As a result the tribal populations are suffering from food insecurity, and the

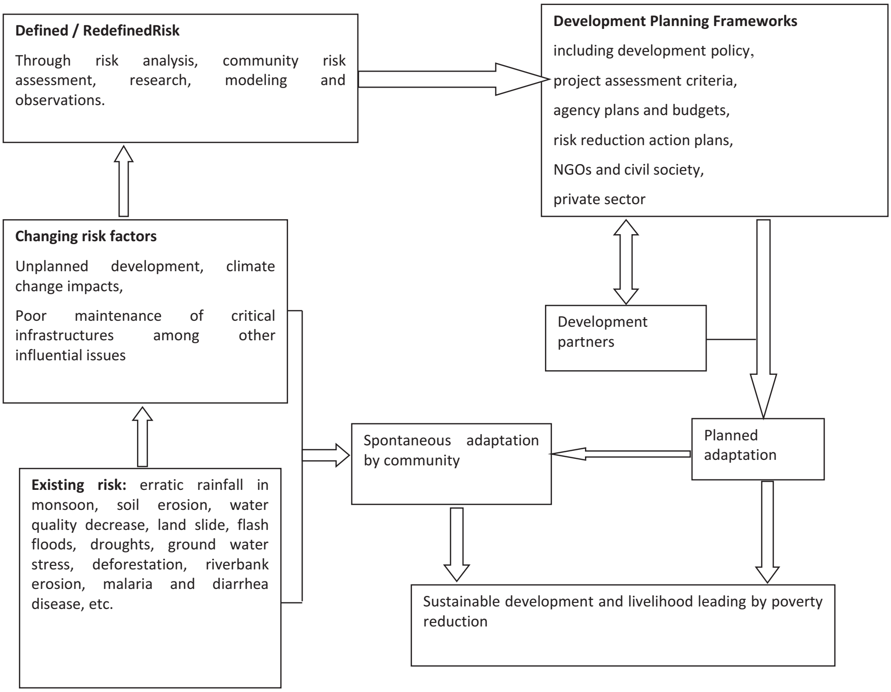

Fig. 5.8 Development planning framework for risk and adaptation. *NGOs* nongovernmental organizations. (Modified from CDMP 2010)

shifting agriculture has led to indiscriminate destruction of forests for food, resulting in ecological degradation. Identifying communities' own priorities and needs—and valuing their knowledge alongside science-based knowledge—is key to the development of sound adaptation strategies. Agricultural adaptation strategies employed by indigenous peoples include adjustment of crop varieties and planting dates (e.g., mixed cropping is practiced in Burkina Faso, and rotational cropping is practiced in the Indian Himalayas) and relocation of crops (e.g., the indigenous peoples of Guyana move from their savannah homes to forest areas during droughts, etc.)

There is very little information on the CHTs, specifically on current *jhum* production and how people cope in order to maintain their livelihoods. Despite declining productivity, farmers practice *jhum* because they feel it is the basis of the hill people's cultural identity (Ahmed 2002). In the focus group discussions the household heads commented that besides *jhum* cultivation they are adapting agroforestry and horticulture systems. Household coping strategies in agriculture in the CHT areas are locally managed using different practices, such as determining sowing and plant harvesting times, homestead gardening related to high nutritional value, plain land farming, etc. Adoption of different practices by the respondent farmers has been observed, to cope with the impacts of climate change. The planning of their agriculture is mostly based on the weather calendar, particularly precipitation, as well as adoption of agroforestry to adapt to the reduction of forest resources for fodder and firewood. In order to tackle changes in cropping and harvesting, and heavy rainfall, the respondent farmers have adopted indigenous strategies. Some such strategies include covering vegetables with bamboo nets, cultivating before the rainy season, spreading burning ashes and dry leaves over crops to protect them from insect attacks, use of support sticks to prevent crops from falling down due to heavy rainfall, and mixing of manure with dry leaves and ash.

Generally, flat to moderately steep sloping land is used for annual cash crops such as ginger, turmeric, cassava, and legumes, with intercrops of pigeon pea, sorghum, maize, and green manure crops. Steep sloping land is used with some mixed annual cropping, cultivated with tree cover. South-, west-, and southwest-facing slopes are used for fruit tree crops (jackfruit, lemons, limes, guava), which are cheap, easy to obtain, and hardy. These crops are planted between contours. North-, east-, and northeast-facing slopes are planted with bananas (*champa*, *bangla* and *anazi*), as moisture retention is greater on these slopes during the dry season. Under normal plantation practices, cover crops are used to protect the slopes from soil erosion and to increase fertility.

A new rice variety called *Narika* (a drought-resistant variety from Uganda) has been obtained by the government of Bangladesh and tested in different locations. They have set up different trial plots of the *Narika* rice variety with improved cultural practices, local and Bangladesh Rice Research Institute (BRRI) rice varieties with improved and traditional methods, and other crops such as rock melon in mixed *jhum* on separate land.

Food security remains an issue for the CHTs, particularly from June to August when the food harvests are limited because of various factors such as extreme weather conditions and pest attacks. In this regard the concept of a rice bank has been launched in this area by introducing the Farmer Field School (FFS). The FFS is a concept of integrated farm management (introduced in the CHTs in 2010), giving farmers the opportunity to acquire better skills, express their needs, and access services from government institutions. Yields have increased by 37% as a result. The Chittagong Hill Tract Development Facility (CHTDF)–supported rice banks have contributed to an increase of 0.8 months in the food-secure period for 98,824 inhabitants of rice bank communities across the CHTs, in comparison with the usual 2.6 months of the lean period each year. Community members have improved the functioning of rice banks with the training they have received.

Because the area of cultivable land in Rangamati is limited, the CHTDF introduced floating vegetable plots in 2010, utilizing water hyacinths. These vegetable plots have increased the possibility of vegetable cultivation by the Kaptai lakeshore inhabitants for household consumption and income-generating activities. The farmers who earlier used water hyacinths as floating beds are now utilizing the biomass of water hyacinths after harvesting vegetables in their fruit gardens, which is also an environmentally friendly technique. It has also gradually reduced the use of chemical fertilizers.

In horticulture and garden practice, high-quality saplings of mango, lychee, *malta*, mandarin, jackfruit, pumelo, cashew nut, sapota, lemon, guava, jujube, *latkan*, hog plum, coffee, banana, papaya, pineapple, turmeric, ginger, papaya, and seasonal vegetables are also planted as intercrops.

Indigenous peoples have preserved an intimate knowledge of plant and animal cycles, which has been gained over thousands of years and passed down from generation to generation. The ability to link events in the natural world to a cycle that permits prediction of seasonal events has been a key element in the survival of indigenous communities, and to this end they have developed seasonal weather calendars that are finely tuned to local conditions and natural events.

Among the respondents, 27% described an increment in agricultural productivity achieved by better timing relative to rainfall, better farming through crop rotation, use of new seeds and organic fertilizers, and training interventions. Meanwhile, the decline in agricultural produce has been mainly due to pest infestation, use of old seeds, loss of soil nutrients, decreasing manpower to work on the fields, and increasing dependency on tourism. They stated that gradual transitions of *jhum* land into horticulture crops and teak plantations, and of cropland into tobacco cultivation, are the best options for food security.

Thoughtful research about this section is limited, and the capacity is poor among CHT people. In a broad sense the respondents suggested that vast cultivable areas could be adapted by shifting crop locations with environment sustainability, improving land management by controlling and preventing erosion through plantation, and crop diversification related to temperature, rainfall patterns, and understanding of the changing crop calendar. Traditionally, indigenous peoples existed outside the cash economy. Today, an increasing number are running their own small businesses (such as restaurants) or taking up trades, moving into textile and cottage industries.

Policies can be implemented to impose taxes on fertilizers and promote better timing of fertilizer and manure applications, better feed quality for livestock, improved livestock waste management, and expansion of agroforestry. On the adaptive side, various measures can be taken to alleviate the effects of extreme conditions affecting agriculture and livelihoods, such as breeding of crops, vegetables, livestock, and fish with greater tolerance of higher temperatures; development of low-cost water conservation technologies; development of early warning and drought and flood forecasting systems; development of preparedness plans for relief and rehabilitation; development and implementation of land use systems that stabilize slopes and reduce the risks of soil erosion and landslides; and construction of livestock shelters and food stores (IISD and IES 1997).

5.7.2 Water Sector

It is known that the people collect water from *chharas*, springs, rivers, and tube wells for household use. But in the dry season, most nearby springs and *chharas* become waterless, so the people collect water from long distances and by digging holes near canals or rivers. With this traditional practice, they are now harvesting rainwater by creation of reservoirs, pond excavation, and retention of rainwater in *chharas* at the household and community levels. Because of the scarcity of water, the Jumma of Bangladesh has devised systems to hold rainwater and seepage water for irrigation and household use. Cross dams made of earth, bamboo, and wood are constructed between two hills to store water for irrigation, which is then brought to the fields by use of bamboo. Another system is a bamboo pitch, which courses seepage water from the rocky hill slopes. This water is collected in an earthen pitcher, which is used for drinking purposes. Vegetation on the upper slopes is carefully maintained to ensure that the water is cool and clean.

Reuse of water by recycling, removal of water pollutants by refining, efficient water use in households, irrigation, and other measures could be implemented by the government, NGOs, or donor agencies with research.

5.7.3 Health Sector

Climate change–attributable waterborne diseases—including cholera, diarrhea, salmonellosis, and giardiasis—as well as malnutrition conditions, are prevalent in Bhutan, India, Myanmar, and Nepal. The risk of contracting such diseases or suffering from malnutrition in 2030 is expected to increase as a result of elevated temperatures and increased flooding (Patz et al. 2005).

The incidence rates of diarrheal diseases and other infectious diseases such as cholera, hepatitis, malaria, and dengue fever increase during severe floods, heavy rainfall, and droughts, in combination with poverty, poor access to safe water, and poor sanitation. High temperatures and poor hygiene contribute to bacterial proliferation.

The burden of climate-attributable diarrhea and malnutrition is already large in Bangladesh relative to other countries in Asia. Future climate projections suggest that this large relative risk is expected to increase. Increasing temperatures are likely to yield a spread in insect-borne diseases.

Climate change will have a wide range of health impacts across the CHTs. Water supply, food security, and land degradation all place pressures on rural populations and will lead to deteriorating health, with increases in malnutrition due to failure of food security, disease and injury due to extreme weather events, diarrheal diseases from deteriorating water quality, infectious diseases, and respiratory diseases. In particular, the combined exposure to higher temperatures and air pollutants appears to be a critical risk factor for health during the summer months (Piver et al. 1999).

Health is related to water and sanitation systems, mostly. A major proportion of household members have no access to any kind of toilet facilities. They use either forest areas or open places, and sometimes use public toilets. For specific diseases in the hilly areas, they go to the government hospital, and some people use local medicinal plants and indigenous therapy. But they want emergency health services for remote areas, research for identification and prevention of climate change–related diseases, and motivation for the people to plant and preserve indigenous or local medicinal plants. In the focus group discussions, it was the opinion of the household heads that compulsory use of mosquito nets and introduction of general health education must be practiced.

5.7.4 Energy and Fuel Supply Sector

The electricity facilities are very poor in the hill districts. In Khagrachhari, the percentage of households with access to electricity is the lowest (14.52%). The percentage of households with access to electricity in Rangamati is 43.38%, while the national average in Bangladesh is 33%. Also, Rangamati has the highest percentage of consumers of solar electricity (5.57%). Electricity fluctuation is a common phenomenon in the hill districts, and sometimes disruptions continue for 2–3 days.

From the focus group discussions it came out that in the past, mainly forest wood was used as fuel, which was collected from natural forests, and kerosene was used as a light source (and still is used by most households). The proportion of households with electricity is very small. The government and some NGOs are taking initiatives to increase use of solar energy, but it has not been well explored among the communities, and they have no easy access to it, given its high cost. Natural forest degradation has a major effect on changes in cooking fuel use, as forest wood is not available and not free of cost. With changes overtime the fuel sources for households have changed a lot. They have adapted to use of fuel from cow dung/manure, agricultural residue, etc. Some NGOs are providing opportunities to set up biogas plants, but only in a small proportion of communities.

5.7.5 Forestry Sector

It is important to note that many of the impacts of climate change are experienced because changes in rainfall and temperature aggravate existing vulnerabilities. For example, upstream deforestation is a major factor in recurrent flooding, but the impact of flooding becomes increasingly severe as rainfall increases or extreme rainfall events become more frequent. Massive landslides, soil erosion, destroyed crops, and even forests have become vulnerable in the CHTs. The people have managed to devise new sustainable forest management practices, which are still largely based on their traditional knowledge and practices. They have formed village common forests (VCFs), under the leadership of the *mouza* headmen and managed by the villagers. They have planted diverse trees, which are now crucial for watershed management, biodiversity conservation, and sources of biomass and bamboo for construction of houses and temples. Most household heads commented on the practice of VCFs, agricultural forestry, and social forestation for regeneration of the forest sector. By adapting such schemes, they could improve their socioeconomic conditions, but they are unfamiliar about its environmental as well as climatic condition.

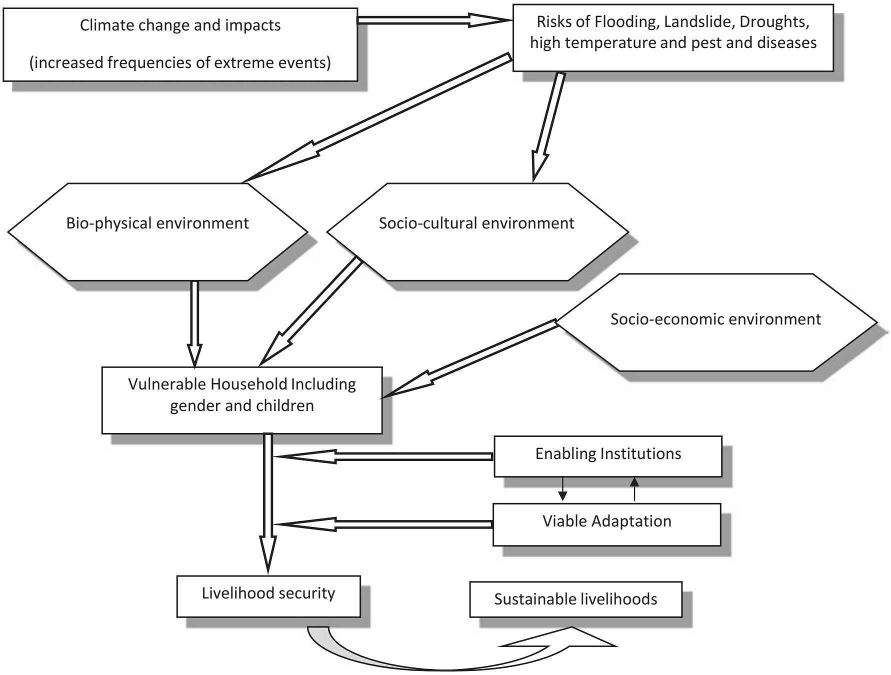

Fig. 5.9 Conceptual framework for improving livelihood security and sustainable livelihoods through adaptation to climate change. (Source: ADPC and FAO 2006)

5.7.6 Livelihood Sector

Formulation of adoption strategies is the vehicle of change to cope with the adverse situations caused by climate change. Local people are motivated to design adoption strategies themselves if the climate change directly affects their livelihoods. This is a universal truth. Local people have carried out different community-level initiatives in order to combat climate change.

On the basis of the theoretical insights discussed above, a model has been developed to implement adaptation to climate variability and change, with an overall aim to improve the adaptive capacity of rural livelihoods (Fig. 5.9).

Figure 5.9 shows how different environmental factors, together with risk factors, influence household livelihood strategies and decision-making processes over time, taking the role of gender and other population vulnerabilities into account. In the model the household is the main part where strategies are developed and decisions are taken to develop and maintain livelihoods by means of the livelihood portfolio. Looking at the model from a systems perspective, climate change could influence the biophysical (agriculture), sociocultural, and socioeconomic environments of households, impacting resources and assets, including social capital. The resource management strategies and decision-making potential of the local population is also affected. The fact that the coping range drops significantly under climate change is one of the reasons that improving adaptive capacity to maintain or improve livelihood security is one of the core aims of this effort.

For livelihood adaptation the CHT community people are now choosing the wood business, harvesting of nontimber forest products, horticulture, limited paddy production on fringe lands, timber trafficking, and also vegetable gardening (Khan 2001).

However, these strategies are insufficient for proper adjustment to future climate variability and change-related threats, and climate change brings limitations as well as new opportunities for livelihood.

5.8 Conclusion

The changing pattern of climate is now a reality in the CHTs. The large-scale dependency on natural resources and low resilience have exposed the hill people to a vulnerable situation because of the adverse impacts of climate change. The main threats of abnormal climatic behavior, as identified by the local communities, are low food production and food insecurity, water scarcity, disease increase, and forest resource degradation. Extreme climatic events, such as droughts and high-intensity rainfall in a short period, causing landslides and flash floods, can have a devastating impact on the human habitat, the economy, and the livelihoods of vulnerable people. However, the awareness among the local communities regarding climate change and its impacts is not at a satisfactory level. Creating awareness among the local people is crucial to identity the threats of climate variability, find adaptation strategies to mitigate the impacts of climate change and, at the same time, apply initiatives related to climate change adaptation at the local level with community involvement. Again, there is an acute scientific research gap and a vacuum of available data to study the climate change trends in the region properly.

References

ADPC and FAO (Asian Disaster Preparedness Center and Food and Agriculture Organization of the United Nations) (2006) Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh: developing institutions and options. Case study report under the project Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector-DP9/1-BGD/01/004/01/99, Asian Disaster Preparedness Center and Food and Agriculture Organization of the United Nations

Ahmed FU (2002) An ethnographic perspective on the CHT: the people and the resources. In: Khan NA, Alam MK, Kisha SK, Millat-e-Mustafa M (eds) Farming practices and sustainable development in the Chittagong Hill Tracts. Chittagong Hill Tracts Development Board (CHTDB) and VEFP-IC, Chittagong, pp 11–34

Ahmed AU (2006) Bangladesh climate change impacts: a synthesis. Climate Change Cell, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka

Alam M, Rahman S, Haider MS, Hasan S (2007) Relationship between climate change and incidence of malaria in Chittagong Hill Tracts. In: 2nd International Workshop on Community Based Adaptation to Climate Change. Organised by: Bangladesh Centre for Advanced Studies, IIED & The Ring. Radisson Water Garden Hotel, Dhaka, 24th–28th February, 2007

Alan M, Regmi BR (2005) Adverse impacts of climate change on development of Nepal: integrating adaptation into policies and activities, Capacity Strengthening of Least Developed Countries for Adaptation to Climate Change (CLACC)

AWRRI (Agriculture, Water Resources and Rural Institutions Division) (2010) Bangladesh climate change screening for planners and implementers in agriculture and water supply and sanitation sectors. AWRRI, Planning Commission, Government of the People's Republic of Bangladesh, Dhaka

Bala BK et al (2010) Management of agricultural systems of the upland of Chittagong Hill Tracts for sustainable food security. Final report.PR # 1/08. National Food Policy Capacity Strengthening Programme (NFPCSP). Government of the People's Republic of Bangladesh

BBS (Bangladesh Bureau of Statistics) (2012) Community series: Khagrachri District, 2011. BBS Planning Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka

CDMP (Comprehensive Disaster Management Programme) (2010) Enhancing national and community resilience, integrating disaster risk reduction and climate change adaptation measures into development planning and process in Bangladesh, guide to practice. Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh, Dhaka

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C, Huu Ninh N (2007) Asia. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: 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, pp 469–506

Epstein Y, Sohar E, Shapiro Y (1995) Exceptional heatstroke: a preventable condition. Israel J Med Sci 31:454–462

Gunter GB, Rahman A, Rahman AFMA (2008) How vulnerable are Bangladesh's indigenous people to climate change? Bangladesh Development Research Center (BDRC), Bangladesh Development Research Working Paper Series (BDRWPS), BDRWPS 1 (April 2008). http://www.bangladeshstudies.org. Accessed 14 Aug 2014

Hassan M, Akanda MAM, Hossain MI (1995) Bangladesh: Prakritik Bhugol OParibesh (in Bangla). Bangla Academy, Dhaka

Houghton RA et al (1999) The US carbon budget: contributions from land-use change. Science 285:574–578

IISD and IES (International Institute for Sustainable Development and Institute for Environmental Studies) (1997) Agriculture and climate change: a prairie perspective. University of Toronto, Toronto

IPCC (Intergovernmental Panel on Climate Change) (2003) Climate change 2001: impacts, adaptation and vulnerability. GRID-Arendal

IPCC (Intergovernmental Panel on Climate Change)(2014) Climate change 2014: synthesis report summary for policy makers. IPCC. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Khan FH (1991) Geology of Bangladesh. University Press Limited, Dhaka

Khan MI (2001) Livelihood context of the south-eastern region of Bangladesh, Livelihood Monitoring Project. CARE, Dhaka

Martens P, Kovats RS, Nijhof S, De Vries P, Livermore MTJ, Bradley DJ, Cox J, McMichael AJ (1999) Climate change and future populations at risk of malaria. Glob Environ Chang S9:89–107

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) (2001) Climate change 2001: impacts, adaptation and vulnerability, Intergovernmental Panel on Climate Change (IPCC), Work Group II input to the third assessment report. Cambridge University Press, Cambridge

MCHTA (Ministry of Chittagong Hill Tracts Affairs) (2012) CHTDF annual report 2011. MCHTA, Government of the People's Republic of Bangladesh, Dhaka
NAPA (National Adaptation Programme of Action) (2005) National Adaptation Programme of Action (NAPA) final report. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka
Patz JA, Martens WJM (1996) Climate impacts on vector-borne disease transmission: global and site-specific. J Epidemiol 6:S145–S148
Patz JA, Campbell-Lendrum D, Holloway T, Foley JA (2005) Impact of regional climate change on human health. Nature 438:310–317
Piver WT, Ando M, Ye F, Portier CT (1999) Temperature and air pollution as risk factors for heat stroke in Tokyo, July–August, 1980–1995. Environ Health Perspect 107(11):911–916
Rafi M, Chowdhury AMR (eds) (2001) Counting the hills: assessing development in Chittagong Hill Tracts. The University Press Limited, Dhaka
Rahman A (2012) Protecting human health from climate change. Seminar paper presented at the 1st National Conference on Youth Think Tank on Climate Change and Health, organized by Ministry of Health and Family Welfare, Government of the People's Republic of Bangladesh, 24 May 2012
Rahman A (2014) Bangladesh climate vulnerability: floods and cyclones. Seminar paper presented at the International Food Policy Research Institute (IFPRI) 2020 conference on building resilience for food and nutrition security, 15–17 May, 2014. Addis Ababa, Ethiopia
Rashid H (1991) Geography of Bangladesh. University Press Limited, Dhaka
Reiter P (1998) Global warming and vector-borne disease in temperate regions and at high altitude. Lancet 351:839–840
Roy RD, Guhathakurta M, Mohsin A, Tripura P, Gain P (eds) (2000) The Chittagong Hill Tracts: life and nature at risk. Society for Environment and Human Development (SEHD), Dhaka
Tong SL, Ying LV (2000) Global climate change and epidemic disease. J Dis Control 4(1):17–19
UNDP (United Nations DevelopmentProgramme) (2004) User's guidebook for the adaptation policy framework. UNDP, February 2004, p 33
UNDP (United Nations DevelopmentProgramme) (2008) Human development report 2007. NewYork
UNDP (United Nations DevelopmentProgramme) (2009) Socio-economic baseline survey of Chittagong Hill Tracts. Chittagong Hill Tracts Development Facility (CHTDF), UNDP, Dhaka
UNFCCC (United Nations Framework Convention on Climate Change) (2004) The first ten years. Climate Change Secretariat, Bonn
World Bank (2000) Bangladesh: climate change and sustainable development. Report no. 21104-BD, Rural Development Unit, South Asia Region, World Bank (WB), Dhaka, p 95. http://www.iwgia.org/environment-and-development/climate-change

Chapter 6
Climate Change Impacts on the Coastal Zones of Bangladesh: Perspectives on Tropical Cyclones, Sea Level Rise, and Social Vulnerability

Edris Alam, Salim Momtaz, Hafiz Uddin Bhuiyan, and Sultana Nasrin Baby

Abstract Climate change is one of the greatest threats to human security and sustainability. This chapter illustrates five key areas of its effects in relation to climate change in Bangladesh. These are (i) changes in temperature; (ii) intensity of tropical cyclones; (iii) storm surge heights; (iv) sea level rise; and (v) social vulnerability. In 2008, the Ministry of Environment and Forests revealed that Bangladesh and its adjoining areas had warmed by 0.5 °C over the preceding 100 years. The rise in temperature is generally observed in the monsoon season (June–August). An analysis of the relationship between tropical cyclones and sea surface temperatures (SSTs) for the period between 1901 and 1998 showed that despite increases in SSTs, the frequency of tropical cyclones had decreased since 1981 in the Bay of Bengal. Under the Intergovernmental Panel on Climate Change (IPCC) scenario, it is projected that tropical cyclone activity in the future is likely to decrease in the Bay of Bengal. It is predicted that rises in the mean sea level (MSL) and increases in the tropical cyclone wind speed will increase the depth of inundation along the Bangladeshi coast by more than 3 m and increase exposed areas by 69% in size. Increases in SST of up to 2 °C will increase the height of storm surges by 23% and increase areas of inundation by up to 1.26 times the present levels of inundation. Analyzing 22 years of data (1977–1988), the South Asian Meteorological Research Council (2003) showed that the relative sea levels in the Bay of Bengal have risen by 4.0 mm/year and 7.8-mm/year along the western and eastern coasts, respectively.

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Climate change and its associated impacts may include, but are not limited to, declines in livelihood diversity, migration, and disease. The government of Bangladesh and local residents have adopted various strategies in response to extreme events related to climate change. This review identifies further areas of research in relation to understanding of the distinctive impacts of climate change and developing synergy between institution- and community-led adaptation strategies.

6.1 Introduction

Human-induced climate change is now undeniable. A growing number of research studies from around the world have evidenced symptoms and impacts of climate change (CCC 2009; Khan et al. 2011; Luetz 2013). Climate change and its associated impacts are experienced through changes in temperatures, precipitation, and sea levels; and changes in the frequency and severity of climate extremes (IPCC 2014). Developing countries are highly susceptible to climate change because of their exposure and sensitivity to climate extremes coupled with their limited adaptive capacities to deal with the consequences of climate change (Adger et al. 2003; Pouliotte et al. 2009).

Bangladesh is in the frontline of climate change and its associated effects because of a combination of several physical and social characteristics. The country is located in the lower part of the Ganges–Brahmaputra–Meghna River catchment, which is 1.5 million km^2. Bangladesh comprises only 7.5% of this catchment area (Brammer 1990). A rise in precipitation and associated flooding in the upper catchment will add to the existing burden of flooding during the rainy season in Bangladesh. To the south of the country is the Bay of Bengal. The coastal zone accounts for 32% of the total area of the country, and 28% of the population live in this zone. The landward limit of the coastal zone from the shore is between 30 and 195 km. The coastal zone is characterized by a low-lying flat land surface, wide rivers, canals, and estuarine areas, which permit sea surges to propagate quickly and to inundate far inland (As-Salek 1998; Barua 1991; Talukder et al. 1992). These elements are some of the major causes of disastrous storm surges flooding this region (SMRC 1998). The ground height of the region, within some 200 km from the coast, which is 62% of the total land, is less than 3 m above sea level (Umitsu 1985) and one third of the land is under tidal influence (Karim and Mimura 2008). The livelihoods of two thirds of Bangladesh is depend on climate-sensitive agriculture and farming activities. Poor people's daily lives and livelihoods are very much dependent on climate.

In this chapter, we begin by introducing the climate, weather, and tropical cyclones in the Bay of Bengal, then we discuss climate change and possible effects in five key areas. These are (i) changes in temperature; (ii) intensity of tropical cyclones;(iii) sea level rise; (iv) storm surge heights; and (v) social vulnerability.

This is followed by a description of adaptation strategies led by the government of Bangladesh and communities,a subsequent discussion, and conclusions.

6.2 Climate, Weather, and Tropical Cyclones in the Bay of Bengal

The weather in the Bay of Bengal is characterized by the southwest (SW) monsoon in summer and the northeast (NE) monsoon in winter (Vinayachandran et al. 1999). The term “monsoon” refers to the dominant seasonal wind and accompanying weather characteristics. The moist SW monsoon flows from June to September, and the NE monsoon flows from December to March. The SW monsoon is characterized by frequent rain with very warm and humid weather conditions both day and night. The NE monsoon is characterized by cooler, drier air, with brighter weather (Ahmed 1997).

A tropical cyclone is a cyclic wind that forms over tropical oceans and is mainly powered by heat transfer from the ocean (Emanuel 2003). Tropical cyclones are formed when SSTs remain above 26 °C over an ocean depth of 60 m for a period (Gray 1978). Tropical cyclone genesis occurs in an oceanic environment where weak vertical shear of the horizontal wind and relatively large cyclonic low-level vorticity prevail (Gray 1978). Other conditions that favor genesis of cyclones are larger values of the Coriolis parameter, the heat content in the upper ocean, and the relative humidity of the middle troposphere (Gray 1978). In the southern Bay of Bengal, tropical cyclones form through a combination of all favorable genesis factors in the premonsoon (April–May) and postmonsoon (October–November) seasons. During these two periods, SSTs remain constantly over 28 °C (Kikuchi and Wang 2010; Yokoi and Takayabu 2010). Tropical cyclones in the Bay of Bengal at first follow tracks toward the north–northwest (NNW). Some continue to move NNW and make landfall on the east coast of India. Others move from the north–northeast (NNE) to the northeast corner of the Bay of Bengal and strike the coasts of Bangladesh and Myanmar (Fig. 6.1) (SMRC 1998).

6.3 Climate Change Effects in Bangladesh

Bangladesh is one of the least contributors to global total greenhouse gas emissions, but the country is considered to be one of the high-risk countries for climate change and its associated effects (Rawlani and Sovacool 2011). A detailed analysis of climate change effects is beyond the scope of this study, but we discuss five key areas of the effects, as mentioned in Sect. 6.1.

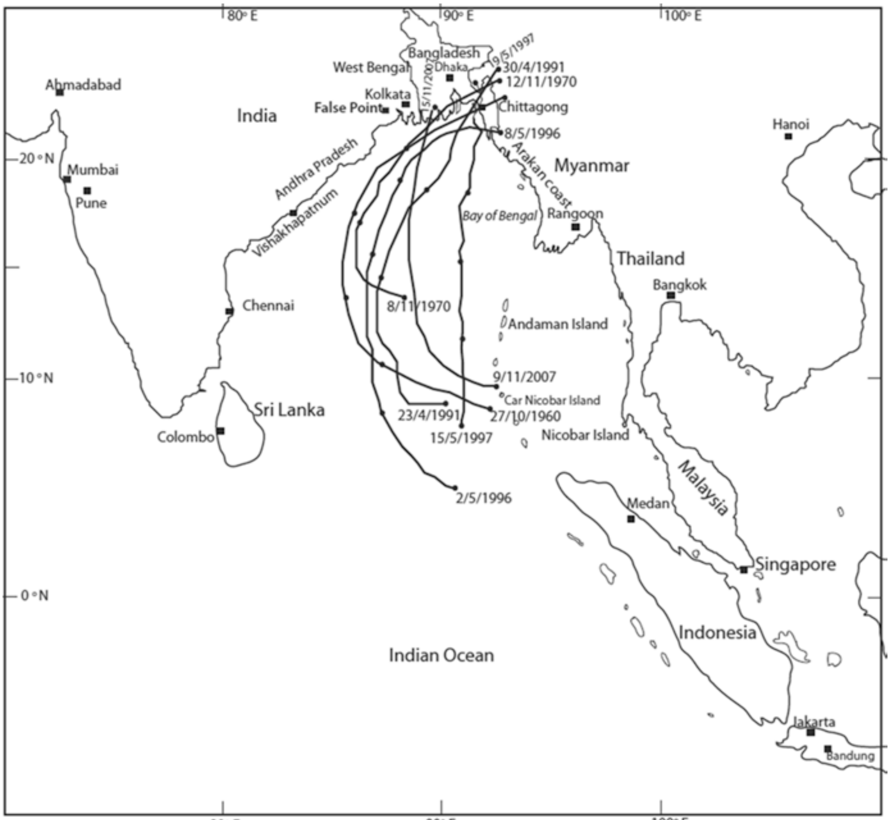

Fig. 6.1 Tracks of tropical cyclones occurring in 1960, 1970, 1991, 1996, 1997, and 2007 that made landfall in Bangladesh. The *lower ends* of the tracks show the points and dates of origin, and the *upper ends* show the locations and dates of landfall (As-Salek 1998; Choudhury 2001; Dunn 1962)

6.3.1 Changes in Temperature

Bangladesh and its adjoining areas have warmed by 0.5 °C over the last 100 years (MoEF 2009). The rise in temperature is generally observed in the monsoon season (June–August). The average monsoon maximum and minimum temperatures have increased annually at the rates of 0.05 and 0.03 °C, respectively (Ahmed and Alam 1999). The resulting trend in the temperature depends on the spatial and temporal extent of the data available for analysis. By analyzing temperature data from 34 weather stations in Bangladesh, the Climate Change Cell of the Ministry of Environment and Forests estimated that in the periods of 1948–2007 and 1980–2007, the mean annual temperatures rose by 0.10 and 0.21 °C per decade, respectively (1.03 and 2.14 °C per century, respectively) (Fig. 6.2) (CCC 2009). An estimation of temperature change from 1990 levels indicated that the average projected increase

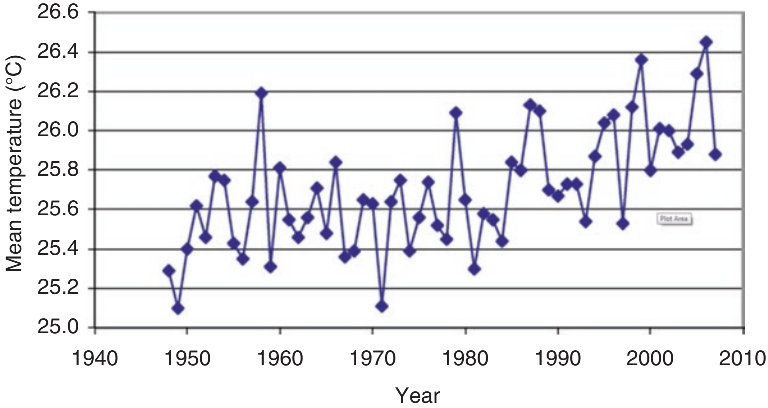

Fig. 6.2 Time series of annual mean temperatures in Bangladesh. (Source: Adapted from CCC 2009)

Table 6.1 Trends in mean temperatures (°C per century) in Bangladesh for the data periods of 1948–2007 and 1980–2007

Season	Data period 1848–2007	1980–2007
Winter (November–February)	+1.67	+1.33
Summer (March–May)	+0.26	+2.15
Monsoon (June–October)	+1.05	+2.44
Annual (January–December)	+1.03	+2.14

Source: CCC (2009)

in temperature would be 1.3 °C by the year 2030 and 2.6 °C by the year 2075 (Ahmed and Alam 1999; MoEF 2009). Synthesizing the available climate variability data, the National Adaptation Program of Action (NAPA) estimated 1.0, 1.4, and 2.4 °C temperature rises (Table 6.1) by the years 2030, 2050, and 2100, respectively (MoEF 2005). As noted, temperature is one of the factors for tropical cyclone genesis. In Sect. 6.3.2 we review whether any rise in temperature increases the frequency and intensity of tropical cyclones in the Bay of Bengal.

6.3.2 Tropical Cyclones in Bangladesh

Tropical cyclones have frequently devastated large areas, taken numerous lives, and caused extensive damage to property in coastal and island areas of the northern Bay of Bengal, which include the east coasts of India, Bangladesh, and Myanmar (SMRC 1998). Records of tropical cyclones date back to a 1484 event, which is reported to have killed over 200,000 people in Bangladesh (Alam and Dominey-Howes 2014; Table 6.2). An estimated 1,700,000 people were killed during ten

Table 6.2 Major tropical cyclones that made landfall in Bangladesh, with associated coastal storm surges and casualties

Landfall date	Landfall location	Maximum wind speed (km/h)	Maximum surge height (m)	Deaths
1484	Chittagong	–	–	200,000
1582	Barisal	–	–	200,000
1584	Barisal	–	–	200,000
1767	Barisal	–	13.1	30,000
1822	Barisal	–	5.26	100,000
1876	Noakhali	220	13.7	500,000
1897	Chittagong	–	–	175,000
1911	Cox's Bazar	–	–	120,000
1960	Chittagong	–	6.6	15,000
1961	Chittagong	160	6.10–8.84	10,466
1963	Chittagong	241	5.18	50,000
1965	Cox's Bazar	210	4.7–6.1	873
1970	Barisal	223	3.05–10.05	300,000
1985	Noakhali	154	4.57	15,000
1991	Chittagong	225	3.66–6.70	138,866
1997	Chittagong	150	4.55	184
2007	Barisal	213	4.57–6.10	4234

Sources: Compiled from Frank and Husain (1971), SRMC (1998), Choudhury (2001), BMD (2012), and Alam and Dominey-Howes (2014)

tropical cyclone events (in 1582, 1584, 1822, 1876, 1897, 1911, 1965, 1970, 1985, and 1991), which struck the Bangladeshi coast between 1582 and 1991 (see Table 6.2). The tropical cyclone that struck on November 12, 1970, was particularly deadly because it struck the entire coast with a storm surge between 7.62 and 21.33 m in height and caused over 300,000 deaths (Flierl and Robinson 1972). Approximately 20 years later, on April 29, 1991, the coastal region of Bangladesh was struck by another great tropical cyclone, which killed over 135,000 people (Chowdhury et al. 1993).

The effects of tropical cyclones vary on the basis of their location of origin and place of landfall (Lal et al. 2012; Fig. 6.3). For example, just 5% of global tropical cyclones originate in the Bay of Bengal, but the adjacent countries (i.e., Bangladesh, India, and Myanmar) experience more than 75% of the global casualties (Chowdhury 2002). Bangladesh experiences about 50% of all global casualties, even though the country is only affected by about 1% of all annual tropical cyclones (Ali 1999). Seventy-one tropical cyclones that occurred between 1484 and 2009 caused approximately 2,072,509 human deaths in Bangladesh (Alam and Dominey-Howes 2014). In Bangladesh, the number of deaths associated with tropical cyclones has decreased significantly in recent times (Alam and Dominey-Howes 2014; Haque et al. 2012; Fig. 6.4). It should be borne in mind that the death data associated with tropical cyclones further back in history are very doubtful because of problems of over- and underreporting. The reduction in fatalities during tropical cyclones may be

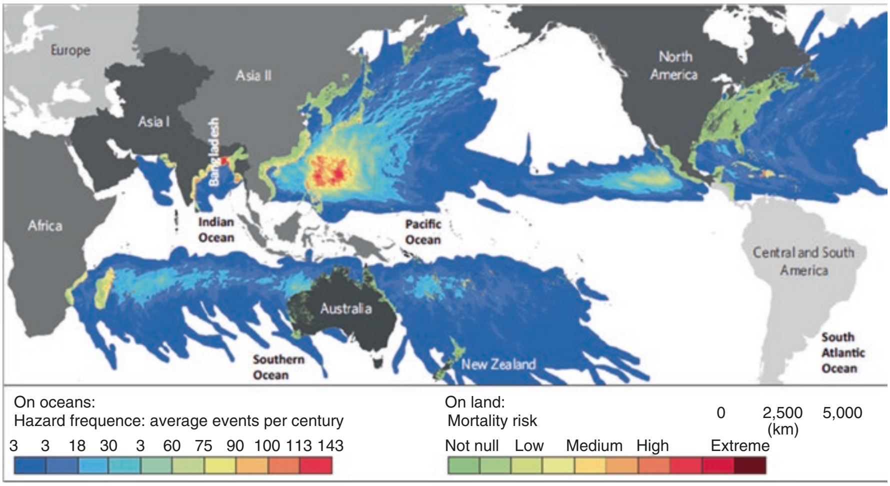

Fig. 6.3 Distribution of hazard frequency and mortality risk from tropical cyclones for the year 2010. Estimates are applied to all pixels on a geographic grid. Mortality risk is categorized from low to extreme. (Source: Adapted from Peduzzi et al. 2012)

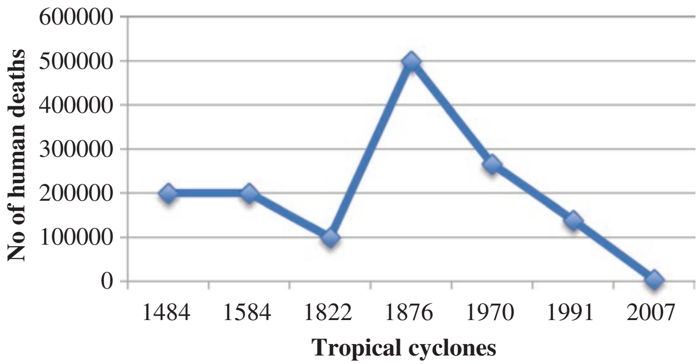

Fig. 6.4 Variations in the numbers of deaths associated with several major tropical cyclones from historical to recent events. The data suggest that the occurrence of deaths associated with tropical cyclones from 1970 to 2007 decreased markedly

attributable to the well-managed and experienced tropical cyclone responses and mitigation strategies in more recent times.

Despite recent success in the reduction of deaths associated with tropical cyclones and storm surges, the number of people becoming exposed to the devastation of tropical cyclones is increasing because of rapid population growth in Bangladesh (Peduzzi et al. 2012)(Fig. 6.5). Eleven tropical cyclones, which occurred between 1923 and 2009, caused 9,435,000 people to become homeless, and between 1961 and 2009, ten tropical cyclones resulted in economic damage of over US$4.6 billion (Alam and Dominey-Howes 2014). It is therefore important to understand the vary-

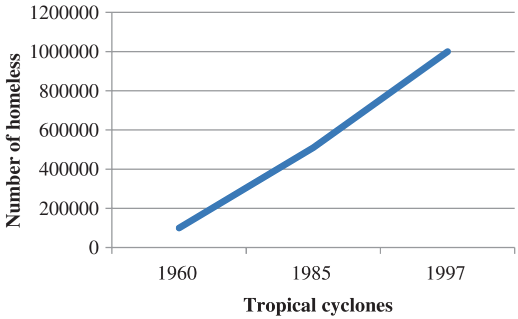

Fig. 6.5 The numbers of people made homeless by tropical cyclones increased from 1960 to 1997

Table 6.3 Changes in the numbers and percentages of category 4 and 5 tropical cyclones in the different ocean basins during the 15-year periods of 1975–1989 and 1990–2004

Ocean Basin	1975–1989		1990–2004	
	Number	Percentage	Number	Percentage
East Pacific	36	25	49	35
West Pacific	85	25	116	41
North Atlantic	16	20	25	25
Southwest Pacific	10	12	22	28
North Indian	1	8	7	25
South Indian	23	18	50	34

Source: Webster et al. (2005)

ing effects of tropical cyclones in Bangladesh from a historical perspective (Alam and Dominey-Howes 2014).

6.3.2.1 Changes in the Intensity of Tropical Cyclones

Climate change, SSTs, and the intensity of tropical cyclones are interrelated phenomena (Emanuel 2005)—that is, theory and modeling suggest that observed increases in SSTs, which are thought to be associated with climate change, have led to increases in tropical cyclone intensity (Emanuel et al. 2008; Hoyos et al. 2006; Knutson and Tuleya 2004; Solomon et al. 2007; Webster et al. 2005). For example, Webster et al. (2005) suggested that the frequency of category 4 and 5 tropical cyclones increased by 17% between the periods of 1975–1989 and 1990–2004 (Table 6.3).

Contrary to the suggestion of an increase in the intensity of tropical cyclones, Klotzbach (2006) showed that despite warming of SSTs by 0.2–0.4 °C between 1986 and 2005, there was no significant change in overall global tropical cyclone activity. Similarly, in analyzing tropical cyclone data between 1877 and 1995, Ali (1999) did not find any increase in the frequency of tropical cyclones despite increases in SSTs in the Bay of Bengal. In contrast to the increase in total cyclone

Table 6.4 Contrasting evidence on the relationship between sea surface temperatures (SSTs) and tropical cyclone frequency and intensity in the Bay of Bengal

Frequency and intensity of tropical cyclone	Sources	Data period	Comments
Observed increase in frequency of tropical cyclones	MoEF (2009)	–	The MoEF made a general statement about an increase in tropical cyclones without referring to any data period
	Webster et al. (2005)	1975–1989	The period of data analyzed was relatively short
	Singh et al. (2001)	1990–2004 1877–1988	Tropical cyclone frequency mainly increased in May and November
Observed decrease in frequency of tropical cyclones	Mandke and Bhide (2003)	1901–1998	Storm frequency has decreased on a decadal scale since the 1980s despite increasing SSTs
	Kumar and Sankar (2010)	1951–2007	
Likelihood of increase in frequency of future tropical cyclones	MoEF (2009) Unnikrishnan et al. (2011)	2071–2100	The MoEF made a general statement about increases in tropical cyclones without referring to any data period
Likelihood of decrease in frequency of future tropical cyclones	Murakami et al. (2013)	2075–2099	Reduction of 31% in the frequency of tropical cyclones
Observed increase in intensity of tropical cyclones	Elsner et al. (2008)	1981–2006	Analysis of satellite imagery for 2097 tropical cyclones around the globe suggested a significant increase in the intensity of tropical cyclones
	Webster et al. (2005)	1975–1989 1990–2004	
Likelihood of increase in intensity of future tropical cyclones	MoEF (2009) Unnikrishnan et al. (2006)	2041–2060	The MoEF predicts an increase in wind speed of tropical cyclones and associated storm surge heights

MoEF Ministry of Environment and Forests

activity in the North Atlantic, the frequency of tropical cyclones decreased in the Northeast Pacific (Klotzbach 2006) and the Bay of Bengal (Mandke and Bhide 2003).

However, in the Bay of Bengal, the evidence of changes in the frequency and intensity of tropical cyclones is contradictory (Table 6.4). A recent study conducted by Kumar and Sankar (2010) to understand the relative changes between SSTs and tropical cyclone activity did not find any significant relationship in the Bay of Bengal. Further, it suggested that some atmospheric parameters such as low-level vorticity, midtropospheric humidity, and vertical wind shear play significant roles in the genesis and intensity of tropical cyclones in the Bay of Bengal.

However, the trend between the overall tropical cyclone activity and intense tropical cyclones may not be reliable, because of recent improvements in detection that have resulted in more intense tropical cyclones being recorded (Klotzbach 2006; Landsea et al. 2006). For example, the intensity of tropical cyclones was underesti-

Table 6.5 Projected storm surge heights along the Bangladeshi coast induced by coupled sea level rises (SLRs) and sea surface temperatures (SSTs)

Factors		Surge height location	Storm surge height (m [% change])	Source
SLR(m)	SST rise (°C)			
0	2	Chittagong	9.2 [21]	Ali (1999)
0.3	2	Chittagong	9.1 [20]	Ali (1999)
1	2	Chittagong	8.6 [13]	Ali (1999)
0	4	Chittagong	11.3 [49]	Ali (1999)
0.3	4	Chittagong	11.1 [46]	Ali (1999)
1	4	Chittagong	10.6 [40]	Ali (1999)
2	2	Western Bangladesh	– [15.3]	Karim and Mimura (2008)
0	0	Western Bangladesh	7.6	Karim and Mimura (2008)
0	2	Western Bangladesh	9.2	Karim and Mimura (2008)
0	4	Western Bangladesh	11.3	Karim and Mimura (2008)
0.3	2	Western Bangladesh	9.1	Karim and Mimura (2008)
0.3	4	Western Bangladesh	11.3	Karim and Mimura (2008)
1	0	Western Bangladesh	7.1	Karim and Mimura (2008)
1	2	Western Bangladesh	8.6	Karim and Mimura (2008)
1	4	Western Bangladesh	10.6	Karim and Mimura (2008)

mated as recently as in the 1980s. The November 14, 1984, Bay of Bengal tropical cyclone was considered category 3 or less, but reanalysis of this cyclone by satellite revealed that it could have been category 3 or 4 (Landsea et al. 2006).

6.3.3 Increases in Storm Surge Height

Climate change and its effects on the intensity of tropical cyclones and increases in storm surge height may be coupled with possible sea level rises (Table 6.5). However, increases in the intensity of tropical cyclones have been estimated only on the basis of data between 1900 and 1998. There is also a great paucity of data on storm surge height (Alam and Dominey-Howes 2014). It is predicted that rises in the mean sea level (MSL) and increases in the intensity of tropical cyclone wind speed will increase the depth of inundation along the Bangladeshi coast by more than 3 m and increase the exposed areas by 69% in size (Dasgupta et al. 2010). Increases in SST of up to 2 °C will increase the height of storm surges by 23% and increase areas of inundation to 1.26 times the present levels of inundation (Ahmed and Alam 1999; Karim and Mimura 2008; MoEF 2005). Such projections, if they materialize, will result in increased demand for additional shelters to accommodate people during future tropical cyclone events (Karim and Mimura 2008). Furthermore, an increase in the coastal population and development activities will greatly increase exposure. A review of social vulnerability to reported climate effects in Bangladesh is presented in Sect. 6.3.5.

6.3.4 Sea Level Rise

The coastline of Bangladesh is highly susceptible to increased sea levels and tidal level fluctuations. Studies of sea level rise along the Bangladeshi coast have generated different forecasts. For example, analyzing 22 years of data (1977–1998), the South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre (SMRC) (2003) showed that relative sea levels in the Bay of Bengal have risen by 4.0 mm/year and by 7.8 mm/year along the western and eastern coasts, respectively. Synthesizing data from multiple sources, including the Intergovernmental Panel on Climate Change (IPCC), the NAPA for Bangladesh estimated possible sea level rises of 14, 32, and 88 cm by 2030, 2050, and 2100, respectively (MoEF 2005). The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) apprehended that if the projected sea level rise occurs, this would lead to submergence of low-lying coastal areas and intrusion of salt water into coastal rivers and groundwater aquifers (MoEF 2009).

6.3.5 Social Vulnerability

Climate change effects may include—but not be limited to—livelihood, migration, and health (Table 6.6). In this chapter we report only those effects that peer-reviewed journal articles have attributed to climate change. The real causes of migration, food insecurity, and health problems or social problems often attributed to climate change are difficult to determine, because some other factors may also cause them to happen. For example, people may wish to migrate from their homes to other areas not only because of climate change and its associated problems but also because of some other pull factors (i.e., job opportunities, education, health, etc.). However, it is impossible to dismiss climate change as one of the main push factors (Luetz 2013). Bangladeshi communities are vulnerable to climate extremes and other hazards due to a variety of sociocultural and economic factors (Table 6.7).

Table 6.6 Reported effects of climate extremes on local communities on the Bangladeshi coast

Sectors of effects		Description of effects	Sources
Livelihood	Food security	Decrease in rice production	Ali (2006), Khan et al. (2011), Parvin and Ahsan (2013), Pouliotte et al. (2009), Warner and van der Geest (2013)
	Fishing	Decrease in fish catch in the Bay of Bengal and on the Bangladeshi coast	Islam (2009), Ahmed et al. (2012), Islam et al. (2014)
	Food diversity	Decrease in crop varieties due to intrusion of salt water and monoculture	Khan et al. (2011), Parvin and Ahsan (2013)
			Pouliotte et al. (2009)
Migration	Forced migration from the coast to inland Bangladesh	The inhabitants in the remote island areas of the Bay of Bengal, when they lost their habitations to coastal erosion and storm surge inundation, migrated to adjacent urban areas. They generally formed two types of settlements: (i) slum dwellings within major city areas; and (ii) settlements adjacent to the hills	Black et al. (2011), Kartiki (2011), Alam et al. (2012), Mallick and Vogt (2014), Luetz (2013)
	Forced migration from the coast to adjacent Indian regions	Sea level rise and natural hazard–induced displacement of people from the Bangladeshi coast, who have taken shelter in adjacent India illegally	Bose (2013)
Health	Deaths and injuries	Deaths resulting from cardiorespiratory diseases associated with high and low temperatures	Rashid et al. (2013)
	Malnutrition	Higher malnutrition rate among coastal residents, due to reduction in food diversity	Khan et al. (2011)
	Safety of drinking water	Risesintide levels and frequent coastal flooding increase salinity in groundwater. Drinking of saline-contaminated water increases pre-eclampsia, eclampsia, and hypertension among women in coastal areas	Khan et al. (2008), Pouliotte et al. (2009), Khan et al. (2011)
	Gender dimensions of effects	Decrease in women's income and stressful social life	Pouliotte et al. (2009), Abedin et al. (2013)
	Increase of climate extreme–related disease and sickness	Mosquito-borne diseases, tick-borne diseases (e.g., malaria, dengue) and air pollution–related mortality and morbidity	Rashid et al. (2013)

Table 6.7 Progression of Bangladeshi coastal communities' vulnerability to disaster

Root causes	Dynamic pressures	Unsafe conditions		Hazards
→	→	→	Disaster	←
Limited access to	**Lack of**	**Fragile physical environment**	Risk = hazard × vulnerability	Cyclonic winds, storm surges, seasonal flooding, saline water intrusion into agricultural land from the Bay of Bengal, and coastal erosion
Safe land and cyclone shelters	Sufficient cyclone shelters	Multiple cyclones and tidal surges in a year		
Sustainable livelihoods	Proper transportation to move to cyclone shelters during cyclone periods	Unprotected coastal land		
Common resources	Lack of awareness about the scientific nature of cyclones	**Local economy**		
Resilient settlements in cyclone-prone areas	Effective disaster management system	Agricultural activities in areas of cyclone risk		
Ideologies	Proper land use management in high-cyclone-risk areas	Fishing in peak cyclone season in the Bay of Bengal		
Inefficient administrative system	Specific housing policy for settling in high-cyclone-risk areas	**Social relations**		
Lack of participatory government system	Alternative skills or income opportunities other than fishing and agriculture	Lack of social networks in at-risk places, due to new settlements being scattered and isolated		
Conservative beliefs	**Macroforces**	**Special groups at risk**		
	Population pressure on hazardous places	Vulnerability of children, women, and the aged		
	Increases in unprotected settlements in hazardous places	Women's long hair and special clothing that hinders swimming in cyclone surges		

(continued)

Table 6.7 (continued)

Root causes	Dynamic pressures	Unsafe conditions		Hazards
→	→	→	Disaster	←
	Poor people's debt to money lenders	Women's purdah culture that obstructs them from deciding to move to cyclone shelters that are not women-only		
		Lack of decision-making power on the part of women		
		Agricultural and fishing communities at risk		
		Public actions		
		Late responses to cyclone warnings		
		Excessive love/ devotion for properties		

Sources: Modified from Alam (2007); pressure and release model adapted from Wisner et al. (2004)

6.4 Adaptation Actions Against Climate Change Impacts in Bangladesh

Reduction of emissions of greenhouse gases (GHGs) and adaptation to the changing environment are considered two anthropogenic ways that humankind can tackle climate change (Fussel and Klein 2006; IPCC 2001). Climate change adaptation means adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harms or exploits beneficial opportunities (Perry et al. 2007). Building capacity to adapt to climate change implies that people must protect themselves against inevitable new and exogenous threats to their health and wellbeing (Collins 2008). The United Nations (UN) Intergovernmental Panel on Climate Change (IPCC)has noted that "adaptation to climate change takes place through adjustments to reduce vulnerability or enhance resilience in responses to observed or expected changes in climate and associated extreme weather events" (IPCC 2001).

Climate change adaptation may be divided into two categories: institution-led adaptation strategies and community-led adaptation strategies. Bangladesh developed a NAPA in 2005. The NAPA identified potential impacts of climate change, and vulnerable sectors and geographic areas, and also proposed the most important and immediate adaptation actions (Huq 2011). The successive development of the

NAPA is the BCCSAP, aimed at developing long-term, more practical strategies than those of the NAPA (Table 6.8). In the BCCSAP, the action plan prioritizes six issues (Table 6.8).

Nongovernmental organizations (NGOs) have been making significant contributions in promoting local residents' health and sustainable livelihoods, and in mitigating disasters in Bangladesh. Noticeably, they have achieved significant success in reducing waterborne diseases and promoting alternative livelihoods among Bangladeshi coastal communities. For example, Caritas Bangladesh and its local partner, Sushilan, have assisted local communities in southwestern Bangladesh in emptying and cleaning ponds, which are the sole sources of drinking water. Before their programs were in operation, diarrhea, dysentery, and skin diseases were widespread among the local residents. However, repeated activities of emptying and cleaning of ponds have significantly reduced such diseases.

We reviewed peer-reviewed journal papers and reports to understand community-led adaptation actions for climate extremes on the Bangladeshi coast. From this review, we can report three main sectors of adaptations—livelihood, human habitation, and health—which have been adopted as responses to tropical cyclone hazards, salinity intrusion into inland areas, and other extreme climatic conditions (Table 6.9). Although the adaptation responses have been autonomous for these events, the scientific evidence on the relationship between climate change and tropical cyclone intensity, salinity intrusion, or other climatic fluctuations is less clear.

6.5 Discussion and Conclusions

Bangladesh and its adjoining areas have observed increases in the temperature, storm surge height, and sea level. Different studies (Haque et al. 2013; Kartiki 2011) have referred to autonomous adaptation strategies as responses to increases in the intensity of tropical cyclones, which were indicative of climate change. However, our analysis for the Bay of Bengal did not provide a conclusive trend in the intensity of tropical cyclones. It is postulated that the projected rises in the temperature, tropical cyclone intensity, storm surge height, and sea level would add significant burdens to highly vulnerable communities on the Bangladeshi coast.

We have reviewed the reported effects of climate change on the reduction of livelihood security and diversity, forced migration, and health on the Bangladeshi coast. These reviews suggest that the reported effects have disproportionately burdened poor communities because of declines in traditional rice and fish culture, and crop varieties. To offset the effects of extreme climate events, vulnerable communities are often forced to migrate within and outside the country. Health impacts of climate change generally include, but are not limited to, deaths and injuries, malnutrition, gender dimensions of effects, and increases in disease and sickness. To offset climate extremes and other stressors, local residents adopt several autonomous adaptation strategies to secure their livelihoods, habitations, and health. Although different studies (Haque et al. 2013; Sarkar et al. 2013) have attributed these adapta-

Table 6.8 The BCCSAP programs

Thematic action	Name of program
(1) Food security, social protection, and health	Institutional capacity for research on climate-resilient cultivars and their dissemination
	Development of climate-resilient cropping systems
	Adaptations against drought
	Adaptations in fisheries sector
	Adaptations in livestock sector
	Adaptations in health sector
	Water and sanitation programs in climate-vulnerable areas
	Livelihood protection in ecologically fragile areas
	Livelihood protection of vulnerable socioeconomic groups (including women)
(2) Comprehensive disaster management	Improvement of flood forecasting and warning
	Improvement of tropical cyclone and storm surge warning
	Awareness raising and public education for climate resilience
	Risk management against loss on income and property
(3) Infrastructural development	Repairs and maintenance of existing flood embankments
	Repairs and maintenance of flood shelters
	Repairs and maintenance of existing coastal folders that used to strengthen existing embankments
	Improvement of urban drainage
	Adaptations against floods
	Adaptations against tropical cyclones and storm surges
	Planning and design of river training works
	Planning, designing, and resuscitating rivers and *khals* through dredging and desiltation work
(4) Research and knowledge management	Establishment of a center for knowledge development and training on climate change
	Climate change modeling at national and subnational levels
	Participatory studies on adaptations against sea level rise
	Monitoring of ecosystem and diversity changes and their impacts
	Monitoring macroeconomic and sectoral economic impacts of climate of change
	Monitoring of internal and external migration of adversely impacted populations and providing them with support through capacity building for their rehabilitation in their new environment
	Monitoring of impacts on various issues relating to management of tourism in Bangladesh and implementation in priority action plan

(continued)

Table 6.8 (continued)

Thematic action	Name of program
(5) Mitigation and low-carbon development	Improved energy efficiency in production and consumption of energy
	Gas exploration and reservoir management
	Development of coal mines and coal-fired power stations
	Renewable energy development
	Lower emissions from agricultural land
	Management of urban waste
	Afforestation and reforestation program
	Rapid expansion of energy-saving devices, e.g., compact fluorescent lamps
	Energy and water efficiency in built environments
	Improvement of energy consumption patterns in the transport sector and options for mitigation
(6) Capacity building and strengthening	Revision of sectoral policies for climate resilience
	Mainstreaming of climate change in national, sectoral, and spatial development programs
	Strengthening of human resource capacity
	Strengthening of gender capacity in climate change management
	Strengthening of institutional capacity in climate change management
	Mainstreaming of climate change in media

tion strategies to climate change, it is hard to determine whether they were adopted in response to other stressors as well (Luetz 2013).

The government of Bangladesh has adopted the BCCSAP for mitigation and adaptation to climate change and its associated impacts. Local residents on the Bangladeshi coast are continuously adopting self-instinctive/autonomous survival strategies to live with changing climatic conditions. However, from the current literature, it is less clear if synergy is occurring between the actions of the government of Bangladesh and the community-led autonomous adaptations.

Further to the current analysis and synthesis, this chapter identifies two areas of research for further investigation in relation to climate change impacts and adaptation strategies: (i) investigation of the distinctive and separate evidence available from local-level experiences of climate change impacts on the Bangladeshi coast; and (ii) investigation of the effectiveness of institution-led adaptation strategies and the continuous autonomous adaptation strategies of the local residents on the Bangladeshi coast, in terms of disaster resilience and sustainability.

Table 6.9 Community-led autonomous adaptation actions in Bangladesh

Adaptation sector		Description of adaptation	Sources
(1) Livelihood	Changing rice farming to non-rice farming	Farming of different variety of crops; cultivation of jute, wheat, plums, and different types of pulses	Sarkar et al. (2013)
	Increasing involvement in a variety of income sources	Earning money by wage labor, small business, construction work, and livestock farming	Pouliotte et al. (2009), Abedin et al. (2013)
	Selling land and taking loans	Poor households often temporarily adapt to extreme climate events by selling land and taking loans	Alam (2002),Alam (2003a), Pouliotte et al. (2009)
	Gender dimensions	Women are forced to take difficult jobs outside their comfort zone	Abedin et al. (2013)
(2) Human habitation	Raising homesteads on plinths	Low-lying coastal and island inhabitants often raise their homesteads on plinths much higher than those used by mainland people, to mitigate severe effects of coastal flooding	Alam (2002), Alam (2003b)
	Planting of trees	Planting of trees around houses to reduce the intensity of storm surge attack	Alam (2002)
(3) Health	Household coping strategies	Season-specific household-level strategies to prevent sickness and diseases caused by extreme heat, cold, and precipitation	Haque et al. (2013)

References

Abedin MA, Habiba U, Shaw R (2013) Gender and climate change: impacts and coping mechanism of women and special vulnerable groups. In: Shaw R, Mallick F, Rahman A (eds) Climate change adaptation actions in Bangladesh. Springer, Tokyo

Adger WN, Huq S, Brown K, Conway D, Hulme M (2003) Adaptation to climate change in the developing world. Prog Dev Stud 3(3):179–195

Ahmed R (1997) Abhaoa O Jalabayu Vijnan (Meteorology and Climatology) (in Bengali). Department of Geography and Environmental Studies, University of Rajshahi, Bangladesh

Ahmed AU, Alam M (1999) Development of climate change scenarios with general circulation models. In: Huq S, Karim Z, Asaduzzaman M, Mahtab F (eds) Vulnerability and adaptation to climate change for Bangladesh. Kluwer Academic Publishers, Dordrecht

Ahmed N, Occhipinti-Ambrogi A, Muir JF (2012) The impact of climate change on prawn postlarvae fishing in coastal Bangladesh: socioeconomic and ecological perspectives. Mar Policy 39:224–233

Alam E (2002) Post cyclone adjustment process: the case of Sandwip, Bangladesh. MSc Thesis, Department of Geography and Environment, University of Dhaka, Bangladesh

Alam E (2003a) Coping with cyclone: an occupational group perspective. J Asiatic Soc Bangladesh (Humanities) 48(2):59–74

Alam E (2003b) Post cyclone adjustment process: basic needs perspective. Oriental Geographer 47(2):47–60

Alam E (2007) Understanding vulnerability and local responses to cyclone disasters: experiences from Bangladesh coast. MSc dissertation in Disaster Management and Sustainable Development, The University of Northumbria at Newcastle, UK
Alam E, Dominey-Howes D (2014) A new catalogue of tropical cyclones of the northern Bay of Bengal and the distribution and effects of selected landfalling events in Bangladesh. Int J Climatol. doi:https://doi.org/10.1002/joc.4035
Alam E, Momtaz S, Collins A (2012) Adaptation actions and human security in Bangladesh: an analysis of disaster resilient response mechanisms in the context of coastal hazards. In: Australian Meteorological & Oceanographic Society Annual Conference, 31 January–2 February 2012, Sydney, Australia
Ali A (1999) Climate change impacts and adaptation assessment in Bangladesh. Clim Res 12:109–116
Ali AMS (2006) Rice to shrimp: land use/land cover changes and soil degradation in southwestern Bangladesh. Land Use Policy 23:421–435
As-Salek JA (1998) Coastal trapping and funnelling effects on storm surges in the Meghna estuary in relation to cyclones hitting Noakhali–Cox's Bazar coast of Bangladesh. Am Meteorol Soc 28:227–249
Barua DK (1991) The coastline of Bangladesh—an overview of processes and forms. In: Proceedings of the Seventh Symposium on Coastal and Ocean Management, ASCE, Long Beach, CA, pp 8–12
Black R, Bennett SRG, Thomas SM (2011) Migration as adaptation: mobility can bring opportunities for coping with environmental change. Nature 478:477–479
BMD (Bangladesh Meteorological Department) (2012) Chronology of severe cyclonic storms for the period of 1584 to 2009. BMD, Government of the People's Republic of Bangladesh, Dhaka
Bose S (2013) Sea-level rise and population displacement in Bangladesh: impact on India. Marit Aff 9(2):62–81
Brammer H (1990) Floods in Bangladesh: geographical background to the 1987 and 1988 floods. Geogr J 156(1):112–122
CCC (Climate Change Cell) (2009) Characterizing long-term changes of Bangladesh climate in context of agriculture and irrigation. CCC, Department of Environment, Ministry of Environment and Forests, Component 4b, Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management, Dhaka
Choudhury AM (2001) Cyclones in Bangladesh. In: Nizamuddin K (ed) Disaster in Bangladesh: selected readings. Department of Geography and Environment, University of Dhaka, Dhaka, pp 61–76
Chowdhury KMMH (2002) Cyclone preparedness and management in Bangladesh. In: Bangladesh Public Administration Training Centre (BPATC), improvement of early warning system and responses in Bangladesh towards total disaster risk management approach. BPATC, Savar, pp 115–119
Chowdhury AMR, Bhuyia AU, Choudhury AY, Sen R (1993) The Bangladesh cyclone of 1991: why so many people died. Disasters 17(4):291–304
Collins AE (2008) Health security or climate change adaptation? What do we really mean by disaster risk reduction in times of disease? In: Walter MP, Ammann J, Hakkinen E, Hoffer G (eds), International Disaster and Risk Conference (IDRC), Davos 2008, Switzerland, p 46
Dasgupta S, Huq H, Khan ZH, Ahmed MMZ, Mukherjee N, Khan MF, Pandey K (2010) Vulnerability of Bangladesh to cyclones in a changing climate: potential damages and adaptation cost. Policy research working paper 5280. Development Research Group, Environment and Energy Team, The World Bank, Washington, DC
Dunn GE (1962) The tropical cyclone problem in East Pakistan. Mon Weather Rev 90:83–86. The American Meteorological Society
Elsner JB, Kossin JP, Jagger TH (2008) The increasing intensity of the strongest tropical cyclones. Nature 455:92–95
Emanuel K (2003) Tropical cyclones. Annu Rev Earth Planet Sci 31:75–104

Emanuel K (2005) Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686–688

Emanuel K, Sundararajan R, William J (2008) Tropical cyclones and global warming: results from downscaling IPCC AR4 simulations. Bull Am Meteorol Soc 89:347–367

Flierl GR, Robinson AR (1972) Deadly surges in the Bay of Bengal, dynamics and storm tide tables. Nature 239:213–215

Frank NL, Husain SA (1971) The deadliest tropical cyclone in history? Am Meteorol Soc 52(6):438–444

Fussel H-M, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Climate Change 75:301–329

Gray WM (1978) Hurricane and their formation structure and likely role in the tropical circulation. Prepared for the Risk Management Solutions/American Meteorological Society (RMS/AMS) conference on meteorology over tropical oceans, London, August 21–25, 1978, and RMS conference volume

Haque U, Hashizume M, Kolivras KN, Overgaard HJ, Das B, Yamamotoa T (2012) Reduced death rates from cyclones in Bangladesh: what more needs to be done? Bull World Health Organ 90:150–156

Haque MA, Budi A, Malik AA, Yamamoto SS, Louis VR, Sauerborn R (2013) Health coping strategies of the people vulnerable to climate change in a resource-poor rural setting in Bangladesh. BMC Public Health 13(565):1–11

Hoyos CD, Agudelo PA, Webster PJ, Curry JA (2006) Deconvolution of the factors contributing to the increase in global hurricane intensity. Science 312:94–97

Huq S (2011) Lessons of climate change, stories of solutions. Bangladesh: adaptation. Bull At Sci 67(1):56–59

IPCC (Intergovernmental Panel on Climate Change) (2001) Climate change 2001: the scientific basis. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York. In: Houghton JT,Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds), 881 pp

IPCC (Intergovernmental Panel on Climate Change) (2014) Climate change 2014: impacts, adaptation, and vulnerability. Final draft, IPCC Working Group II (WGII) Fifth Assessment Report (AR5) technical summary

Islam MM (2009) Living on the edge: relating climate change impacts to the poverty in small-scale coastal fisheries of Bangladesh. IOP conference series: earth and environmental science 6. Climate Change: Global Risks, Challenges and Decisions, Copenhegen, Denmark

Islam MM, Sallu S, Hubacek K, Paavola J (2014) Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. Reg Environ Chang 14:281–294

Karim MF, Mimura N (2008) Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. Glob Environ Chang 18:490–500

Kartiki K (2011) Climate change and migration: a case study from rural Bangladesh. Gend Dev 9(1):23–38

Khan A, Mojumder KS, Kovats S, Vineis P (2008) Saline contamination of drinking water in Bangladesh. Lancet 371(9610):385

Khan AE, Xun WW, Ahsan H, Vineis P (2011) Climate change, sea-level rise, and health impacts in Bangladesh. Environ Sci Policy Sustain Dev 53(5):18–33

Kikuchi K, Wang B (2010) Formation of tropical cyclones in the northern Indian Ocean associated with two types of tropical intraseasonal oscillation modes. J Meteorol Soc Jpn 88(3):475–496

Klotzbach PJ (2006) Trends in global tropical cyclone activity over the past twenty years (1986–2005). Geophys Res Lett 33(L10805):1–4

Knutson TR, Tuleya RE (2004) Impact of CO_2-induced warming on simulated hurricane intensity and precipitation: sensitivity to the choice of climate model and convective parameterization. J Clim 17:3477–3495

Kumar MRR, Sankar S (2010) Impact of global warming on cyclonic storms over north Indian Ocean. Indian J Geo-Mar Sci 39(4):516–520

Lal PN, Mitchell T, Aldunce P, Auld H, Mechler R, Miyan A, Romano LE, Zakaria S (2012) National systems for managing the risks from climate extremes and disasters. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge/New York, pp 339–392

Landsea CW, Harper BA, Hoarau K, Knaff JA (2006) Can we detect trends in extreme tropical cyclones? Science 333:452–454

Luetz JM (2013) Climate migration: preparedness informed policy opportunities identified during field research in Bolivia, Bangladesh, and Maldives. PhD thesis at the Institute of Environmental Studies, The University of New South Wales, Australia, p 502

Mallick B, Vogt J (2014) Population displacement after cyclone and its consequences: empirical evidence from coastal Bangladesh. Nat Hazards 73:191–212

Mandke SK, Bhide UV (2003) Study of decreasing storm frequency over Bay of Bengal. J Indian Geophys Union 7(2):53–58

MoEF (Ministry of Environment and Forests) (2005) National adaptation program of action. Final Report. MoEF, Government of the People's Republic of Bangladesh, Dhaka

MoEF (Ministry of Environment and Forests) (2009) Bangladesh climate change strategy and action plan 2009. MoEF, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh, xvii, 76 pp

Murakami H, Sugi M, Kitoh A (2013) Future changes in tropical cyclone activity in the north Indian Ocean projected by high resolution MRI-AGCMs. Clim Dyn 40(7):1949–1968

Parvin GA, Ahsan SMR (2013) Impacts of climate change on food security of rural poor women in Bangladesh. Manag Environ Qual 24(6):802–814

Peduzzi P, Chatenoux B, Dao H, Bono AD, Herold C, Kossin J, Mouton F, Nordbeck O (2012) Global trends in tropical cyclone risk. Nat Clim Chang 2:289–294

Perry M, Canziani O, Palutikof J, Linden PVD, Hanson C (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of the Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York

Pouliotte J, Smit B, Westerhoff L (2009) Adaptation and development: livelihoods and climate change in Subarnabad, Bangladesh. Climate Dev 1:31–46

Rashid FH, Gani S, Sarker M (2013) Urban poverty, climate change and health risks for slum dwellers in Bangladesh. In: Shaw R, Mallick F, Rahman A (eds) Climate change adaptation actions in Bangladesh. Springer, Tokyo

Rawlani AK, Sovacool BK (2011) Building responsiveness to climate change through community based adaptation in Bangladesh. Mitig Adapt Strateg Glob Chang 16:845–863

Sarkar MAR, Alam K, Gow J (2013) Assessing the determinants of rice farmers' adaptation strategies to climate change in Bangladesh. Int J Clim Chang Strateg Manag 5(4):382–403

Singh OP, Khan TMA, Rahman MS (2001) Has the frequency of intense tropical cyclones increased in the north Indian Ocean. Curr Sci 80(4):575–580

SMRC (South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre) (1998) The impact of tropical cyclones on the coastal region of SAARC countries and their influence in the region, SRMC No. 1. SMRC, Dhaka

SMRC (South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre) (2003) The vulnerability assessment of the SAARC coastal region due to sea level rise: Bangladesh case, SMRCNo. 3. SMRC, Dhaka

Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (2007) Climate change 2007: the physical science basis. Cambridge University Press, Cambridge/New York. 996 pp

Talukder J, Roy GD, Ahmad M (1992) Living with cyclone: study on storm surge prediction and disaster preparedness. Community Development Library, Dhaka. 124 pp
Umitsu M (1985) Regional characteristics of the landforms in the Bengal Basin. Studies in socio-cultural change in rural in Bangladesh, no. 1, pp 1–44
Unnikrishnan AS, Kumar KR, Fernandes SE, Michael GS, Patwardhan SK (2006) Sea level changes along the Indian coast: observations and projections. Curr Sci 90(3):362–368
Unnikrishnan AS, Kumar MRR, Sindhu B (2011) Tropical cyclones in the Bay of Bengal and extreme sea-level projections along the east coast of India in a future climate scenario. Curr Sci 101(3):327–331
Vinayachandran PN, Masurnoto Y, Mikawa T, Yarnagata T (1999) Intrusion of the southwest monsoon current into the Bay of Bengal. J Geophys Res 104(C5):11077–11085
Warner K, van der Geest K (2013) Loss and damage from climate change: local-level evidence from nine vulnerable countries. Int J Glob Warming 5(4):367–386
Webster PJ, Holland GJ, Curry JA, Chang HR (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 309:1844–1845
Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, people's vulnerability and disasters. Routledge, London
Yokoi S, Takayabu YN (2010) Environmental and external factors in the genesis of tropical cyclone Nargis in April 2008 over the Bay of Bengal. J Meteor Soc Jpn 88(3):425–435

Chapter 7
Climate Variability Impacts on Agricultural Land Use Dynamics in the Madhupur Tract in Bangladesh

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Abstract Bangladesh is a small country, but it has different land types in different areas. According to the Bangladesh Agricultural Research Council, in 2014 about 80% of people in Bangladesh were directly or indirectly involved with agriculture. Climatic variation is the most pressing issue for agriculture now all over the world. Weather is the day-to-day condition of the atmosphere at a specific place and includes changes taking place over a matter of seconds, minutes, or hours, and their effects upon life and human activities. Climate change may refer to a change in average weather conditions, or a time variation in longer-term (30- to 40-year) average weather conditions. Generally, the impacts of climate change are progressively familiar as a substantial aspect disturbing life. Several studies have indicated that the climate in Bangladesh is changing and becoming more unpredictable every year. The climate is changing rapidly, resulting in a rise in the earth's average temperature. Global climate change and its consequences are having a bad impact on developing countries, which face natural calamities and poverty. Climatic variation impacts include temperature rise; erratic rainfall; greenhouse and CO_2 gas emissions; salinity intrusion; increases in floods, cyclones, storm surges, and drought; and melting of ice sheets. These impacts will seriously affect agriculture and livelihood, especially for the poor. Bangladesh, because of its geographical location, is likely to be one of the most seriously affected countries.

Climate change can influence agricultural land use patterns and cause farmers to fall into poverty. The study described in this chapter shows that climatic variation and its impact, especially variability in temperature and rainfall, are highly responsible for changes in agricultural land use patterns in the Madhupur Tract agro ecological zone (AEZ) of Bangladesh. An AEZ is an area of nearly the same ecological and soil characteristics for agricultural crop production, so cropping patterns in a definite AEZ are mostly the same. The homogeneity of an AEZ is more prominent in a sub region and most prominent at a unit level. The AEZs of Bangladesh have

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been determined on the basis of some definite characteristics of physiography, hydrology, cropping patterns, seasons, soil types, and tidal activity. In fact, an AEZ indicates an area characterized by homogeneous agricultural and ecological characteristics. Bangladesh has tentatively been divided into 30 AEZs. These 30 zones have been subdivided into 88 agro ecological sub regions, which have been further subdivided into 535 agro ecological units.

7.1 Introduction

Bangladesh is a small country, but it has different land types in different areas. About 80% of the people of Bangladesh are directly or indirectly involved with agriculture (BARC 2014a). Climate change can influence crop yield and the land area appropriate for agriculture. (Gao and Liu 2011). Climatic variation is the most pressing issue for agriculture now all over the world (Aggarwal et al. 2007). Bangladesh will be one of the countries most affected by climate change (Ali 2004) Weather is the day-to-day conditions of the atmosphere at a specific place, and includes changes taking place over a matter of seconds, minutes, or hours, and its effects upon life and human activities (Brammer 2012). Climate change may refer to a change in average weather conditions, or a time variation in longer-term (30- to 40-year) average weather conditions. Generally, the impacts of climate change are progressively familiar as a substantial aspect disturbing life (Kurukulasuriya and Rosenthal 2003). Conversely, significant concern for the world's agricultural future, and presents a spatially explicit view of the possible global impacts (Lobell et al. 2011), assuming that the temperature would not exceed the 35 °C threshold limit for rice production (CDMP 2008). Temperature elevations are likely to pose a great threat to winter or rabi crops (CDMP 2008). Several studies have indicated that the climate in Bangladesh is changing and becoming more unpredictable every year (Syeda 2012). The Intergovernmental Panel on Climate Change (IPCC) report for South Asia predicts that monsoon rainfall will increase, resulting in greater flows during monsoon season in the river systems (IPCC 2014). The climate is changing rapidly as a result of the rise in the earth's average temperature. Global climate change and its consequences are having a bad impact on developing countries, which face natural calamities and poverty (Jones et al. 2009). The IPCC has estimated that by 2050, changing rainfall patterns with increasing temperatures, flooding, and droughts could reduce Bangladesh's rice production by 8% and wheat production by 32%, in comparison with 1990 as the base year (MoEF 2008). Ecological and Biological responses to climate change are occurring as shifts in time, space and organism throughout terrestrial, aquatic, and marine habitats (Reid et al. 2000). Climatic variation impacts include temperature rise; erratic rainfall; greenhouse and CO_2 gas emissions; salinity intrusion; increases in floods, cyclones, storm surges, and droughts; and melting of ice sheets. These impacts will seriously affect agriculture and livelihood, especially for the poor (Shamsuddin et al. 2015).

Weather changes affect hydrological processes of rainfall, runoff, river flow, and reservoir storage, which then impact the water supply downstream. Furthermore, agriculture water demands are affected (David 2010). Adaptations to climate change such as agronomic manipulations, implementation of sustainable climate-resilient agriculture, shifting of planting dates, and use of short-duration crop cultivars can reduce vulnerabilities (Ali 2012). Bangladesh, because of its geographical location, is likely to be one of the country's most affected by climate change. Climate change can influence agricultural land use patterns and cause farmers to fall into poverty (Hertel and Rosch 2010). The impacts of climate change will cause enhanced vulnerability for the crop production systems in Bangladesh (Rahman and Alam 2004).

This study shows that climatic variation and its impact, especially on temperatures and rainfall, are highly responsible for changes in the agricultural land use pattern in the Madhupur Tract agro ecological zone (AEZ) in Bangladesh. An AEZ is an area of nearly the same ecological and soil characteristics for agricultural crop production (Brammer 2014), so cropping patterns in a definite AEZ are mostly the same. The homogeneity of an AEZ is more prominent in a sub region and most prominent at a unit level (Quddus 2009). Compounded climate factors can decrease plant productivity, resulting in price increases for many important agricultural crops (Islam and Rahman 2012). The AEZs in Bangladesh have been determined on the basis of some definite characteristics of physiography, hydrology, cropping patterns, season, soil types, and tidal activity (Mondal 2005). In fact, an AEZ indicates an area characterized by homogeneous agricultural and ecological characteristics (Mizyed 2009). Bangladesh has tentatively been divided into 30 AEZs (Brammer 2000). These 30 zones have been subdivided into 88 agro ecological sub regions, which have been further subdivided into 535 agro ecological units (Banglapedia 2009).

One of the most significant AEZs in Bangladesh is the Madhupur Tract. It is unique and extensively used for national and local-level production-planning purposes. Agro ecological resources are increasingly playing an important role in agricultural planning, technology transfer, and utilization of specific biophysical resource program activities (Bryan et al. 2009).

7.1.1 Research Aim and Objectives

The main aim of this study was to investigate how climatic variables affect agricultural land use patterns and how farmers adapt or select agricultural crops for the change in climate. The specific objectives were the following:

(i) To analyze seasonal variations in temperature in the study area
(ii) To investigate seasonal dynamics of the rainfall in the study area
(iii) To examine agricultural land use patterns over time and space, using Landsat images
(iv) To analyze adaptation strategies for agriculture with climate change in the study area

7.2 Data Sources and Methodology

The research methodology is entirely responsible for the systematic arrangement and processing of the research work (Berg 1995). Mainly this research has been completed using secondary and primary data sources. The daily average temperature and rainfall data from 1975 to 2014 from the Dhaka, Tangail, and Mymensingh weather stations were collected from the Bangladesh Meteorological Department (BMD) to examine the climate variability. Satellite images from the Landsat Thematic Mapper (TM) and Landsat Multispectral Scanner System (MSS) of 30 m resolution were collected from the Earth Explorer and US Geological Survey (USGS) global visualization viewer to investigate the dynamics of the agricultural land use at the study site. Data related to local farmers' perceptions about climate change and agricultural land use dynamics were collected through focus group discussion (FGD). Exploratory statistical techniques were deployed to analyze the seasonal weather elements' variability. The satellite images were analyzed to measure the agricultural land use through unsupervised image classification techniques by using Erdas Imagine software 14. Arc GIS 10.2.1 was used to synthesize the data for mapping purposes. The primary sources provided first-hand testimony or direct evidence concerning the topic under investigation. A questionnaire survey to ascertain the local people's perception of climatic changes in the locality confirmed that the climate in the region is becoming more severe day by day and is affecting the local agricultural land use.

Climate change and agriculture are interrelated processes, both of which take place on a global scale. Climate change affects agriculture in a number of ways, including through changes in average temperatures, changes in rainfall, and climate extremes. This study examined climate variables through time on different scales and their effects on agricultural land use.

7.3 Study Area

Bangladesh is a small country, but it has different land types in different areas. Fig. 7.1 shows the study area map of Madhupur Tract. The Madhupur Tract land areas have been recognized as an AEZ on the basis of their hydrology, physiography, soil types, tidal activity, land levels in relation to flooding and agro climatology, cropping patterns (this was done on the basis of the length of the rabi and kharif seasons and the major and minor agricultural crops that are cultivated in a particular area), and seasons (this was done on the basis of the depth and duration of seasonal flooding in a particular area). The Madhupur Tract is one of the major AEZs in Bangladesh.

The Madhupur Tract (4244 km^2) is a region of complex relief and soils developed over the Madhupur Clay. The landscape comprises level uplands, with closely

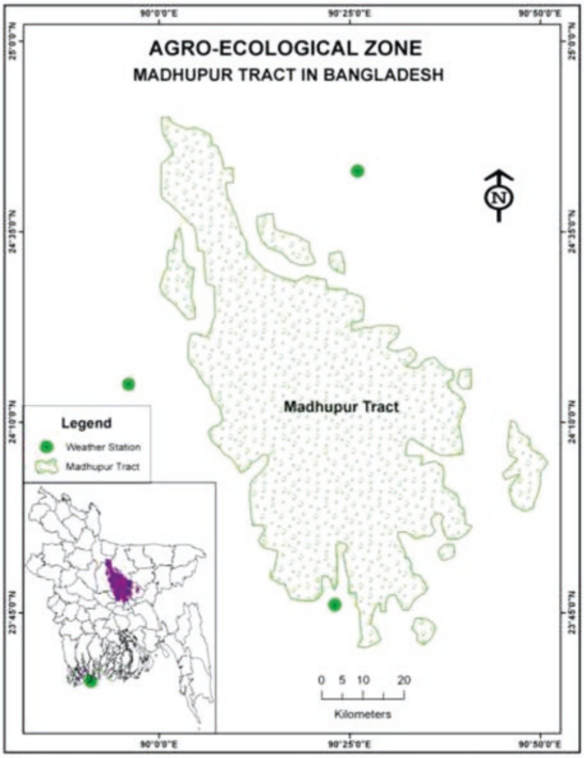

Fig. 7.1 Study area map of the Madhupur Tract

or broadly dissected terraces associated with either shallow or broad, deep valleys. Eleven general soil types exist in the area, of which deep red brown terrace soils, shallow red brown terrace soils, and acid basin clays are the major ones. The soils in the valleys are dark gray heavy clays. They are strongly acidic in reaction with a low status of organic matter, low moisture-holding capacity, and a low fertility level. The Madhupur Tract Pleistocene upland block in the Bengal Basin is located in the central part of Bangladesh, comprising the greater Dhaka and Mymensingh districts, between the courses of the Old Brahmaputra and the Jamuna Rivers. Toward the south, this physiographic subregion extends as far as Dhaka, the capital of the country. Like the Barind Tract, the area is a Pleistocene terrace consisting mainly of red-colored and mottled clays. It is characterized by plateau-like hillocks varying in height from 9 to 18.5 m, and a dendritic drainage pattern, typical of all Pleistocene terraces in Bangladesh. The valleys, mostly flat, are cultivated. The Madhupur jungle contains shal trees (Shorea robusta), the hardwood of which is second to teak in value.

7.4 Results and Discussion

Data from three selected weather stations (Dhaka, Tangail, and Mymensingh) were used for this research. A very noticeable feature of this research was the three cropping seasons at different times of the year. During the kharif-I season, domesticated plants are cultivated and harvested from the month of March to the end of June in the Madhupur Tract. The main kharif-I crop is rice. During this transition period, the soils intermittently become moist and dry. The kharif-II season starts with the beginning of the first rains, usually in July, during the south west monsoon season. This season lasts 4 months from July to October. Rabi crops are sown around mid-November, after the monsoon rains. The rabi season (November–February) starts at the end of the humid period and lasts until the pre-kharif season.

Seasonal data from the three selected weather stations are presented below for measurement of the Madhupur Tract climatic conditions. Table 7.1 shows the Dhaka weather station temperature variations in different agricultural seasons. This study analyzed the three cropping seasons' temperature trends. Some figures are mentioned below that symbolize the temperature trends in the Madhupur Tract.

Figure 7.2 illustrates the average temperatures in Dhaka in the kharif-I season over a 40-year period. It can be seen from the graph that the temperatures increased in 1988 and 2010, and slightly decreased in 1977, 1982, and 1993. The average temperature recorded in this season was 28.42 °C.

Figure 7.3 shows the kharif-II season (July–October) average temperatures in Dhaka over the same 40-year period. As illustrated by the graph, the temperature rose to 29.65 °C in 2010 and declined to 27.83 °C in 1975.

Figure 7.4 shows the rabi season average temperature variations in Dhaka over the 40-year period. The highest temperatures were observed in 1987 and 2006, and the lowest were seen in 1975 (20.35 °C) and 1993.

The temperature variations at the Tangail weather station in different agricultural seasons in 1975–2014 are shown in Table 7.2.

Figure 7.5 shows the kharif-I season average temperatures at the Tangail weather station. As can be seen from the graph, the maximum temperature was 29.16 °C in

Table 7.1 Variations in temperature at the Dhaka weather station in different agricultural seasons (1975–2014)

	Seasonal temperature (°C)		
Years	Kharif-I	Kharif-II	Rabi
1975–1984	27.91	28.35	20.97
1985–1994	28.44	28.76	21.74
1995–2004	28.42	28.69	21.57
2005–2014	28.98	29.09	21.78
Average	28.44	28.72	21.51
Maximum	29.92	29.65	22.72
Minimum	27.11	27.83	20.35

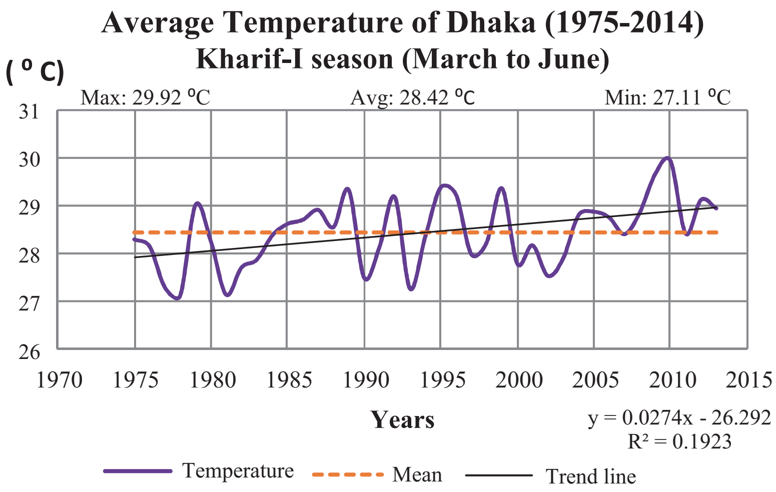

Fig. 7.2 Average temperatures at the Dhaka weather station in the kharif-I season between 1975 and 2014. R^2 coefficient of determination

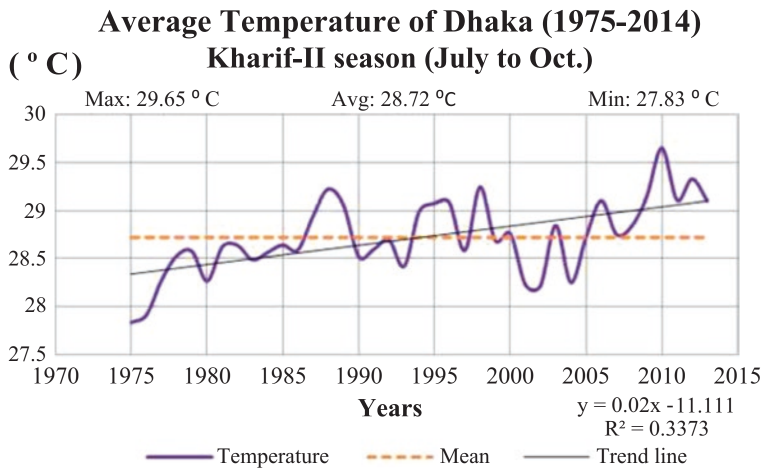

Fig. 7.3 Average temperatures at the Dhaka weather station in the kharif-II season between 1975 and 2014. R^2 coefficient of determination

2010 and the minimum temperature was 26.70 °C in 1993. The straight line represents the average temperature in this season.

Figure 7.6 illustrates the average temperature in the kharif-II season in Tangail. As can be seen, it covers the years of 1987–2014 and shows the temperature trend over 27 years. The data indicate that the average temperature in the kharif-II season was 28.72 °C.

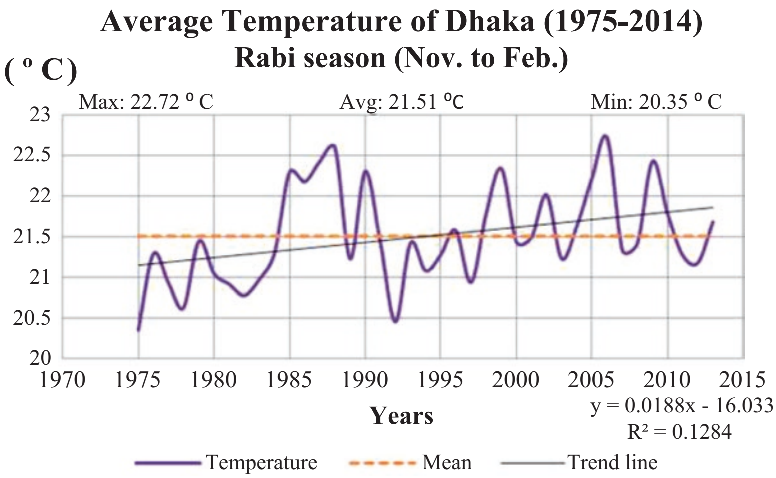

Fig. 7.4 Average temperatures at the Dhaka weather station in the rabi season between 1975 and 2014. R^2 coefficient of determination

Table 7.2 Variations in temperature at the Tangail weather station in different agricultural seasons (1975–2014)

	Seasonal temperature (°C)		
Years	Kharif-I	Kharif-II	Rabi
1975–1984	28.01	28.10	20.70
1985–1994	27.82	28.53	20.68
1995–2004	27.76	28.68	20.52
2005–2014	28.32	29.01	20.48
Average	27.98	28.58	20.6
Maximum	29.16	29.39	22.03
Minimum	26.08	27.25	19.67

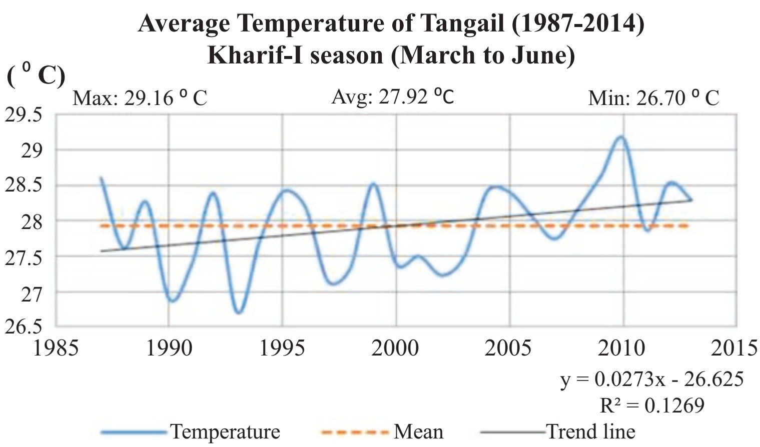

Fig. 7.5 Average temperatures at the Tangail weather station in the kharif-I season between 1987 and 2014. R^2 coefficient of determination

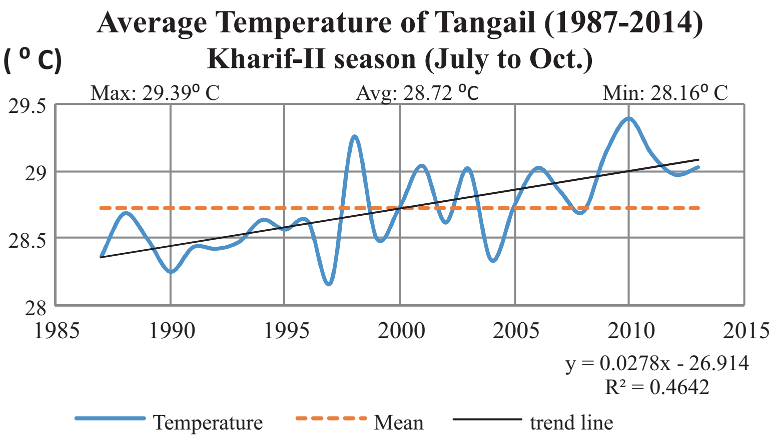

Fig. 7.6 Average temperatures at the Tangail weather station in the kharif-II season between 1987 and 2014. R^2 coefficient of determination

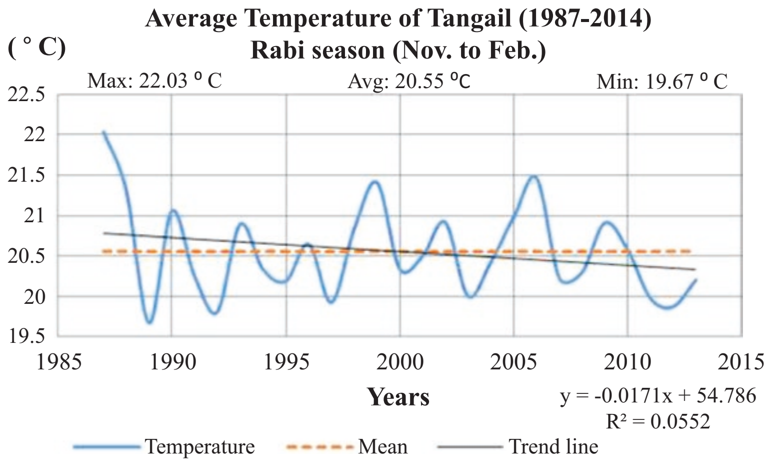

Fig. 7.7 Average temperatures at the Tangail weather station in the rabi season between 1987 and 2014. R^2 coefficient of determination

Figure 7.7 shows the rabi season average temperatures over 27 years in Tangail. From the graph, it is clear that the temperature was slightly higher in 1987 and substantially lower in 2013.

The temperature variations at the Mymensingh weather station in different agricultural seasons are shown in Table 7.3.

Figure 7.8 shows the kharif-I season average temperatures in Mymensingh in 1975–2014. The year with the highest temperature (31.49 °C) was 1982, while the lowest temperature (25.50 °C) was recorded in 1992. The years of 1984, 1985,

Table 7.3 Variations in temperature at the Mymensingh weather station in different agricultural seasons (1975–2014)

Years	Seasonal temperature (°C)		
	Kharif-I	Kharif-II	Rabi
1975–1984	28.26	28.96	21.93
1985–1994	26.93	28.11	20.72
1995–2004	27.05	28.39	20.70
2005–2014	27.31	28.69	20.50
Average	27.39	28.54	20.97
Maximum	31.49	31.82	26.86
Minimum	25.71	27.25	18.91

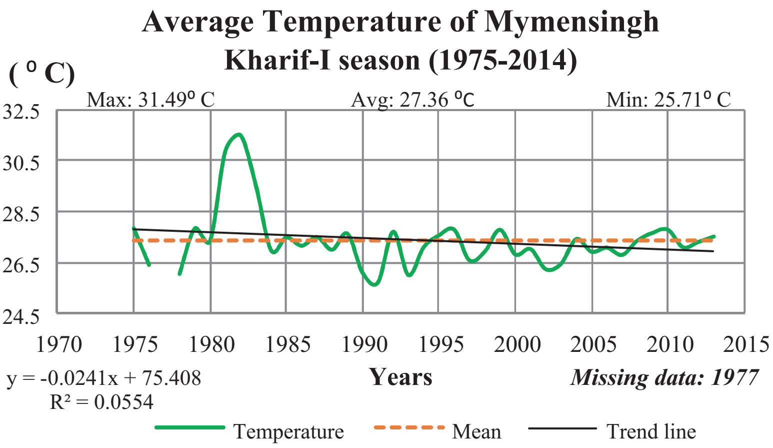

Fig. 7.8 shows average temperatures in Mymensingh in the kharif-I season between 1975 and 2014. R^2 coefficient of determination

1986, 1987, 1995, 1996, 1998, 2000, 2004, 2005, 2008, and 2010 all had temperatures of less than 28.00 °C.

Figure 7.9 shows the average temperature variations in Mymensingh over 40 years in the kharif-II season. From the graph, it is clear that the temperature jumped markedly in 1982, though in the years of 1992–2013 it stayed relatively constant.

Figure 7.10 shows the average rabi season temperatures in Mymensingh from 1975 to 2014. It can be seen from the graph that in 1982 the temperature was 26.86 °C; by 2012 it had gone down to 18.91 °C. The straight line in the graph indicates the mean temperature.

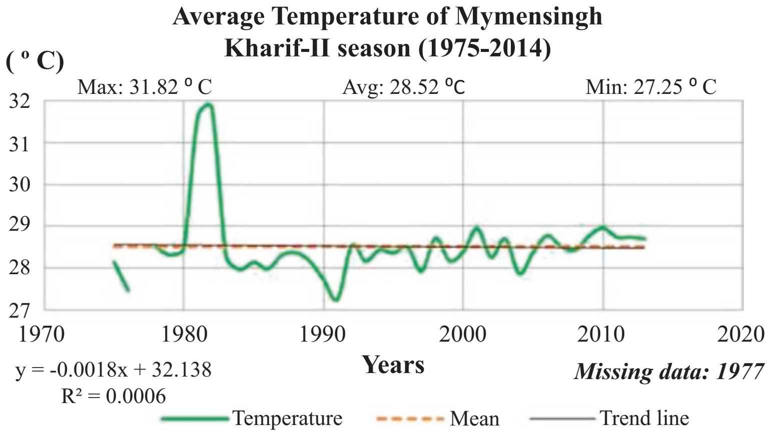

Fig. 7.9 Average temperatures at the Mymensingh weather station in the kharif-II season between 1975 and 2014. R^2 coefficient of determination

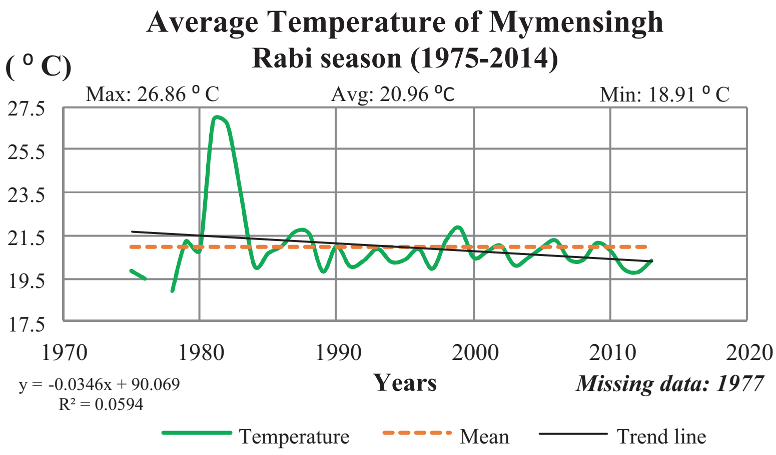

Fig. 7.10 Average temperatures at the Mymensingh weather station in the rabi season between 1975 and 2014. R^2 coefficient of determination

7.4.1 Rainfall

Rain is liquid water in the form of droplets that have condensed from atmospheric water vapor and then precipitated—that is, become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the freshwater on the earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation. The major cause of rain production is moisture moving along three-dimensional zones of temperature and moisture contrasts, known as weather fronts. Table 7.4

Table 7.4 Variations in rainfall at the Dhaka weather station in different agricultural seasons (1975–2014)

Years	Seasonal rainfall (mm) Kharif-I	Kharif-II	Rabi
1975–1984	7.92	9.25	0.52
1985–1994	7.14	9.47	0.85
1995–2004	6.47	9.40	0.52
2005–2014	5.80	9.90	0.62
Average	6.83	9.51	0.63
Maximum	12.08	14.93	0.85
Minimum	2.54	5.08	0.04

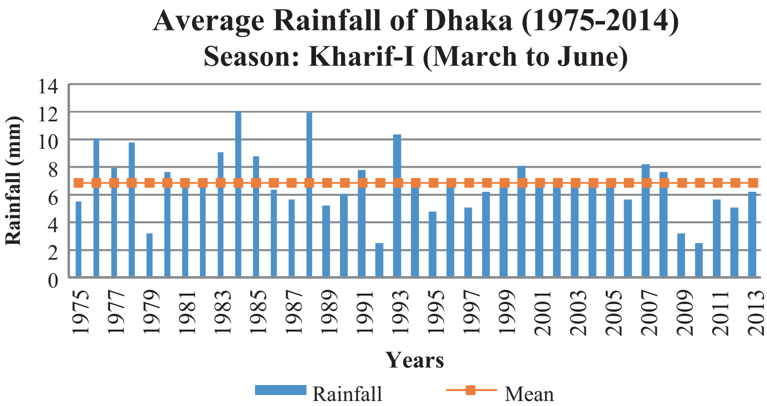

Fig. 7.11 Average rainfall at the Dhaka weather station in the kharif-I season between 1975 and 2014

shows the rainfall variations at the Dhaka weather station in different agricultural seasons.

Figure 7.11 indicates the kharif-I season average rainfall in Dhaka over the period of 1975–2014. The year with the highest rainfall was 1984, with over 12 mm, while 1993 had the lowest rainfall at little more than 2 mm.

Figure 7.12 shows the average rainfall at the Dhaka weather station in the kharif-II season over the same 40-year period. It demonstrates how the pattern changed during the course of 38 years. From the graph, it is clear that 1992, 1993, 1999, 2005, 2007, and 2009 had the greatest amounts of rainfall at more than 13 mm. The lowest rainfall was recorded in 1995.

Figure 7.13 depicts the average rabi seasonal rainfall in Dhaka from 1975 to 2013. It can be seen from the graph that more rainfall was recorded in the years of 1986 and 1987. Less rainfall was recorded in 2006. The straight line in the graph indicates the mean rainfall in the rabi season throughout the 40-year period.

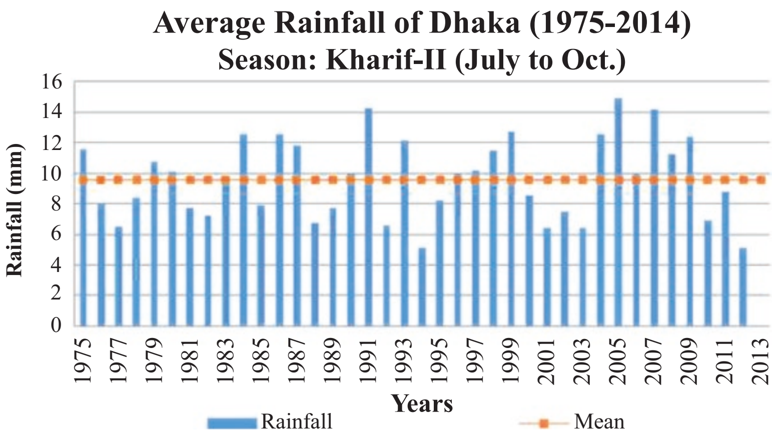

Fig. 7.12 Average rainfall at the Dhaka weather station in the kharif-II season between 1975 and 2014

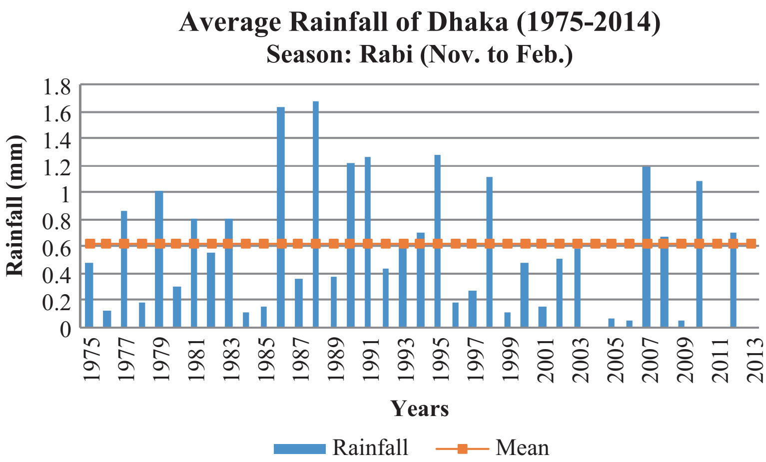

Fig. 7.13 Average rainfall at the Dhaka weather station in the rabi season between 1975 and 2014

Table 7.5 shows the rainfall variations at the Tangail weather station in different agricultural seasons.

Figure 7.14 shows the kharif-I season average rainfall in Tangail in the period of 1987–2014. The year with the highest rainfall was 1993, with over 9 mm, whereas 1999 had the lowest rainfall, at little more than 3 mm. The straight line represents the average rainfall in Tangail in the kharif-I season.

Figure 7.15 indicates the average rainfall in Tangail in the kharif-II season across the 27 years. It demonstrates how the pattern changed over that time. From the graph, it is clear that 1992, 1995, 1999, 2002, and 2013 had nearly equal amounts of rainfall, at just over 8 mm. During 1990–1991, the amount of rainfall rose rapidly

Table 7.5 Variations in rainfall at the Tangail weather station in different agricultural seasons (1975–2014)

Years	Seasonal rainfall (mm)		
	Kharif-I	Kharif-II	Rabi
1975–1984	7.14	9.47	0.64
1985–1994	6.76	8.99	0.79
1995–2004	6.00	8.12	0.55
2005–2014	5.20	8.72	0.59
Average	6.27	8.83	0.64
Maximum	11.91	14.27	1.85
Minimum	2.54	5.07	0.02

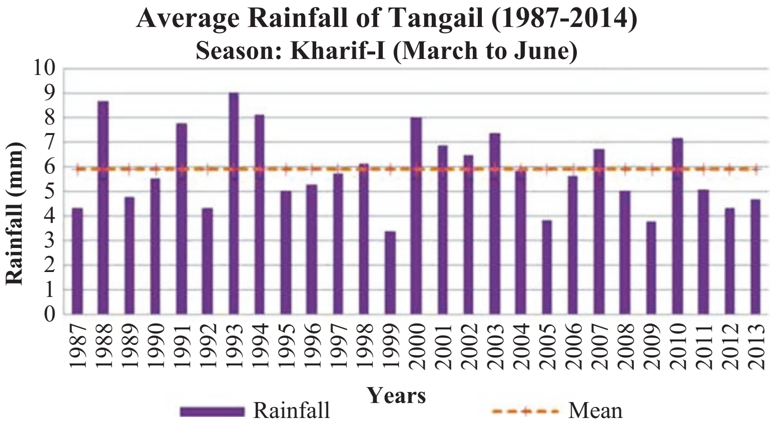

Fig. 7.14 Average rainfall at the Tangail weather station in the kharif-I season between 1987 and 2014

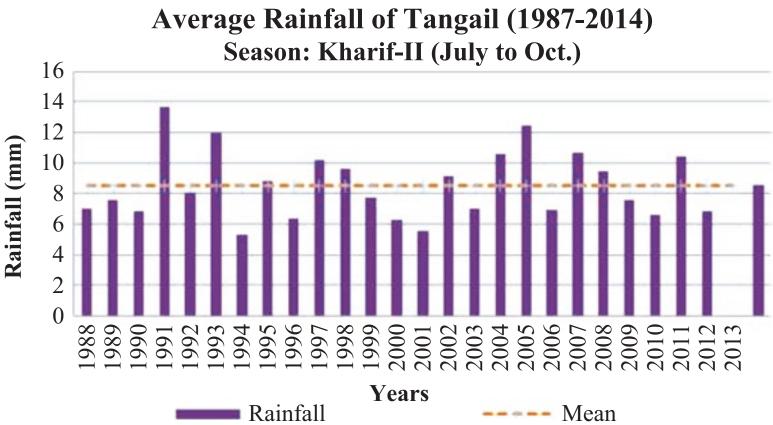

Fig. 7.15 Average rainfall at the Tangail weather station in the kharif-II season between 1987 and 2014

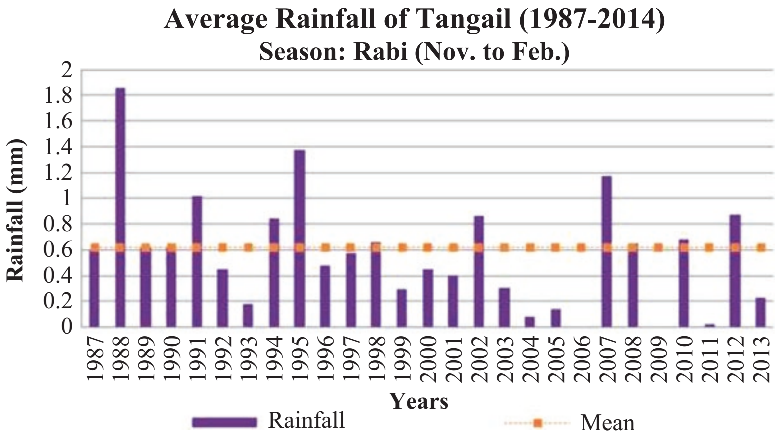

Fig. 7.16 Average rainfall at the Tangail weather station in the rabi season between 1987 and 2014

Table 7.6 Variations in rainfall at the Mymensingh weather station in different agricultural seasons (1975–2014)

	Seasonal rainfall (mm)		
Years	Kharif-I	Kharif-II	Rabi
1975–1984	7.45	9.15	0.49
1985–1994	7.71	11.22	0.64
1995–2004	7.21	10.49	0.38
2005–2014	6.91	9.53	0.43
Average	7.32	10.10	0.49
Maximum	15.22	16.30	1.61
Minimum	0.10	0.18	0.09

toward 13 mm, and the lowest recording occurred in 1994, with less than 6 mm. From then on there was a rise and fall noted. In 1998, the amount of rainfall reached a peak more than 10 mm. After that there was a sudden decline just after next year to continue 2002.

Figure 7.16 shows the rabi season average rainfall variation in Tangail over the 40-year period. From the graph, it is clear that the highest and lowest amounts of rainfalls recorded were in 1988 and 2011, respectively, while the amount of rainfall generally remained unstable.

Table 7.6 shows the rainfall variations at the Mymensingh weather station in different agricultural seasons.

Figure 7.17 presents the kharif-I season average rainfall in Mymensingh in the period of 1975–2014. The year with the highest rainfall was 1977, with over 15 mm, while 1979 had the lowest rainfall, at little more than 3 mm. The straight line represents the average rainfall in the kharif-I season.

Figure 7.18 shows the average rainfall in Mymensingh in the kharif-II season over the 40-year period. It demonstrates how the pattern changed over that time.

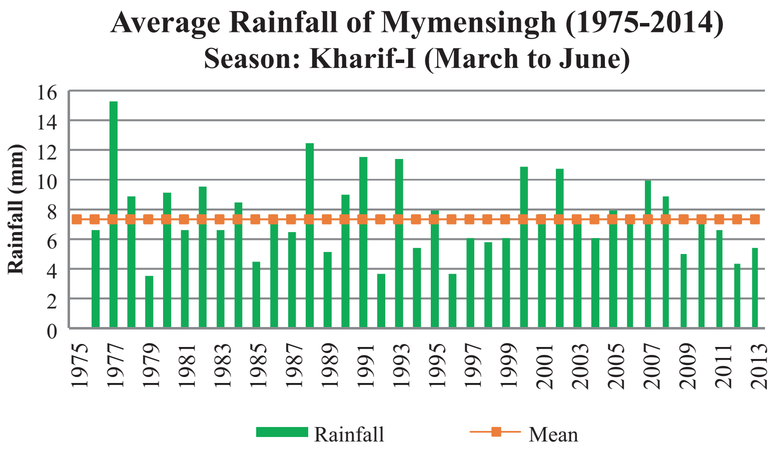

Fig. 7.17 Average rainfall at the Mymensingh weather station in the kharif-I season between 1975 and 2014

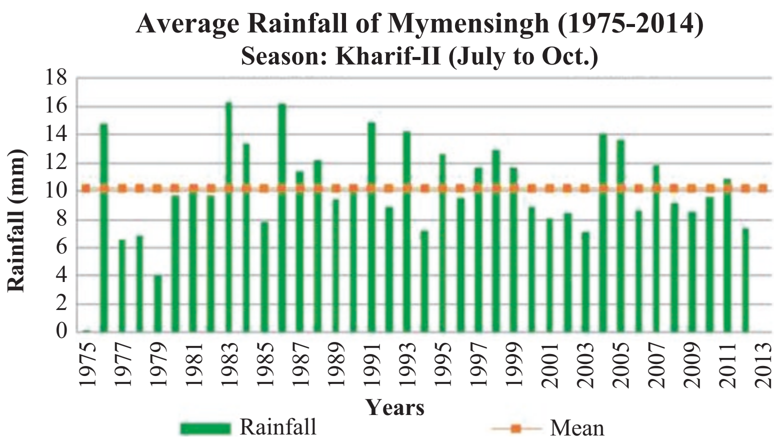

Fig. 7.18 Average rainfall at the Mymensingh weather station in the kharif-II season between 1975 and 2014

From the graph it is clear that 1983, 1987, 1992, and 1993 had more rainfall (above 16 mm) than the other years. The lowest rainfall in this season was recorded in 1975.

Figure 7.19 shows the average rainfall in Mymensingh during the rabi season from 1975 to 2014. From the graph, it is clear that more rainfall was recorded in 1977 and 1989, and less rainfall was recorded in several years such as 1975, 1979, and 1999. The straight line in the graph indicates the average rainfall in the rabi season throughout the 40 years.

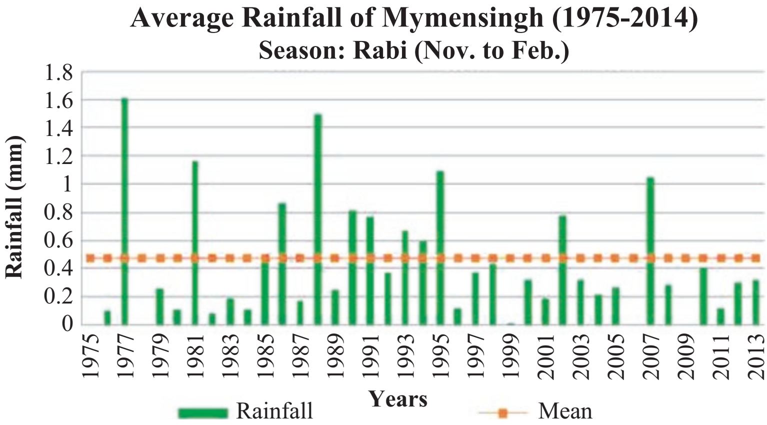

Fig. 7.19 Average rainfall at the Mymensingh weather station in the rabi season between 1975 and 2014

7.4.2 Relationship Between Temperature and Rainfall

Rainfall and temperature are important climatic inputs for agricultural production, especially in the context of climate change. However, accurate analysis and simulation of the joint distribution of rainfall and temperature are difficult because of the possible interdependence between them. The large-scale correlation between the observed monthly mean temperature and precipitation has more importance. Observed changes in regional temperature and precipitation can often be physically related to one another. This section assesses the consistencies of these relationships in the observed trends.

Figure 7.20 illustrate the average monthly temperature and rainfall over a period of 40 years in the Dhaka part of the Madhupur Tract. Overall, it is clear that there was a direct link between the mean temperature and mean rainfall, and both of them showed fluctuations throughout the 12-month period. First of all, the most noticeable feature of the line graph is that the temperature reached its first peak in April and it's second in August (just above 28.0 °C and well over 27.0 °C, respectively). The next striking feature of this graph is the temperature, which had its lowest point (approximately 20.5 °C) in December. Comparing the temperatures over the 40-year time frame, it is apparent that the temperature in January was lower than that in December (around 17.5 °C and 20.5 °C, respectively). Looking at the bar graph, it can be seen the peak mean rainfall over the 40-year period was in July (around 12.3 mm), and in September the figure was around 11 mm. The lowest rainfall over the 40-year period was in January, with just under 1.0 mm. Over the 40-year period, there was more rainfall in the middle 5 months of the year (May–September).

Figure 7.21 show the average monthly temperature and rainfall for a period of 27 years in the Tangail part of the Madhupur Tract. Generally, it is clear that there was a direct link between the mean temperature and mean rainfall, both of which

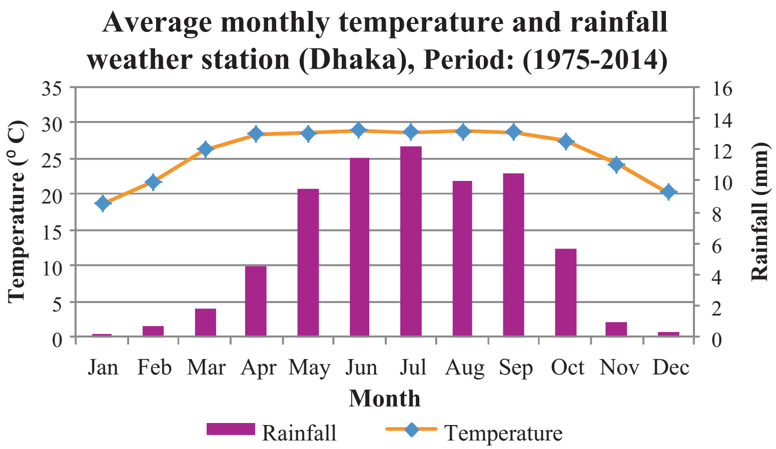

Fig. 7.20 Average monthly temperature and rainfall at the Dhaka weather station in 1975–2014

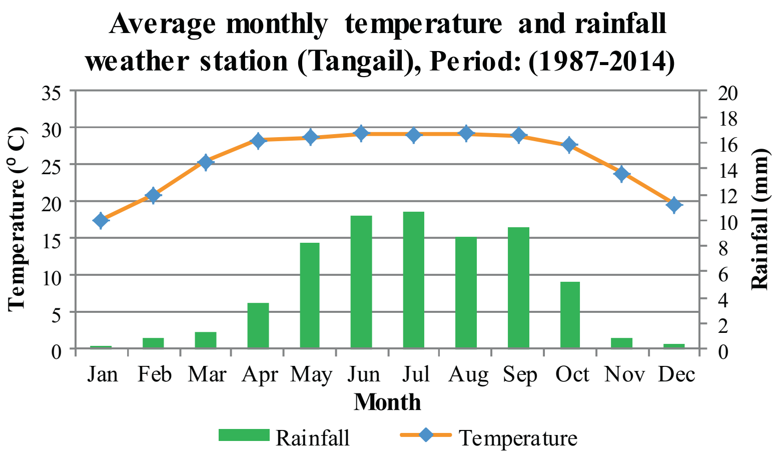

Fig. 7.21 Average monthly temperature and rainfall at the Tangail weather station in 1987–2014

showed fluctuations throughout the 12-month period. The most evident feature of the line graph is that the temperature reached its first peak in April and its second in August (just above 28.0 °C and well over 27.0 °C, respectively). The next striking feature of this graph is that the temperature had its lowest point in December (approximately 19.0 °C). Turning to the bar graph, it is clear that the peak mean rainfall over the 27 years was in July (around 11.0 mm). The lowest rainfall was in January, with just under 1.0 mm.

Figure 7.22 shows the average monthly temperature and rainfall over 40 years in the Mymensingh part of the Madhupur Tract. It is clear that there was a link between the mean temperature and mean rainfall, and both of them showed changeability throughout the 12-month period.

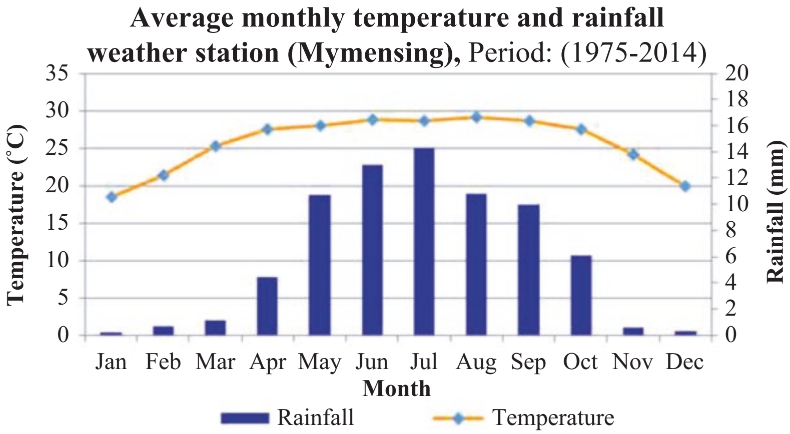

Fig. 7.22 Average monthly temperature and rainfall at the Mymensingh weather station in 1975–2014

Firstly, the supreme visible feature of the line graph is that the temperature shows its first peak in April and its second in August (just above 28.50 °C and well over 28.0 °C, respectively). Looking at the bar graph, it can be seen that the peak mean rainfall throughout the 40-year period was in July, with around 14.0 mm. The lowest rainfall was in January and December, with just under 1.0 mm. Throughout the 40-year period, there was more rainfall in the middle 5 months of the year (May–September).

7.5 Season-Wise Agricultural Land Use Changes

Land use is a complicated concept. Natural scientists define land use in terms of syndromes of human activities such as agriculture, forestry, and building construction, which alter land surface processes including its biogeochemistry, hydrology, and biodiversity. Few studies have inspected modifications in both land cover and particular climate variables over large areas using a suitable complete spatial measure and over a long period of time (Salvati et al. 2013).

Land use, also known as land change, is a general term for human modification of the earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, the current rates, extents, and intensities of land use changes are far greater than ever before in history, driving unprecedented changes in ecosystems and environmental processes at the local, regional, and global scales. These changes encompass the greatest environmental concerns of human populations today, including climate change, biodiversity loss, and pollution of water, soils, and air. In this research, three seasons of land use dynamics over two 20-year intervals in the Madhupur Tract were measured and analyzed, as discussed in Sects. 7.5.1–7.5.3.

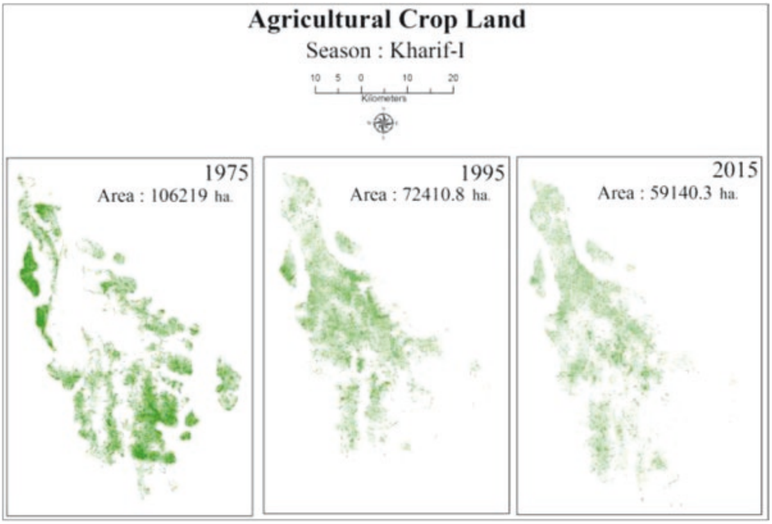

Fig. 7.23 Agricultural land use dynamics in the kharif-I season, shown at 20-year intervals in 1975, 1995, and 2015

7.5.1 Kharif-I Season

In the kharif-I season, domesticated plants are cultivated and harvested from the month of March to the end of June in the Madhupur Tract. The main kharif-I crop is rice. During this transition period, the soils intermittently become moist and dry. The relative lengths and frequencies of such periods depend on the timing and intensity of the pre-monsoon rainfall during this season in individual years. With the expansion of irrigation facilities, some pre-kharif crops are now grown under irrigated conditions. These include sugarcane, boro rice, pineapple, wheat, ginger, jute, banana, etc. From Fig. 7.23, it can be seen that the land area used for agriculture in the kharif-I season gradually decreased over the two 20-year intervals because of climatic variations, especially in temperature and rainfall.

In 1975 the land area used for agriculture in the kharif-I season was 106,219 ha, but this decreased by 31.82% over the next 20 years. Over the subsequent 20 years there was another 18.33% decrease. In total, therefore, the land area used for agriculture in the kharif-I season decreased by 44.32% between 1975 and 2015. We can see here that the relationship between temperature and rainfall (Fig. 7.24) was the main factor in this decrease. The rapid changes in land use and land cover have to be included in impact analysis. Linking of the socioeconomic aspects needs to be strengthened (Aggarwal et al. 2007).

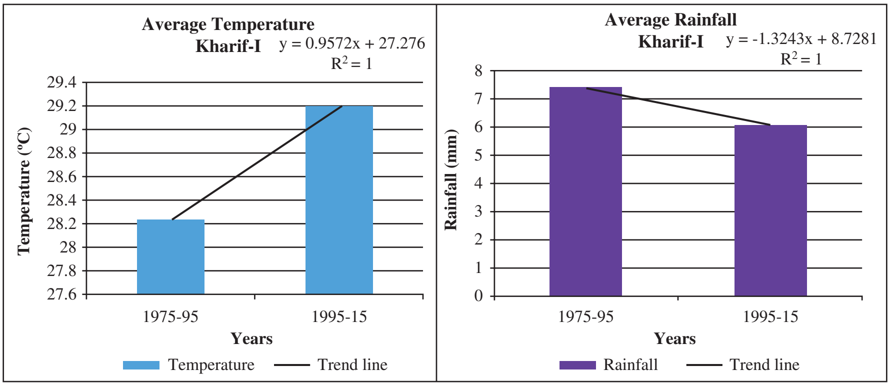

Fig. 7.24 shows Temperature and rainfall trends in the kharif-I season between 1975–1995 and 1995–2015. R^2 coefficient of determination

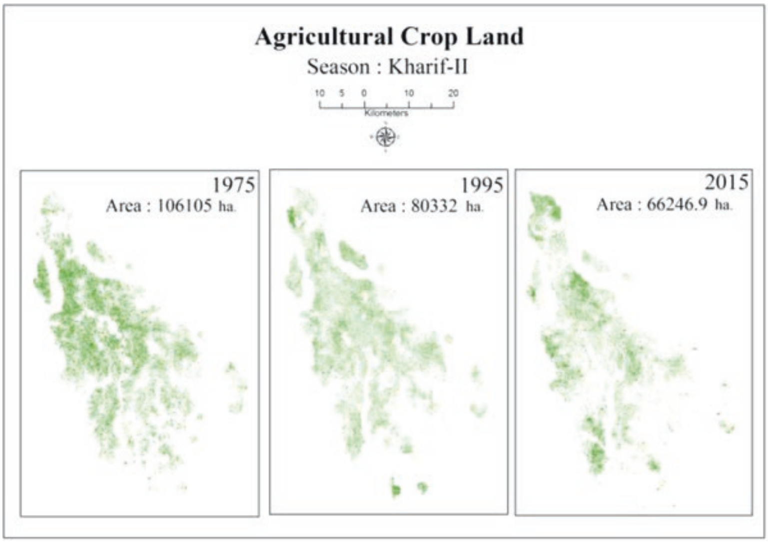

Fig. 7.25 Agricultural land use dynamics in the kharif-II season, shown at 20-year intervals in 1975, 1995, and 2015

7.5.2 *Kharif-II Season*

The kharif-II season usually starts with the first rains in July during the southwest monsoon season. This season lasts for 4 months from July to October. Figure 7.25 shows reductions in the use of the land for agriculture in the kharif-II season over the two 20-year intervals between 1975 and 2015. The most noticeable feature in this figure is the 37.57% reduction in the agricultural use of the land during the

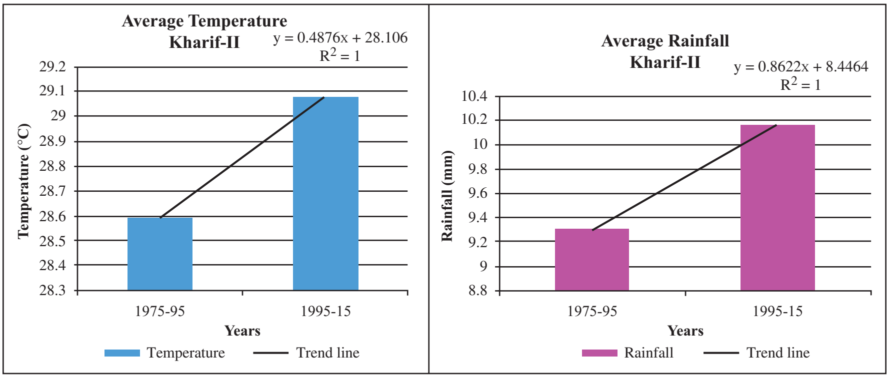

Fig. 7.26 Temperature and rainfall trends in the kharif-II season between 1975–1995 and 1995–2015. R^2 coefficient of determination

kharif-II season over the 40-year period. The reduction between 1975 and 1995 was 24.29%, with a further reduction of 17.53% between 1995 and 2015.

Figure 7.26 shows the temperature and rainfall trends during the same period. These climatic variations were not the main factor in the reduction but did play a vital role in it. It has been acknowledged that land cover and land use changes are related to ecological features (Dale 1997).

7.5.3 Rabi Season

The term "rabi" is derived from the Arabic word for "spring" and is used in the Indian subcontinent, where it is the spring harvest (also known as the "winter crop"). Rabi crops (or winter crops) are sown around mid-November, after the monsoon rains. The rabi season (November–February) starts at the end of the humid period and lasts until the pre-kharif season. The most common rabi crops are wheat, maize, boro rice, mustard, groundnut, sesame, potato, sweet potato, sugarcane, lentil, chickpea, and grass pea.

Figure 7.27 shows the reductions in agricultural land use during the rabi season at 20-year intervals between 1975 and 2015, which were smaller than the reductions that occurred in the kharif seasons. Nobody has studied the connection between climate change and land use change, except on a theoretical level (Lambin et al. 2003).

1975 was the base year, with a 78,085 ha area of land used for crops in the rabi season. In the two 20-year intervals from 1975 to 1995 and from 1995 to 2015, the cropland in the rabi season decreased by 0.62% and 15.51%, respectively. During the whole 40-year period (1975–2015) the total decrease was 16.13%.

Temperature and rainfall dynamics were the main causes of the reduction in cropland in the rabi season, but a lot of climatic variables interact with human activities. The relationship between temperature and rainfall in the rabi season between 1975–1995 and 1995–2015 is shown in Fig. 7.28.

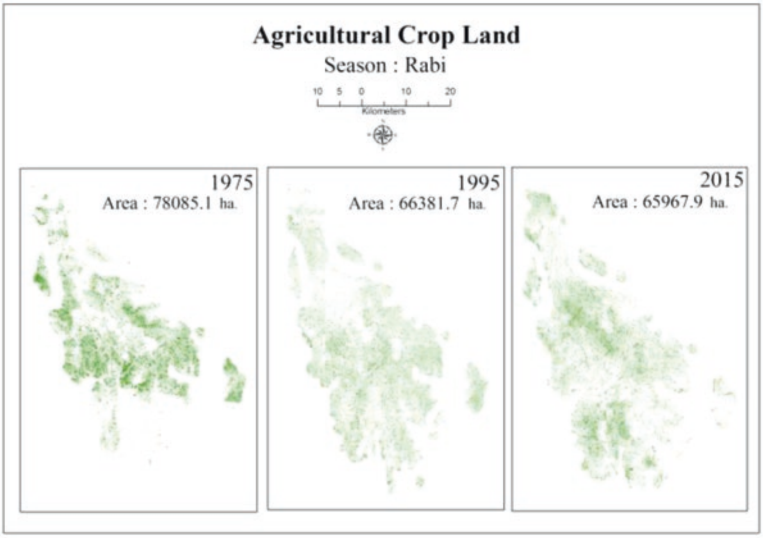

Fig. 7.27 Agricultural land use dynamics in the rabi season, shown at 20-year intervals in 1975, 1995, and 2015

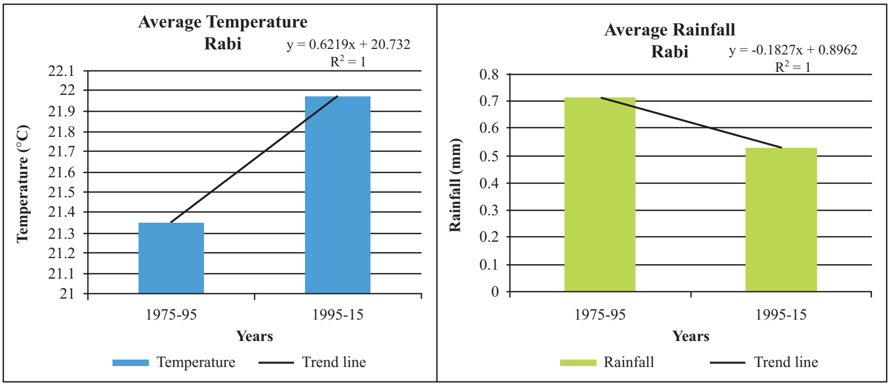

Fig. 7.28 Temperature and rainfall trends in the rabi season between 1975–1995 and 1995–2015. R^2 coefficient of determination

7.6 Strategies for Adaptation to Climate Change

Climatic variables, especially temperature and rainfall, have a great impact on agriculture. A lot of crops are grown in the Tangail district, which contributes continuously to the gross domestic product (GDP). But sometimes crop production is significantly hampered by climate change in the Tangail district. For this reason, adaptation strategies are needed for climate change. Some strategies are described below that could help the agricultural sector in the Tangail district to provide more crops, despite climatic hazards, and thereby enrich the national economy.

(a) *Climate Forecasting:* Climate forecasting is needed for prediction of climatic hazards. If farmers can predict the impact of climate changes, they will be better able to factor these changes into their decision making.
(b) *Alternative Cropping Times:* To avoid growing crops at times when their production will be harmed by the impacts of climatic hazards, use of new cropping timetables could help to minimize decreases in production.
(c) *Water Management Systems:* Judicious management of water resources is vital for agriculture, especially in areas that experience droughts, so that farmers can cope with drought conditions.
(d) *Increasing Technology Usage:* Many technologies are now used in European countries for the purpose of agriculture. With an appropriate initiative led by the government of Bangladesh, farmers could benefit greatly from access to technological tools, with appropriate training, for use in agriculture.
(e) *Changes in Cropping Patterns:* To cope with adverse conditions caused by climatic variations, farmers may need to consider the possibility of crop changes. It is difficult to changing cropping patterns but possible to consider planting new crops. Planting of crops that are easier to grow in more hostile conditions, such as jute, may be an effective way to adapt agriculture to changing climatic conditions.

7.7 Conclusion

This study analyzed climatic (temperature) records, provided by the BMD, for a 40-year period (1975–2014). The results revealed that the climatic variables changed through time on different scales. During this 40-year period, the maximum average temperature was 30.23 °C, recorded during the kharif-II season, and the minimum average temperature was 19.48 °C, recorded in the rabi season.

In the kharif-I season, the Dhaka weather station recorded a maximum average temperature of 29.92 °C and a minimum average temperature of 27.11 °C, the Tangail weather station recorded a maximum average temperature of 29.16 °C and a minimum average temperature of 26.70 °C, and the Mymensingh weather station recorded a maximum average temperature of 31.49 °C and a minimum average temperature of 25.71 °C.

In the kharif-II season, the Dhaka weather station recorded a maximum average temperature of 29.65 °C and a minimum average temperature of 27.83 °C, the Tangail weather station recorded a maximum average temperature of 29.39 °C and a minimum average temperature of 28.16 °C, and the Mymensingh weather station recorded a maximum average temperature of 31.82 °C and a minimum average temperature 27.25 °C.

In the rabi season, the Dhaka weather station recorded a maximum average temperature of 22.72 °C and minimum average temperature of 20.35 °C, the Tangail weather station recorded a maximum average temperature of 22.03 °C and a minimum average temperature of 19.67 °C, and the Mymensingh weather station recorded a maximum average temperature of 26.86 °C and a minimum average temperature of 18.91 °C.

With respect to the first objective of the study, it was shown that the temperature gradually increased over the 40-year period, and agricultural land use was affected by this. For better cropping, consistent temperatures are best, as high and low temperatures are harmful to cropland.

Concerning the second objective of the study, the research results showed that in the kharif-I season, the Dhaka weather station recorded maximum average rainfall of 12.08 mm and minimum average rainfall of 2.54 mm, the Tangail weather station recorded maximum average rainfall of 9.00 mm and minimum average rainfall of 3.38 mm, and the Mymensingh weather station recorded maximum average rainfall of 15.22 mm and minimum average rainfall of 0.10 mm.

In the kharif-II season, the Dhaka weather station recorded maximum average rainfall of 14.92 mm and minimum average rainfall of 5.06 mm, the Tangail weather station recorded maximum average rainfall of 13.69 mm and minimum average rainfall of 5.33 mm, and the Mymensingh weather station recorded maximum average rainfall of 16.03 mm and minimum average rainfall of 0.18 mm.

In the rabi season, the Dhaka weather station recorded maximum average rainfall of 1.67 mm and minimum average rainfall of 0.04 mm, the Tangail weather station recorded maximum average rainfall of 1.85 mm and minimum average rainfall of 0.02 mm, and the Mymensingh weather station recorded maximum average rainfall of 1.61 mm and minimum average rainfall of 0.008 mm. With regard to the third objective of the study, the results showed that agricultural land use has gradually decreased because of climatic variations, especially in temperature and rainfall. The land use was analyzed in the three seasons of kharif-I, kharif-II, and rabi. The total agricultural land use in the kharif-I season measured 106,219 ha in 1975, decreasing to 72,410.8 ha in 1995 and 59,140.3 ha in 2015. According to the agricultural cropping seasons, the agricultural land use in the kharif-II season measured 106,105 ha in 1975, decreasing by 24.29% in the 20-year interval to 1995 and by a further 17.53% in the 20-year interval to 2015. In the rabi season, the agricultural land use measured 78,085.1 ha in 1975, 66,381.7 ha in 1995, and 65,967.9 ha in 2015. These results indicated that over the two 20-year intervals (1975–1995 and 1995–2015), the total agricultural land use gradually decreased.

This study exposed the relationship between temperature and rainfall as the main factor in the decrease in agricultural land use. In the kharif-I season, agricultural land use decreased by 31.82% between 1975 and 1995 and by a further 18.33% between 1995 and 2015, representing a total reduction of 44.32% of the original area over the 40-year period. In the kharif-II season, the total decrease in agricultural land use over the 40-year period was 37.57%: 24.29% from 1975 to 1995 and

17.53% from 1995 to 2015. In the rabi season, the reductions in agricultural land use over the 40-year period were smaller than those observed in the kharif seasons: from the initial area of 78,085 ha in 1975, decreases of 0.62% in the 20-year interval to 1995 and 15.51% in the 20-year interval to 2015 were observed. Over the total 40-year period (1975–2015) the reduction in agricultural land use during the rabi season was 16.13%. Temperature and rainfall dynamics are the main causes of the reductions in cropland, but a lot of climatic variables interact with human activities.

With respect to the fourth objective of the study, strategies for adaptation of agriculture to cope with climate change have been suggested. Climate change has a major impact on agriculture, especially changes in temperature and rainfall. For this reason, adaptation strategies are needed. The strategies suggested here include use of climate prediction to reduce production risk, shifting the timing or location of cropping activities, managing water to prevent water-sorting that means lack of water and erosion with increased rainfall, etc. All of them could be very helpful if incorporated into a national policy on crop production. Future climatic adaptation strategies for Bangladesh should take into account the insights gained from the findings of this research in the Madhupur Tract.

References

Aggarwal PK, Gupta NC, Mukesh S, Debashis C (2007) Impacts of climate change on agriculture. Outlook Agric 36(2):109–118

Ali M (ed) (2004) Agricultural diversification and international competitiveness. Asian productivity organization, Tokyo

Ali MM (2012) Impacts of climate change on cropping pattern in coastal region of Bangladesh: a case study of Sharankhola Upazila, Bagerhat. Department of Architecture, BRAC University

Banglapedia (2015) The national encyclopedia of Banglades

BARC (Bangladesh Agricultural Research Council) (2014a) Climate and LRI database BARC, Dhaka

BARC (Bangladesh Agricultural Research Council) (2014b) Climate and LRI database. BARC, Dhaka

BBS (Bangladesh Bureau of Statistics) (2010) Various issues. Statistical yearbook of Bangladesh, 1975, 1995, 2005, and 2009. BBS, Dhaka

Berg AMJ (1995) Qualitative research methods for the social sciences. California Stole University, Long Beach, ISBN-13: 978–0205809387

Brammer H (2000) Agroecological aspects of agricultural research in Bangladesh. The University Press Limited, Dhaka, ISBN 984 05 1506 3

Brammer H (2012) The physical geography of Bangladesh. The University Press Limited, Dhaka

Brammer H (2014) Bangladesh's dynamic coastal regions and sea-level rise. Climate Risk Manage 1:51–62

Bryan ETT, Deressa GA, Ringler C (2009) Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environ Sci Pol 12(4):413–426

CDMP (Comprehensive Disaster Management Programme) (2008) Climate change cell, who is doing what in Bangladesh? Report on the first meeting. 2008, CDMP, Government of the People's Republic of Bangladesh, Dhaka

Dale VH (1997) The relationship between land-use change and climate change. Ecol Appl 7:753–769

David B (2010) Bangladesh, India most threatened by climate change, risk study finds. National Geographic. Retrieved 21 Dec 2011.

Gao J, Liu Y (2011) Climate warming and land use change in Heilongjiang Province, Northeast China. Appl Geogr 31:476–482. 64

Hertel TW, Rosch SD (2010) Climate change, agriculture, and poverty. Appl Econ Perspect Pol 32(3):355–385

IPCC (Intergovernmental Panel on Climate Change) (2001) Climate change 2001: mitigation, contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, UK

IPCC (Intergovernmental Panel on Climate Change) (2014) Climate change 2014: impacts, adaptation, and vulnerability: global and sectoral aspects to the Intergovernmental Panel on Climate Change 5th assessment report. Paris

Islam N, Rahman MM (2012) An assessment of crop diversification in Bangladesh: a spatial analysis. Appl Econ Lett 19:29–33

Jones PG, Thornton PK, Heinke J (2009) Generating characteristic daily weather data using down-scaled climate model data from the IPCC's fourth assessment. Bonn, Germany; Nairobi, Kenya: Federal Ministry for Economic Cooperation and Development; International Livestock Research Institute. Accessed 5 June 2010

Khan S (2012) Effects of climate change. Envirocivil.com. Retrieved 27 Oct 2013

Kurukulasuriya P, Rosenthal S (2003) Climate change and agriculture. World Bank Environment. Department Paper # 91, Washington, DC

Lambin EF, Geist HJ, Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. Annu Rev Environ Resour 28:205–241

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333:616–620

Mizyed N (2009) Impacts of climate change on water resources availability and agricultural water demand in the West Bank. Water Resour Manag 23(10):2015–2029

MoEF (Ministry of Environment and Forests) (2008) Bangladesh climate change strategy and action plan 2008, MoEF, Government of the People's Republic of Bangladesh, September 2008

Mondal MH (2005) Challenges and opportunities of sustainable crop production in Bangladesh. Eighth Biennial Agronomy Convention, Bangladesh Society of Agronomy

Quddus MA (2009) Crop production growth in different agro-ecological zones of Bangladesh. J Bangladesh Agric Univ 7:351–360

Rahman A, Alam M (2004) Mainstreaming adaptation to climate change in least developed countries (LDCs): Bangladesh Country Case Study. International Institute for Environment and Development (IIED) working paper, 2003(2). 65

Reid R, Kruska R, Muthui N, Taye A, Wotton S, Wilson C, Mulatu W (2000) Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. Landsc Ecol 15:339–355

Salvati L, Sateriano A, Zitti M (2013) Long-term land cover changes and climate variations a country-scale approach for a new policy target. Land Use Policy 30:401–407

Shamsuddin SD, Ahmed R, Jahan R (2015) Climate variability: issues and perspectives for Bangladesh. Shahitya Prakash, Dhaka, ISBN 984–70124–0218-4

Syeda JA (2012) Trend and variability analysis for forecasting of temperature in Bangladesh. J Environ Sci Nat Res 5(1):243–252

Chapter 8
Detection of Climate Change Impacts on the Hakaluki Haor Wetland in Bangladesh by Use of Remote Sensing and GIS

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Abstract Bangladesh possesses enormous areas of wetlands including rivers and streams, fresh water lakes and marshes, *haors*, *baors*, *beels*, water storage reservoirs, fishponds, flooded cultivated fields, and estuarine systems with extensive mangrove swamps. The *haors*, *baors*, *beels*, and *jheels* are of fluvial origin and are commonly identified as freshwater wetlands. Wetlands are subject to periodic inundation, changing from shallow to deep water during the wet monsoon. Most of the wetlands are inland wetlands located in the northeastern part of Bangladesh. The total area of the wetlands in this country has been estimated at 7–8 million ha, or about 50% of the total land surface. The wetlands provide habitats for many special plants, birds, mammals, reptiles, amphibians, fish, and invertebrate species. The wetlands are critically important in Bangladesh for human settlements, biodiversity, fisheries, agricultural diversity, irrigation, navigation, communication, and ecotourism. Wetlands help to reduce the impacts of flooding, maintain good water quality in rivers, recharge groundwater, store carbon, stabilize climatic conditions, and control pests. Wetlands also improve water quality by trapping sediments, filtering out pollutants, and absorbing nutrients that would otherwise result in poor water quality for downstream users.

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8.1 Introduction

Bangladesh possesses enormous areas of wetlands, including rivers and streams, freshwater lakes and marshes, *haors*, *baors*, *beels*, water storage reservoirs, fishponds, flooded cultivated fields, and estuarine systems with extensive mangrove swamps (Kam 1995). The *haors*, *baors*, *beels*, and *jheels* are of fluvial origin and are commonly identified as freshwater wetlands (FAP 1994). Wetlands are subject to periodic inundation, changing from shallow to deep water during the wet monsoon. Most of the wetlands are inland wetlands located in the northeastern part of Bangladesh. The total area of the wetlands in this country has been estimated at 7–8,000,000 ha, or about 50% of the total land surface (Khan et al. 1994). The wetlands provide habitats for many special plants, birds, mammals, reptiles, amphibians, fish, and invertebrate species (Thomson and Hardin 2000). The wetlands are critically important in Bangladesh for human settlements, biodiversity, fisheries, agricultural diversity, irrigation, navigation, communication, and ecotourism (Lunetta et al. 2004). Wetlands help to reduce the impacts of flooding, maintain good water quality in rivers, recharge groundwater, store carbon, stabilize climatic conditions, and control pests (Park and Tateishi 1998). Wetlands also improve water quality by trapping sediments, filtering out pollutants, and absorbing nutrients that would otherwise result in poor water quality for downstream users (Şirinyildiz 2004).

Hakaluki Haor is one of the biggest palustrine wetlands of Bangladesh. It consists of a large number of *beels* surrounded by heavily grazed grassland and rice fields. The major functions of this wetland include protecting and improving water quality, providing safe places for fish and wildlife habitats, storing floodwaters, and maintaining surface water flow during dry periods (Singh 1989). These beneficial services, considered valuable to societies worldwide, result from the inherent and unique natural characteristics of wetlands (Teeffelen et al. 2001). Hakaluki Haor shows all of the characteristics and function of a standard wetland; for this reason it has achieved fame nationwide (Ahmed et al. 2008). To derive optimum benefit from this *haor*, the sustainability of it is also important. But all of the wetlands in Bangladesh are facing serious challenges from environmental change and anthropogenic impacts. Land grabs, climate change, illegal hunting of migratory birds, and disorganized agricultural activities degrade the standard and natural beauty of Hakaluki Haor. Degradation of wetlands has caused several problems including extinction and reduction of wildlife; extinction of many indigenous wild and domesticated rice varieties; loss of many indigenous aquatic plants, herbs, shrubs, and weeds; loss of natural soil nutrients; loss of natural water reservoirs and of their resultant benefits; increases in the occurrence of flooding; and degeneration of wetland-based ecosystems, occupations, socioeconomic institutions, and cultures (Jung 2004; Walter 2004). For this reason it is becoming important to save our wetlands. To protect this environmentally critical area, continuous monitoring is very important, so we have to study it and make a plan and a strategy to safeguard this environment (Miller et al. 2005). It is very easy these days to monitor any environmental phenomenon, using remote sensing data, especially to identify and to assess changes.

8.2 Aim and Objectives

Different components of natural and cultural features can be identified using satellite images. It is possible to compare multi date images to detect the changes over consecutive periods and years. The main aim of this study was to identify the physio-environmental components to interpret the changing patterns of Hakaluki Haor. The specific objectives were as follows:

(a) To know the physio-environmental components of Hakaluki Haor
(b) To assess the changes in the physio-environmental components of the study from 1990 to 2015

8.3 Sources of Data

Various primary and secondary data were used to execute this study. Primary data were collected by field observations, focus group discussions, and formal and informal interviews. Secondary data such as satellite images of the study area were collected from the US Geological Survey (USGS) website (Table 8.1), and information was collected from different journals, reports, research papers, and other published and unpublished documents from government and nongovernmental organizations (McFeeters 1996).

Table 8.1 Landsat image scenes

Satellite	Path	Row	Acquisition date	Sensors	Spatial resolution(m)
Landsat 5	136	43	February 17, 1990	TM	30, thermal band 60
Landsat 5	136	43	February 7, 2001	ETM	30, thermal band 60
Landsat 7	136	43	February 8, 2010	ETM+	30, thermal band 60
Landsat 8	136	43	February 6,2015	OLI/TIRS	30, thermal band 60

Source: USGS 2015
ETM Enhanced Thematic Mapper, *ETM+* Enhanced Thematic Mapper Plus, *OLI* Operational Land Imager, *TIRS* Thermal Infrared Sensor, *TM* Thematic Mapper

8.4 Methodology

This study planned to use the techniques of remote sensing and GIS. Firstly, Landsat images of the study area in 1990, 2001, 2010, and 2015 were collected, then radiometric and atmospheric corrections had to be completed. Then the normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and land surface temperature (LST) were estimated (Hazel 2001). Thermal band and spectral band digital number (DN) values were used to estimate the land surface temperature (Quere and Maupin 1997). Finally the data were analyzed and interpreted by using Erdas Imagine 11 and Arc GIS 10.2.1 software (Zhang et al. 2002). Thus we prepared vegetation cover, water body, and temperature maps of the study area and did a change analysis with the help of statistical diagrams.

To identify a feature of the environment, two bands are needed, one of which is totally reflected by the feature and the other totally absorbed by the feature (Yagoub 2004). It is very important to select bands that are totally reflected and totally absorbed by vegetation or water bodies to identify the vegetation cover and water bodies. It is known that vegetation absorbs all red lights. On the other hand, infrared light is highly reflected by vegetation (Hall and Hall 2003). Therefore, these two bands can be useful for identifying vegetation cover. It is also known that water absorbs nearly all light of a near-infrared wavelength, where water bodies appear very dark (Miller et al. 2005). On the other hand, the green band highly reflects water bodies. Therefore, these two bands can be useful for identifying water bodies.

8.4.1 Identification of Vegetation Cover

The NDVI was used for identification of vegetation overage, using red light and values between −1 and +1, where −1 indicates bare soil, rock, and water; and +1 indicates vigorous vegetation (Iasillo and Albanese 2001). The following formula was used to calculate the vegetation cover in the study area (Stossel and Dockstader 2002):

$$NDVI = \frac{IR - R}{IR + R}$$

where IR is the pixel values from the infrared band; and R is the pixel values from the red band.

8.4.2 Identification of Water Cover

The NDWI was used for identification of water cover, using green light and values between −1 and +1, where −1 indicates soil or vegetation cover; and +1 indicates water cover (Niemeyer and Canty 2003). The index output value of the NDWI is

0–255 and in red–green–blue (RGB) mode the DN value is 0–255. Here, a 255 output value means full water bodies, and with a decreasing water content the DN value also decreases. The NDWI is expressed as follows (McFecters 1996):

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where Green is a green band such as Thematic Mapper (TM) band 2; and NIR is a near-infrared band such as TM band 4.

8.4.3 Identification of Surface Temperature

The LST method is widely used for identification of surface temperatures. There are many established methods that are popularly used to extract and estimate the LST from satellite images (Becker and Li 1990; Gitelson and Henebry 2002). To extract and estimate the LST from Landsat images the following methods are widely used, which consist of three steps: a, b, and c.

(a) Conversion of the thermal DN to spectral radiance (Cho and Alexandros 2002), using the following universal equation:

$$L_\lambda = L_{MIN} + \left(L_{MAX} - L_{MIN}\right) \times DN / 255$$

where L_λ is spectral radiance; L_{MIN} = 1.238 (spectral radiance of DN value 1); and L_{MAX} = 15.600 (spectral radiance of DN value 255) (Ngai et al. 1994)

(b) Conversion of the spectral radiance of the thermal imageries to temperature in Kelvin, using the following equation (Mcdermid et al. 2004):

$$T_b = k_2 / \ln\left\{\left(k_1 / L_\lambda\right) + 1\right\}$$

where K_1 is calibration constant 1(607.76); K_2 is calibration constant 2 (1260.56); and T_b is the surface temperature

(c) Conversion from Kelvin to Celsius, using the following equation:

$$T_b = T_b - 273$$

These equations are used to extract the temperature from Landsat 5 and 7, which have band 6 as a thermal layer; in Landsat 8, there are two thermal layers—band 10 and band 11—and the temperature is the mean of the two layers, where the $K_1$and K_2values are different from those of Lands at 5 and 7 (Li and Nrayanan 2003).

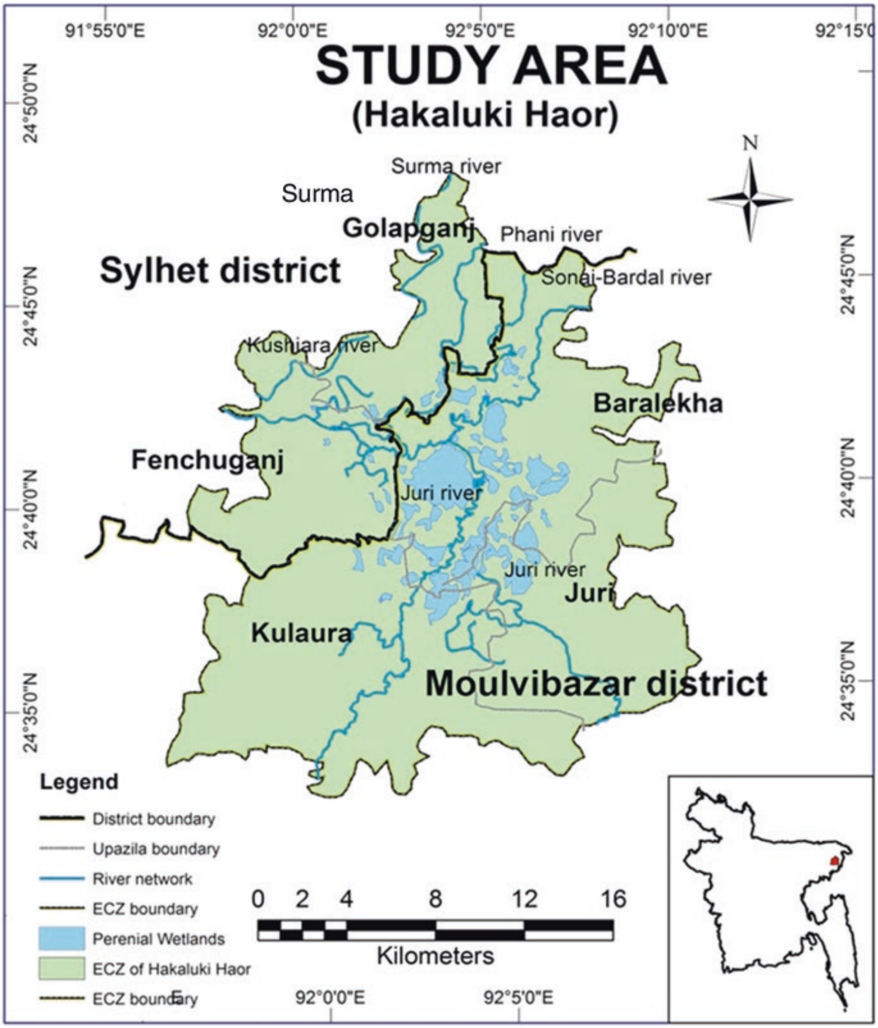

Fig. 8.1 Study area map of Hakaluki Haor Ecological Critical Zone (ECZ). (Source: MoEF 1999)

8.5 Study Area

Hakaluki Haor, a renowned wetland, was the study area. It is located in the Sylhet and Moulvibazar district under the Sylhet division. The study area lies between 24° 34′ N and 24° 47′ N latitude and between 92° E and 92° 10′ E longitude. It consists of five *upazilas*: Kulaura, Juri, Baralekah, Gopalganj, and Fenchuganj (Fig. 8.1). It is a complex ecosystem (Table 8.2), containing more than 238 interconnecting *beels* (CWBMP 2005). An area of over 39,600 ha is demarcated as an ecological critical area (ECA) for Hakaluki Haor, declared by the Ministry of Environment and

Table 8.2 Land use in Hakaluki Haor

Habitat category	Cover		Use
	Hectares	Percentage	
Beels	5003.59	26.95	Fishing, bird hunting, aquatic vegetation collection for food, fodder, and fuel
Rivers/canals	620.21	3.34	Fishing, boating, transportation
Fallow land	2907.84	15.66	Grazing, vegetation, fallow, grass and fuel collection
Boro crops	653.74	35.21	Winter rice cultivation in the seasonal parts of the *beels* and *haor* edges
Robi crops	3495.59	18.83	Oil seed and pulse cultivation on the higher land along the edges of the *haor*

Source: CNRS 2002

Forests. This was marked as the study area, but the total area of this *haor* is approximately 18,000 ha, including an area that is completely inundated during the monsoon (Im and Jensen 2005). The main river systems of Hakaluki Haor are the Kushiyara River, the Sonai-Bardal River, the Juri River, and the Phanai River. The livelihoods of about 190,000 people from 254 villages are directly or indirectly linked with Hakaluki Haor (IUCN 2006).

8.6 Physio-Environmental Change Detection in Hakaluki Haor

The physio-environmental components of the natural environment include only physical factors such as those biotic and abiotic physical components that dominate the environment and also influence each other (Yuan et al. 2005). Change detection of structural and visual components of the environment uses physio-environmental components (Hurskainen and Pellikka 2004). There are many components in a *haor* area, but not all of them are considered here, because remote sensing data were used to detect the changes. The *haor* area is an interaction zone of sub-terrestrial and sub-aquatic zones, so the following physio-environmental components were considered for change detection:

(a) Vegetation cover
(b) Water bodies
(c) Temperature
(d) Soil
(e) Depth/altitude/volume of water

From Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) images, it is possible to identify the temperature, vegetation cover and water bodies. On the other hand, the soil condition cannot be identified accurately; here it is possible to detect only bare soil. Visible light is reflected by bare soil, so if the DN value of visible light is near 255, then it presents as bare soil. But the fact is that bare soils are rare in wetland areas (Johnson and Kasischke 1998). The characteristics of the physio-environmental components of wetlands define the role of the wetlands in the aqua-terrestrial ecosystem (Bitelli et al. 2004). By identifying the physio-environmental components and their changes, it can be said what has happened in the past and what will happen in the future if this condition continues.

8.7 Vegetation Cover in Hakaluki Haor

Ecological characteristics, particularly vegetation patterns, differ sharply between the permanent and seasonal water bodies in Hakaluki Haor. There used to be a dense swamp forest, except in the monsoon season. Within the permanent water bodies, vegetation is less dense in the monsoon than in winter, since the vegetation becomes submerged and does not thrive without light. However, the aquatic vegetation that exists begins germinating with the onslaught of the monsoon floods. Aquatic vegetation grows mainly in the shallower parts of the *haor*. Other than the shorelines (*kanda*), most of the open water areas are weed free (BBS 2012). At least 73 species of different types of plants such as trees, shrubs, grasses, and aquatic plants have been found in the swamp forest (Choudhury and Faisal 2005).Hakaluki Haor contained a very dense swamp forest in the past, but deforestation and lack of conservation practices have virtually destroyed this unique forest in the last two decades. Two small patches of swamp forest remain in Hakaluki Haor. One is in the Chatla *beel* and another is near the village of Kalikrishnapur.

The plants that are common in this type of forest are also found in homestead groves. With the exception of these two swamp forest patches, the vegetation surrounding Hakaluki Haor is unique, since it includes both swamp forest and mixed evergreen rain forest. Thatching material is the most useful natural wetland product of the study area (Ridd and Liu 1998). Local people use this material in various ways, e.g., as roofing and walling material for their houses, and for making mats. The utilization of the wetland is now less intensive, because in recent years the vegetation has decreased considerably (Xue et al. 2004). Another important use of the resources from this wetland is for fuel wood. Because of the scarcity of fuel wood around homesteads, the people are becoming increasingly dependent on this source of fuel. Swamp forest trees, except for *hijol*, are the most popular fuel wood in this area.

The spatial distributions of vegetation cover in Hakaluki Haor can be detected by using the NDVI (Haverkamp and Poulsen 2003) (Fig. 8.2). From Fig. 8.2, it can be seen that the NDVI range in the 1990s Landsat image of HakalukiHaor was 0.634921 to −0.238021 and the range in the 2001 Landsat image was 0.510206 to −0.363636. In 2010 the NDVI range in the Landsat image of the study area was 0.575221 to −0.310345 and the NDVI range in the 2015 Landsat image was 0.41563 to −0.08700666.

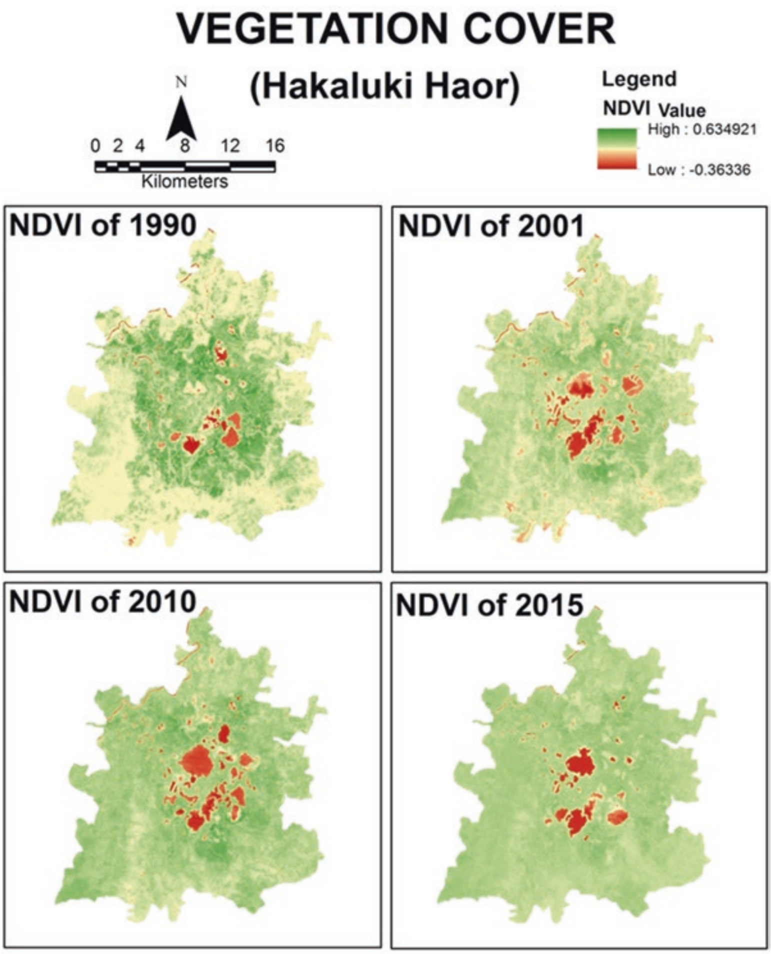

Fig. 8.2 Normalized difference vegetation index (NDVI)in Hakaluki Haor, 1990–2015. (Source: USGS Landsat image; analysis by author, 2015)

8.7.1 Vegetation Cover Classification in Hakaluki Haor

The NDVI outputs values between −1.0 and 1.0, mostly representing greenness, where any negative values are mainly generated from clouds, water, and snow, and values near zero are mainly generated from rock and bare soil. Very low NDVI values (0.1 and below) correspond to barren areas of rock, sand, or snow. Sparse vegetation (0.1–0.2) and moderate values (0.2–0.5) represent shrubs and grassland, while high values (0.6–0.8) indicate temperate and tropical rain forests (Canty and Niemeyer 2003). According to the NDVI values, the existing vegetation cover can be classified into the following four categories (Fig. 8.3):

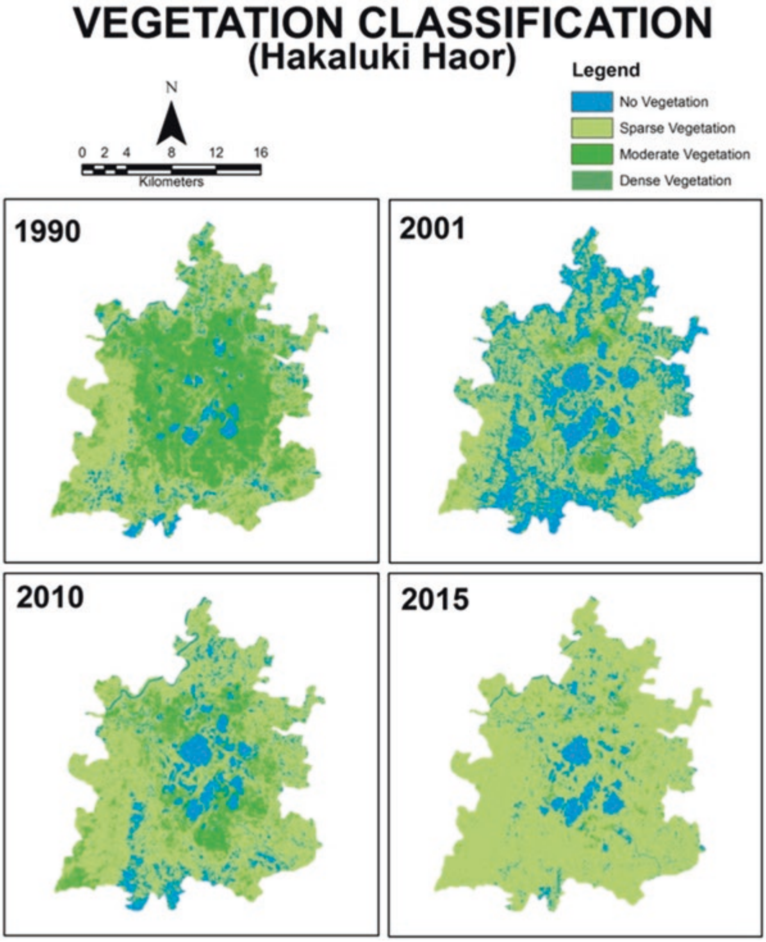

Fig. 8.3 Classification of vegetation cover in Hakaluki Haor, 1990–2015. (Source: USGS Landsat image; analysis by author, 2015)

(a) No vegetation (bare soil or water bodies)
(b) Sparse vegetation
(c) Moderate vegetation
(d) Dense vegetation

8.7.2 Vegetation Cover Change Detection

From the four NDVI images (in 1990, 2001, 2010, and 2015), it can be seen that the dense vegetation cover in the study area totally vanished from only 2 ha in 1990 to no dense vegetation in the subsequent three images (in 2001, 2010, and 2015) (Fig. 8.4 and Table 8.3).

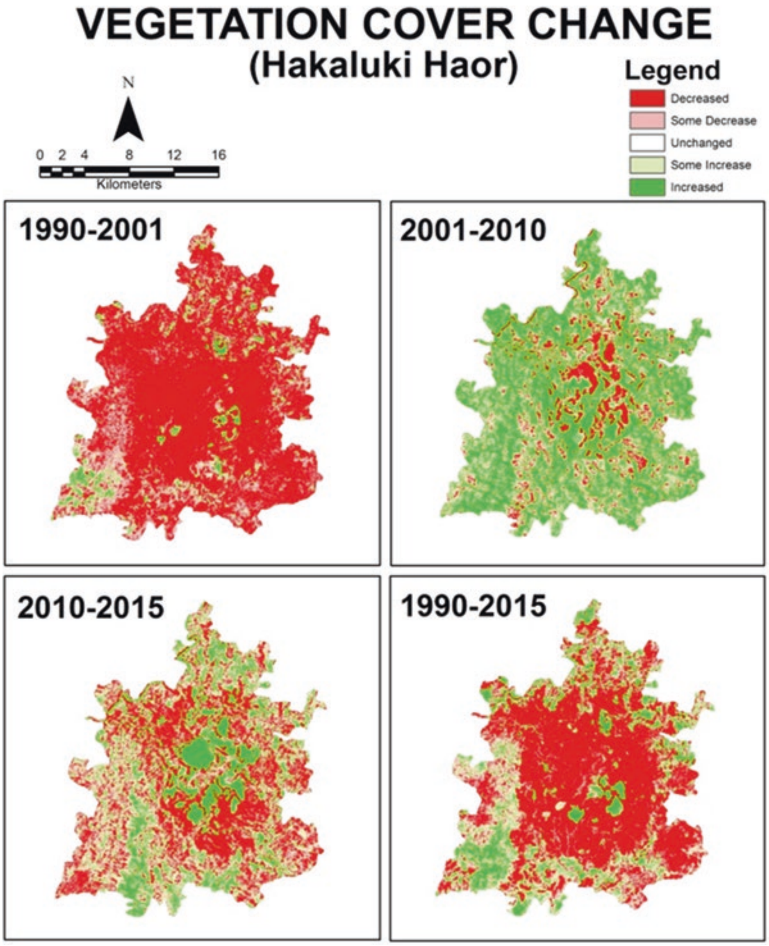

Fig. 8.4 Vegetation cover changes in Hakaluki Haor, 1990–2015. (Source: USGS Landsat image; analysis by author, 2015)

The sparse vegetation cover increased by 1384 ha, which is 4% of the total area, and the annual increase rate was 125.8 ha from 1990 to 2001. From 2001 to 2010 the sparse vegetation cover decreased by 6400 ha, which is 16% of the total area, and the annual decrease rate was 711 ha. From 2010 to 2015 the sparse vegetation cover increased by 19,036 ha, which is 48% of the total area, and the annual increase rate was 3807 ha. From 1990 to 2015 the sparse vegetation cover increased by 14,020 ha.

The moderate vegetation cover decreased by 12,493 ha, which is 32% of the total area, and the annual decrease rate from 1990 to 2001 was 1135.7 ha. From 2001 to 2010 the moderate vegetation cover increased by 18,911 ha, which is 48% of the total area, and the annual increase rate was 2101 ha. From 2010 to 2015 the moderate vegetation cover decreased by 19,906 ha, which is 51% of the total area, and the annual decrease rate was 3981 ha. From 1990 to 2015 the moderate vegetation cover decreased by 13,488 ha.

Table 8.3 Classification of vegetation cover in Hakaluki Haor

Vegetation category	Vegetation cover							
	1990		2001		2010		2015	
	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage	Area (ha)	Percentage
No vegetation	4063	10	15,174	38	2663	7	3533	9
Sparse vegetation	21,455	54	22,839	58	16,439	42	35,475	90
Moderate vegetation	14,080	36	1587	4	20,498	52	592	1
Dense vegetation	2	0	–	–	–	–	–	
Total vegetation cover	35,537	90	24,426	62	36,937	93	36,067	91
Total area	39,600	100	39,600	100	39,600	100	39,600	100

Source: USGS Landsat image, 1990–2015; analysis by author, 2015

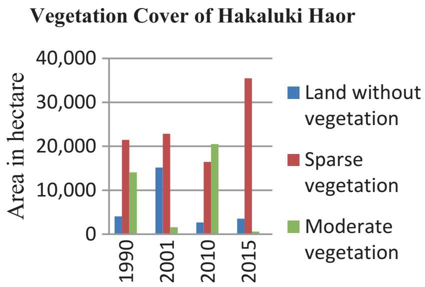

Fig. 8.5 Vegetation cover in Hakaluki Haor, 1990–2015

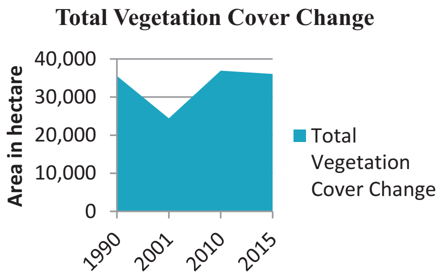

Fig. 8.6 Vegetation cover changes in Hakaluki Haor, 1990–2015

Overall the vegetation cover in Hakaluki Haor increased by 530 ha from 1990 to 2015 (Figs. 8.5 and 8.6). The main cause of the decrease in dense vegetation cover was cutting of vegetation for use as fuel and to clear the land for agricultural use (Tupin and Roux 2003). Settlements increased with the increasing population and new settlements replaced vegetation cover. This vegetation was also used for house hold needs. Displacement of herb and shrub-type vegetation cover by the increase in water bodies was another reason for the vegetation cover decrease in Hakaluki Haor.

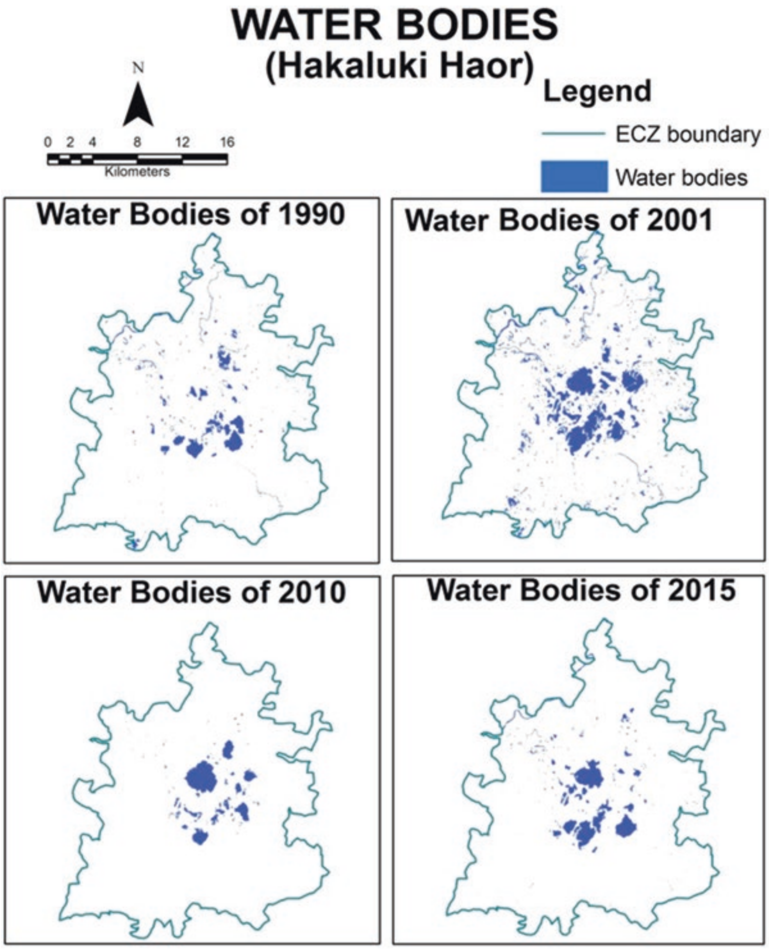

Fig. 8.7 Water bodies in Hakaluki Haor, 1990–2010. (Source: USGS Landsat image; analysis by author, 2015)

8.8 Water Bodies in Hakaluki Haor

The NDWI is a standardized index allowing generation of an image displaying the moisture of the water content on the surface. This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset; then ear-infrared band absorbs vegetation cover and shows the high reflectivity of water bodies (Dekker 2004). To identify the water bodies, it is very important to select those bands that are totally reflected by the water bodies and that are totally absorbed by the water bodies. From the NDWI in Fig. 8.7, it appears that the area of water bodies in the study area increased over the 20 years from 1990 to 2015 (Table 8.4).

Table 8.4 Water bodies areas in Hakaluki Haor, 1990–2015

Image acquisition date	Water body area (ha)	Percentage of the total area
February 17, 1990	1487	3.76
February 7, 2001	3723	9.40
February 8, 2010	1331	3.36
February 6, 2015	1733	4.38

Source: USGS 2015

8.8.1 Water Body Change Detection

The NDWIs in 1990 and 2001 showed that the area of water bodies increased by 2236 ha, and the increase rate was 203 ha per year in the study area (Fig.8.8). The NDWIs in 2001 and 2010 showed that the area of water bodies decreased by 2392 ha, and the decrease rate was 265 ha per year. The NDWIs in 2010–2015 showed that the water body area increased by 402 ha, and the annual increase rate was 80.4 ha. Finally, it was observed from the NDWIs in 1990 and 2015 that the water body cover increased by 246 ha, and the increase rate was 9.84 ha per year (Fig. 8.9). The main cause of the increase in water bodies in the study area was heavy rainfall in the previous rainy season. This was a positive aspect of the increase in wetland in the study area with respect to wetland habitats and wetland ecology (Mascle and Seltz 2004). This increased wetland area provides countless benefits in terms of "ecosystem services," providing freshwater, fish resources, food, biodiversity, flood control, ground water recharge, and climate change mitigation.

8.9 Temperature in Hakaluki Haor

Hakaluki Haor has a subtropical monsoonal climate, so this region is dominated by the onset and withdrawal of the annual monsoon, which creates four distinct seasons: the premonsoon season (April–May), the monsoon season(June–September),the postmonsoon season(October–November),and the dry season(December–March). The LST is a vital physio-environmental component and a key parameter in the interaction of the land–atmosphere system(Balzerek 2001). The LST—controlled by the surface energy balance, atmospheric state, thermal properties of the surface, and subsurface mediums—is an important factor controlling most physical, chemical, and biological processes of the earth (Becker and Li 1990). To estimate the surface temperature, thermal bands are used (band 6, Landsat 5 and 7; and bands 10 and 11, Landsat 8)with spectral band DN values. From Fig. 8.10, it appears that the temperature increased from 1990 to 2015, although the minimum temperature in the 2015 image was 1 °C, but most of the image showed temperatures of more than 20 °C in the study area.

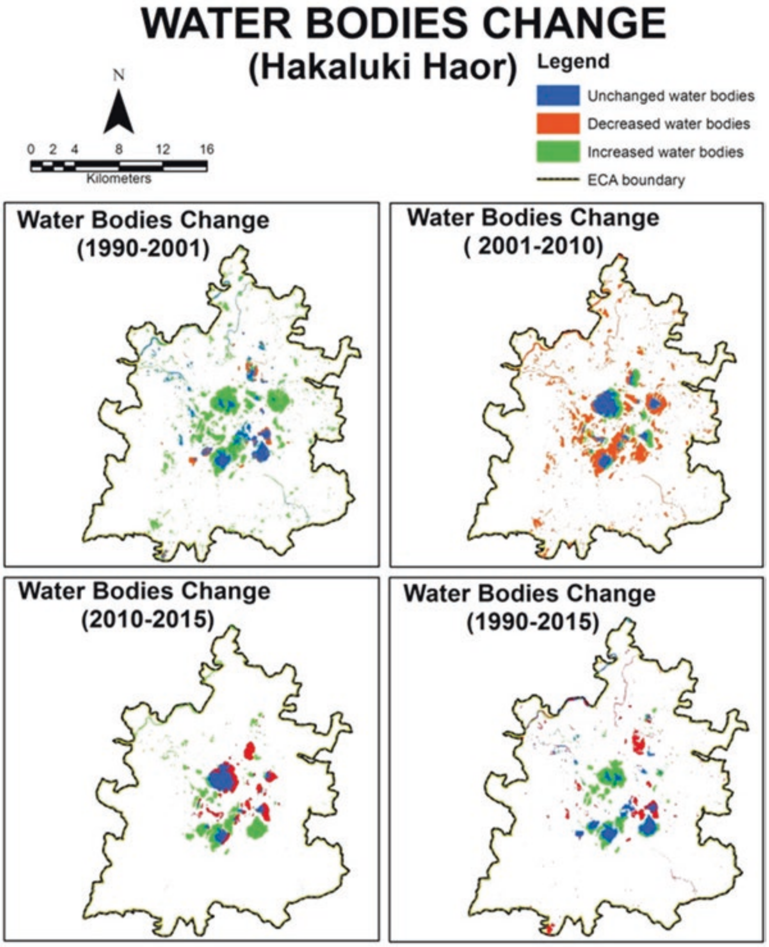

Fig. 8.8 Water body changes in Hakaluki Haor, 1990–2015. (Source: USGS Landsat image; analysis by author, 2015)

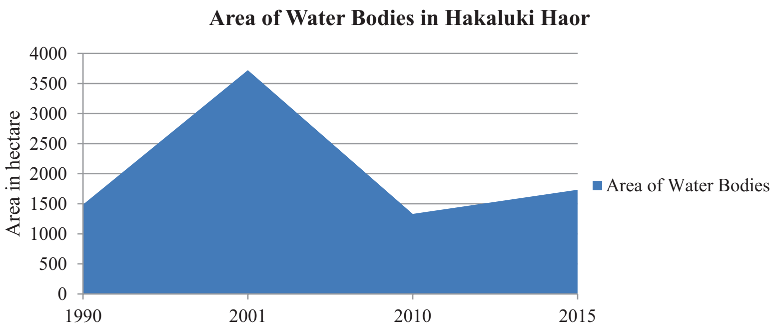

Fig. 8.9 Water body areas in Hakaluki Haor (based on February data), 1990–2015. (Source: USGS Landsat image; analysis by author, 2015)

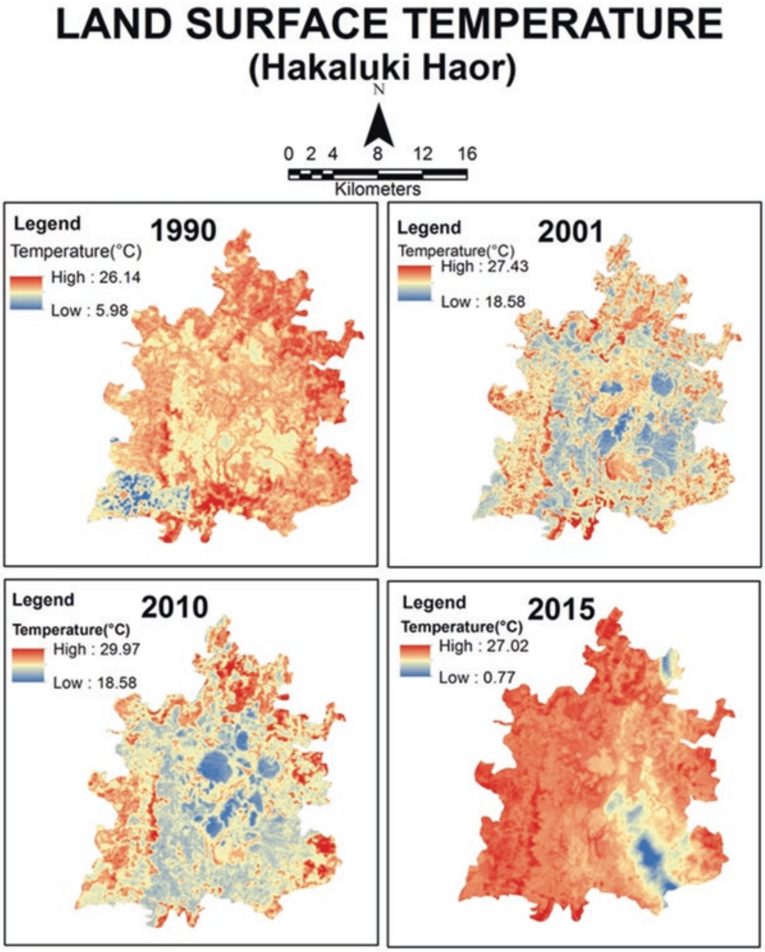

Fig. 8.10 Surface temperatures in Hakaluki Haor, 1990–2015.(Source: USGS Landsat image; analysis by author, 2015)

8.9.1 Surface Temperature Change Detection

The thermal layer and DN value of the spectral band in the Landsat images was converted to spectral radiance and finally to temperature. As a result, the surface temperatures of Hakaluki Haor were found (Fig. 8.11). The highest temperature recorded in the 1990, 2001, 2010, and 2015 Landsat images of the study area was 29.97 °C on February 8, 2010, and the lowest temperature was 1 °C on February 6, 2015. From 1990 to 2001 the average temperature increased by 5 °C from 16.06 to 22 °C, and from 2001 to 2010 the temperature increased by 2.27 °C from 22 to 24.27 °C. The temperature decreased by 10.27 °C from 2010 to 2015. Most of the high-temperature areas were situated in the areas of human existence, i.e., where

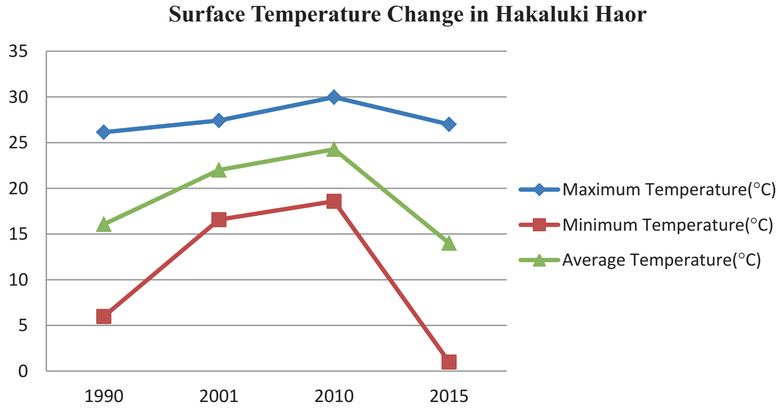

Fig. 8.11 Surface temperature changes in Hakaluki Haor (based on February data), 1990–2015. (Source: USGS Landsat image, 1990–2015)

settlements were located. The main causes of the temperature increase in the study area were climate change (global warming) and cutting of vegetation for fuel. Other causes of the temperature changes were increases in human settlement areas (displacing vegetation) and increased emissions of CO_2.

8.10 Conclusion

Haors play a vital role in our ecological balance, and it is important to protect reservoirs for wildlife habitats in the aquatic ecosystem. The importance of wetlands increases day by day. For this reason, Hakaluki Haor has been declared an ecologically critical area, signifying its importance as a reservoir of disappearing natural resources. So its physio-environmental changes are critical and determine whether it is hospitable to the wildlife of the wetland. The key components of Hakaluki Haor are vegetation cover, water bodies, and temperature. The total vegetation cover has decreased slowly, but the dense vegetation cover has totally vanished. Most of this decrease is located in the middle part of Hakaluki Haor, because of merging of water bodies. Fallow land (areas with no vegetation), water bodies or areas of bare Soil have decreased, and the decrease rate has been 0.5% per year. The overall total vegetation cover has decreased by 530 ha—a 21.2 ha decrease per year. Another important physio-environmental component is the water bodies; their area has increased by 246 ha, with an increase rate of 9 ha per year. The surface temperature of Hakaluki Haor increased by 5.21 °C from 1990 to 2001 and by 2.27 °C from 2001 to 2010. Between 1990 and 2015 the average surface temperature increased by 10.27 °C—0.41 °C per year. This is not a positive change for the wetland ecology. From the spatial distribution map of vegetation cover, water bodies, and temperature, it is clear that extensive changes occurred in the physical components of

Hakaluki Haor from 1990 to 2015. To conserve this wetland, the government must show more concern about the changes in its physio-environmental components. The government should formulate an appropriate policy and necessary laws, and should create awareness among the people to preserve its biodiversity. Bangladesh has demonstrated its concern for wetlands through its National Environmental Policy, convening a workshop on wetlands, and signed the Ramsar Convention in May 1992 (Spitzer et al. 2001). To conserve biodiversity and protect the natural resources of Hakaluki Haor, the following initiatives and measures should be taken: swamp forest restoration and conservation, sustainable management of fisheries resources, protection of wildlife, resource substitution for conservation of the wetland ecology, ensuring alternative sources of income, and development of community-based organizations. It is also necessary to coordinate between different ministries, especially the Ministry of Environment and Forests, Ministry of Water Resources, and Ministry of Land.

References

Ahmed I et al (2008) Wetland ownership and management in a common property resource setting: a case study of HakalukiHaor in Bangladesh. Ecol Econ 68:429–436

Balzerek H (2001) Applicability of Ikonos-satellite scenes; monitoring, classification and valuation of urbanization process in Africa: home page. http://www.rzuser.uniheidelberg.de/-bu/sfb/dI/index.htm

BBS (Bangladesh Bureau of Statistics) (2012) Statistical year book of Bangladesh, 2011. Ministry of Planning, Government of the People's Republic of Bangladesh, OB, Dhaka

Becker F, Li Z (1990) Towards a local split window method. J Remote Sens 11(3):369–393

Bitelli G, Camassi R, Gusella L et al (2004) Image detection on urban area: the earthquake case. International Society for Photogrammetry and Remote Sensing (ISPRS), Istanbul

Canty M, Niemeyer I (2003) Pixel-based and object-oriented change detection analysis using high-resolution imagery. In: Proceedings of the 25th symposium on safeguards and nuclear material management, Stockholm, Sweden, pp 1–6

Cho J, Alexandros N (2002) Effective change detection using sampling. In: Proceedings of the 28th Very Large Data Bases (VLDB) Conference, Hong Kong, China

Choudhury JK, Faisal AM (2005) Plant resources of haors and floodplains; an overview. International Union for Conservation of Nature (IUCN), – The World Conservation Union. Bangladesh Country office, Dhaka, 140 p

CNRS (Center for Natural Resource Studies) (2002) Bio-physical characteristics of HakalukiHaor. Dhaka, pp 7–20

CWBMP (Coastal and Wetland Biodiversity Management Project) document (2005) HakalukiHaor management plan (draft). International Union for Conservation of Nature (IUCN). Prepared & Submitted by: IUCN- Bangladesh. In association with the Center for Natural Resource Studies (CNRS), Dhaka

Dekker RJ (2004) Object-based updating of land-use maps of urban areas using satellite remote sensing. In: Proceedings of the 12th conference on geoinformatics–geospatial information research: bridging the Pacific and Atlantic. University of Gävle, Gävle. 2004. pp 623–630

FAP-6 (Flood Action Plan 6) (1994) Flood Action Plan 6, Fisheries Special Studies, Bangladesh Water Development Board, Government of the People's Republic of Bangladesh. Vol. 2, Appendices, December 1994(P-K3&4)

Gitelson AA, Henebry GM (2002) Consequences of institutional change: land-cover dynamics in Kazakhstan 1960–2000, 2001–2002 Progress Report for National Aeronautics and Space Administration (NASA) Land-Cover and Land-Use Change (LCLUC) Project
Hall O, Hay GJ (2003) A multiscale object-specific approach to digital change detection. Int J Appl Earth Obs Geoinf 4:311–327
Haverkamp D, Poulsen R (2003) Change detection using Ikonos imagery. In: American society for photogrammetry and remote sensing (ASPRS) 2003 Annual Conference Proceedings
Hazel GG (2001) Object-level change detection in spectral imagery. IEEE Trans Geosci Remote Sens 39(3):553–561
Hurskainen P, Pellikka P (2004) Change detection of informal settlements using multitemporal aerial photographs—the case of Voi, Se-Kenya. In: Proceedings of the 5th African Association of Remote Sensing of Environment Conference, pp 17–22
Iasillo D, Albanese F (2001) The urban monitoring with high resolution remote sensing data. In: Institute of Electrical and Electronics Engineers/International Society for Photogrammetry and Remote Sensing(IEEE/ISPRS) Joint Workshop on Remote Sensing and Data Fusion over Urban Areas
Im J, Jensen JR (2005) A change detection model based on neighborhood correlation image analysis and decision tree classification. Remote Sens Environ 99:326–340
IUCN (International Union for Conservation of Nature) (2006) Inception report: economic evaluation of HakalukiHaor. IUCN, Dhaka
Johnson RD, Kasischke ES (1998) Change vector analysis: a technique for the multispectral monitoring of land cover and condition. Int J Remote Sens 19(3):411–426
Jung F (2004) Detectingbuildingchangesfrommulti-temporalaerialstereopairs. ISPRS J Photogramm Remote Sens 58:187–201
Kam T (1995) Integration GIS and remote sensing techniques for urban land-cover and land-use analysis. Geocarto Inter 10(1):39–49
Khan MS et al (1994) Wetlands of Bangladesh, 1st edn. Bangladesh Centre for Advanced Studies (BCAS), Dhaka
Li J, Nrayanan RM (2003) A shape-based approach to change detection of lakes. IEEE transactions on geoscience and remote sensing, vol 41, no 11, University of Nebraska, Lincoln
Lunetta R, Johnson D, Lyon J et al (2004) Impacts of imagery temporal frequency on land cover change detection monitoring. Remote Sens Environ 89:444–454
Mascle SLH, Seltz R (2004) Automatic change detection by evidential fusion of change indices. Remote Sens Environ 91:390–404
Mcdermid GJ, Pape A, Chubey MS, Franklin SE (2004) Object-oriented analysis for change detection. In Proceedings of the 25th Canadian symposium on remote sensing, 14–17 October 2003, Montreal, Canada
McFeeters SK (1996) The use of normalized difference water index (NDWI) in the delineation of open water features. Int J Remote Sens 17:1425–1432
Miller O, Pikaz A et al (2005) Objects based change detection in a pair of gray-level images. Pattern Recogn 38:1976–1992
MoEF (Ministry of Environment and Forests) (1999) Ramsar convention of wetland, India participated in, 7th meeting of the Ramsar Convention, held in Costa Rica from, 10–18 May, 1999
Ngai FM, Curlander JC et al (1994) Model-based feature classification and change detection. Geoscience and remote sensing symposium, Pasadena. IEEE, pp 2531–2533
Niemeyer I, Canty M (2003) Pixel-based and object-oriented change detection analysis using high-resolution imagery. In: Proceedings of the 25th symposium on safeguards and nuclear material management, Stockholm, Sweden, p 1–6
Park JH, Tateishi R et al (1998) Urban expansion change analysis using Russian 2 m resolution DD-5, IRS-1C, and Landsat TM data. IEEE, pp 2577–2579
Quere PL, Maupin P et al (1997) Change detection from remotely sensed multi- temporal images using morphological operators. IEEE

Ridd MK, Liu J (1998) A comparison of four algorithms for change detection in an urban environment. Remote Sens Environ 63:95–100
Singh A (1989) Digital change detection techniques using remotely-sensed data. Int J Remote Sens 10(6):989–1003
Şirinyildiz T (2004) Change detection analysis by using Ikonos imagery. Change detection analysis by using Ikonos imagery. In: XXth International Society for Photogrammetry and Remote Sensing (ISPRS) Congress
Spitzer H et al (2001) Change detection with 1 m resolution satellite and aerial images. IEEE 5:2256–2258
Stossel BJ, Dockstader SL (2002) MOSAIC: a model based change detection process. In: International Society of Information Fusion (ISIF), p 1113–1119
Teeffelen PV, Jong SD et al (2001) Urban monitoring: new possibilities of combining high spatial resolution Ikonos images with contextual image analysis techniques. In: Institute of Electrical and Electronics Engineers/International Society for Photogrammetry and Remote Sensing (IEEE/ISPRS) Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, pp 265–269
Thomson CN, Hardin P (2000) Remote sensing/GIS integration to identify potential low-income housing sites. Cities 17(2):97–109
Tupin F, Roux M (2003) Detection of building outlines based on the fusion of SAR and optical features. ISPRS J Photogramm Remote Sens 58:71–82
US Geological Survey (2015) Mineral commodity summaries 2015: the three volumes that make up the minerals yearbook, vol I
Walter V (2004) Object-based evaluation of LIDAR and multispectral data for automatic change detection in GIS databases. In: XXth International Society for Photogrammetry and Remote Sensing (ISPRS) Congress
Xue C, Xiaowen Li et al (2004) Urban change detection based on self-organizing feature map neural network. In: IEEE: 3428–3431. XXth International Society for Photogrammetry and Remote Sensing (ISPRS) Congress
Yagoub MM (2004) Monitoring of urban growth of a desert city through remote sensing: Al-Ain, UAE, between 1976 and 2000. Int J Remote Sens 25(6):1063–1076
Yuan F, Sawaya KE, Loeffelholz C et al (2005) Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multi temporal Landsat remote sensing. Remote Sens Environ 98:317–328
Zhang Q, Wang J et al (2002) Detection of buildings from Landsat-7 ETM+ and SPOT panchromatic data in Beijing, China. IEEE 5:2977–2979

Index

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