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

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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, dur-

ing 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 prob-

able 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.

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