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Md. Nazrul Islam
André van Amstel *Editors*

# India: Climate Change Impacts, Mitigation and Adaptation in Developing Countries

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# India: Climate Change Impacts, Mitigation and Adaptation in Developing Countries

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ISSN 2352-0698 ISSN 2352-0701 (electronic)
Springer Climate
ISBN 978-3-030-67979-8 ISBN 978-3-030-67865-4 (eBook)
https://doi.org/10.1007/978-3-030-67865-4



This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*Dedicated*
*To my Daughter*
*SABABA MOBASHIRA ISLAM*
*(Only Daughter of Professor Dr. Md. Nazrul Islam)*

# Preface

India has started various remedial measures to minimize the emission of greenhouse gases. It has launched various schemes to promote the production of renewable sources of energy (solar energy, wind energy, geothermal energy, tidal energy, hydroelectric energy, and biomass energy) on a large scale as well as on a small scale in rural area. The government of India has promoted numerous steps to resolve global warming and climate change. They have facilitated the production of renewable sources of energy on a major scale so that the consumption of fossil fuel is minimized, which helps in reducing the carbon load in the atmosphere. Climate change will significantly impact agriculture production, and water will be a major constraint in the future for food production. Developing countries such as India are more vulnerable, and the ramification of climate change on rain-fed agriculture areas has been affecting the rural population owing to the large dependency on agriculture for livelihood. Understanding how the cardinal and sensitive climate variables such as temperature and precipitation changes will affect natural resources, and developing management policies for mitigation and adaption strategies with regional-scale assessments, are crucial steps.

Most of the major cities and towns in India are located in river floodplains, which causes additional stress to the river basins. During the past decades, more developmental activities have taken place in urban and agricultural lands, which has led to additional stress in these floodplains, resulting in the loss of flood spread areas and increase in flood risk in the downstream portions of the basin. For example, most major European cities in England and Germany are located in floodplains that have induced the burden in these rivers, and preventive measures have been undertaken to recreate floodplain storage. In Indian cities such as Delhi, Vijayawada, Hoshangabad, and Surat thers located along the banks of rivers often experience floods for this reason, aggravated by several other factors as discussed subsequently. Climate change may have direct effects on increase in temperature, which may have a negative impact on fruit crops, temperate fruit crops as well as tropical and subtropical fruits. Elevated $CO_2$ and changed precipitation are also considered important, with direct effects on production technology, delay or early harvest, reduced available irrigation water, increased irrigation cost, increased insect pest attacks, increased physiological disorders, inferior fruit quality, and the lack of suitable cultivars, and also an impact on the soil because of the excess rainfall and changes in temperature that negatively impact fruit crops in India.

Changes in two important economic activities, namely, agriculture and fish/shrimp farming practices, were analyzed among the sampled households. Adaptation in agricultural activities was addressed through varied responses, such as no adaptation strategy, crop diversification, change in cropping calendar, adapting of new farming techniques, and transformation of land for fishery adaptation strategies among the sampled households in India. A recent study revealed that climate change leads to alterations in the precipitation and evapotranspiration rate of the country, so it may be considered as an additional major threat to this resource. Hence, understanding the behavior and dimensions of the groundwater regime under future climatic and other changes is significant for adopting an accurate water management strategy. This review presents an outline of the groundwater resource base of India and its susceptibility to ongoing and future trends of changes in climatic variables. The Indian climate is controlled by the monsoon wind; 75% to 90% of the rainfall in the Indian subcontinent is determined by the summer monsoon, which contributes about 60% of the gross water demand in agriculture. Indian summer monsoon rainfall greatly influences the Indian economy because about 55% of the rural workforce is directly linked with agriculture, and 60 percentage of the net area shown belongs to the rain-fed zone.

Forests are an integral part of the terrestrial ecosystem, maintaining biodiversity, carbon flux, and ecosystem services and even supporting livelihoods. Rampant exploitation of forest resources has resulted in deforestation and the loss of associated benefits. It is estimated that deforestation accounts for 11% of global carbon emissions. Their function in carbon sequestration has helped international bodies to create programmes such as reducing emissions from deforestation and forest degradation (REDD+). The phenomena of climate change adversely affect the functioning of forest species, changing the timing of their flowering and fruiting habits, and causing changes in the ecophysiology of the species. However, such changes depend on the species and their climatic conditions to a large extent. Phenology, the temporal order of the annual cycle of plant functions, is quite sensitive to changes in climate. In this chapter we have explored the relationships between climate change and its impact on tree phenology and mitigation and adaptation strategies. Some species may tend to exhibit a certain amount of resilience against climate change.

Three micro-watersheds, undisturbed, semidisturbed, and disturbed catchments covering a distance of 12 km at Geyzing, located in West Sikkim, were selected for this research work. Hydro-meteorological instruments were installed in three micro-watersheds and recorded data for 4 years to monitor the impact of forest cover on stream discharge and water quality. A composite cum rectangular weir was installed at field level to accommodate measuring stream discharge during the monsoon period as well as the pre-monsoon period. El Nino and La Nina events, which are based on sea surface temperature (SST), take place at the Pacific Ocean along the

Equator. The El Nino Southern Oscillation is like a pendulum, as El Nino takes place in one side (west) and La Nina takes place along the other side (east), and vice versa. Its major cause is the trade winds that move from east to west, especially in Ecuador, Peru, and South America. By correlating the rainfall data and El Nino, we can identify the effects along coastal Karnataka. As El Nino and La Nina have major impacts on agriculture, food supply, and the economy of the country, it is necessary to study the related patterns and influence of rainfall.

The energy sector in the world needs major changes for reduction in greenhouse gas emissions and climate change mitigation. It has been believed the current rate in increase of greenhouse gas emissions will cause an increase in sea levels and changes in global climate patterns. These effects will hinder adaptation for climate change mitigation; hence, it is important to incorporate and understand the models that will be implemented in the energy sector for decarbonization. According to this perspective, the geothermal resources are considered as one of the most productive energy sources that can be adopted for the control of greenhouse gas emissions. The purpose of this study is to understand the global status of geothermal energy and its important role in the mitigation of climate change.

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# About the Editors

**Md. Nazrul Islam** is a permanent Professor at the Department of Geography and Environment in Jahangirnagar University, Savar, Dhaka, Bangladesh. Prof. Nazrul has completed his Ph.D. from the University of Tokyo, Japan. Also, he has completed a Two-Year Standard JSPS Postdoctoral Research Fellowship from the University of Tokyo, Japan. Prof. Nazrul's fields of interest include environmental and ecological modeling, climate change impact on aquatic ecosystems, modeling of phytoplankton transition, harmful algae, and marine ecosystems regarding hydrodynamic ecosystems-coupled models on coastal seas, bays, and estuaries, and the application of computer-based programming for numerical simulation modeling. Prof. Nazrul is an expert on scientific research techniques and methods to develop models for environmental systems analysis research. Prof. Nazrul has also visited as an invited speaker in several foreign universities in Japan, the USA, Australia, UK, Canada, China, South Korea, Germany, France, the Netherlands, Taiwan, Malaysia, Singapore, and Vietnam. Prof. Nazrul has been awarded the "Best Young Researcher Award" by the International Society of Ecological Modeling (ISEM) for outstanding contribution to the Ecological Modeling Field, 2013, Toulouse, France, and he has also been awarded "Best Paper Presenter Award 2010" by SautaiN in Kyoto, Japan. He has also been awarded a "Best Poster Presenter Award" at the Techno Ocean Conference, Kobe City Exhibition Hall, at Kobe in Japan.

Prof. Nazrul has made more than 40 scholarly presentations in more than 20 countries around the world and authored more than 100 peer-reviewed articles and 15 books and research volumes. Recently, Prof. Nazrul has published an excellent textbook entitled *Environmental Management of Marine Ecosystems* jointly with Prof. Sven Erik Jorgensen by the CRC Press (Taylor & Francis). He has also currently published an excellent book entitled *Bangladesh I: Climate Change Impacts, Mitigation and Adaptation in Developing Countries*, a Springer publication (Netherlands and Germany). Prof. Nazrul is currently serving as an "Executive Editor-in-Chief" for the journal *Modeling Earth Systems and Environment*, Springer International Publications (journal no. 40808). E-mail: nazrul_geo@juniv.edu

**André van Amstel** is an Assistant Professor at Wageningen University and Research, the Netherlands. Andre van Amstel studied physical geography and planning in Amsterdam and has long-standing expertise in integrated environmental assessment. He contributed to the development of an Integrated Model to Assess the Global Environment at the Institute of Public Health and the Environment in the Netherlands. He is particularly interested in the global environment and the risk of a runaway greenhouse effect by methane from melting of the permafrost in the Arctic. Van Amstel contributed to the IPCC 2006 Guidelines on Agriculture, Forestry and Land use and as such contributed to the Nobel Peace Prize 2007 for Al Gore and the IPCC. Since 2014 he has been a member of the Nordforsk Scientific Advisory Board for the Arctic Council of Ministers on Arctic Integrated Environmental Research. E-mail: andre.vanamstel@wur.nl

# Chapter 1
# New Challenges on Natural Resources and their Impact on Climate Change in the Indian Context

**Sunil Kumar Srivastava**

**Abstract** Global warming resulting from industrialization, excess consumption of fossil fuel, and agricultural activity is a new challenge for human civilization in the twenty-first century. The impact of global warming in the melting of glaciers and the rise in sea level is being observed worldwide (Ayala A, Farias-Barahona D, Huss M, Pellicciotti F, McPhee J, Farinotti D. 2020. Cryosphere 14:2005. doi:10.5194/tc-14-2005-2020). India is a developing country suffering from excess human population and a lack of awareness among the people regarding the impact of global warming on human civilization. India has started various remedial measures to minimize the emission of greenhouse gases. It has launched various schemes to promote the production of renewable sources of energy (solar energy, wind energy, geothermal energy, tidal energy, hydroelectric energy, and biomass energy) on a large scale as well as on a small scale in rural areas. The government of India has promoted numerous steps to resolve global warming and climate change. They have facilitated the production of renewable sources of energy on a major scale so that consumption of fossil fuel is minimized, which helps reduce carbon load in the atmosphere. India has also taken steps to fix carbon by increasing plantation. It has been shown that forest and tree cover in the country has increased from 14% in 1950–1951 to 24.01% in 2011–2012. India is a country with a rich diversity of socioeconomic conditions, geography, and climate: hence, the implementation of a uniform policy throughout the country is always challenging. A policy on a small scale (zone-wise) is needed so that the diversity of socioeconomic conditions, geography, and climate is considered seriously in polices. Hence, it is essential that every section of society also participates to resolve these issues and to cooperate with policies implemented by the government of India.

**Keywords** Natural resource · Climate change · Agriculture · Energy consumption · India

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M. N. Islam, A. van Amstel (eds.), *India: Climate Change Impacts, Mitigation and Adaptation in Developing Countries*, Springer Climate,
https://doi.org/10.1007/978-3-030-67865-4_1

## Introduction

India is a densely populated developing Asian country located in the Northern Hemisphere at latitude 8°4′N to 37°6′N and longitude 68°7′E to 97°25′E. Geographically, India is surrounded on three sides by oceans (the Bay of Bengal, the Arabian Sea, and the Indian Ocean) and on the north sides by the Himalayas, which significantly influence its climatic conditions and local weather. The total length of the coastline of India is approximately 7517 km. The Indian peninsula tapers southward, dividing the Indian Ocean into two water bodies: the Bay of Bengal and the Arabian Sea. India is divided geographically almost into two halves through the Tropic of Cancer (latitude 23°30′N). Land use patterns indicate approximately 46% of area is occupied by arable land, approximately 24% is under forest and tree cover, approximately 23% is not cultivable, and approximately 7% is fallow land (MOEFCC 2015). India's land use pattern has been influenced by demographic needs, industrial growth, urbanization, livestock grazing, diversion of forest lands for development purposes, the creation of irrigation facilities, and natural calamities such as flood and drought (Ranjan et al. 2017; Srivastava 2019). India possesses much variety in geography, climate, and local weather, which has influenced its biodiversity significantly.

India is the second most densely populated developing country in the world after China. India supports approximately 17% of the world population and possesses only about 2.16% in land resources of the total area available to the world. Its population density is approximately 382 persons/km$^2$ higher than most of the developing and developed countries. This large population load has created a burden on nature. The high population density has forced overexploitation of natural resources such as water, soil, forests, and food resources. India is quite rich in natural resources, but overexploitation and mismanagement have caused concern in Indian society, which also influences the world communities. The excessive consumption of fossil fuel for electricity, transportation, industries, and other domestic and commercial activities has produced an increased quantity of greenhouse gases: this may be one of the reasons for global warming and further climate change (Srivastava 2020).

Global warming caused by industrialization, excess fossil fuel consumption, and agricultural activity is a new challenge for human civilization in the twenty-first century. The impact of global warming in the melting of glaciers and the rise in sea level is being observed worldwide (Ayala et al. 2020). India is a developing country suffering excess human population and a lack of awareness among the people regarding the impact of global warming on human civilization. India has started various remedial measures to minimize the emission of greenhouse gases. It has launched various schemes to promote the production of renewable sources of energy (solar energy, wind energy, geothermal energy, tidal energy, hydroelectric energy, and biomass energy) on a large scale as well as on a small scale in rural areas. Statistics of the recent past in the development and consumption of renewable energy in India show positive growth. People have begun using solar, biomass, and wind energy significantly in rural areas for domestic, agricultural, and other small-scale industrial purposes. India has also promoted afforestation on a large scale since 1984, which helps fix atmospheric carbon to reduce the proportion of carbon in the atmosphere.

The carrying capacity of India is quite low in comparison to other developed world countries. Thus, obtaining food and other natural resource requirements of the Indian people becomes a challenging task considering the environmental impact. The availability of natural land resource per person in India is quite poor based on carrying capacity, only about 0.5 hectares (ha). Municipal solid waste (MSW) has contributed approximately 46% (1.7–1.9 billion tonnes) of total solid waste, produced mainly by urban settlement (Srivastava and Ramanathan 2012).

One report suggested solid waste and wastewater worldwide accounted for approximately 1.5 Gt $CO_2$ equivalent in the year 2010 (MOEFCC 2014). Greenhouse gas (GHG) emissions from the building sector have more than doubled since 1970, reaching 9.18 Gt $CO_2$ equivalents in 2010. In 2010, the building sector accounted for approximately 32% of global final energy consumption and approximately 19% of energy-related GHG emissions (including electricity related), which occurred because many modern buildings are highly energy intensive. A rough assessment suggests that to produce 1 tonne of Portland cement roughly 1 tonne of $CO_2$ is released to the atmosphere. In 2013, cement production accounted for 9.5% of global $CO_2$ emissions. A study reported approximately 67% greenhouse gas emitted by the energy sector including the cement industry, approximately 23% greenhouse gas by agriculture activities, approximately 4% greenhouse gas by landfill area, and about 6% greenhouse gas by other industries, in India in the year 2000 (MOEFCC 2015). The emitted GHG is classified as approximately 67.25% $CO_2$, approximately 26.73% $CH_4$, approximately 5.34% $N_2O$, approximately 0.34% $CHF_3$, approximately 0.02% $SF_6$, and approximately 0.42% PFC.

As per the Intergovernmental Panel on Climate Change (IPCC), human-generated GHG emission occurs as the result of population size, economic activities, lifestyle, energy consumption, agriculture and land use, technology, and climate policy (MOEFCC 2015). Further, vulnerability to climate change, GHGs, and the capacity for adaptation and mitigation have been strongly influenced by livelihood, lifestyle, behavior, and culture. These emissions can be substantially lowered through changes in consumption patterns, adoption of energy-saving measures, dietary changes, reduction in food wastes, and the reuse, reducing, and recycling of natural resources. India has a history of low-carbon footprint because of the nature-loving attitudes of the people. These national characteristics and the inclination of the people should be encouraged through mass education and awareness, rather than being replaced by more modern but unsustainable practices and technology (MOEFCC 2015).

## Natural Resources in India

India is very rich in natural resources. The natural resources available in India are classified into five major categories: water resources, mineral resources, forest resource (includes agriculture activity), land resources (includes soil), and energy. India has been rich in natural resources from ancient times, as supported by published historical data. The current scenario has been changed by the increased population and further overexploitation of natural resources to fulfil the requirements of these growing populations. In the recent past, changes in the living patterns and lifestyles of the people have also influenced the rate of consumption of natural resources. Such practices stress natural resources, causing side effects such as drops in the groundwater table, increased GHGs, shortages in food resources, higher salinity of agricultural land, and soil, air, and water pollution (Prasad et al. 2006; Srivastava and Ramanathan 2018a). Global warming and further climate change are caused by excessive emission of GHGs in the atmosphere through anthropogenic activities. Global data indicate that transport accounts for approximately 23% of total energy related to $CO_2$ emissions, with road transport itself accounting for 17–18%. In urban areas and cities, transportation becomes challenging because of the increased number of vehicles used for transportations of goods and passengers (MOEFCC 2015).

### *Water Resources*

India possesses approximately 1123 billion cubic meters (BCM) of water resources, of which about 61.4% is surface water and the remaining approximately 38.6% is subsurface water. India has approximately 4.63% of its total geographic area available as wetland area (MOEFCC 2015). Statistically, India has a surface water area of approximately 360,400 $km^2$: this area is under stress from excessive water consumption for fulfilling various industrial, domestic, and commercial requirements and for irrigation during agriculture activity (https://en.wikipedia.org/wiki/Natural_resources_of_India). The methods of irrigation adopted in India during agriculture activities have caused approximately 55% freshwater wastage. Further contamination of freshwater through various anthropogenic activities has also reduced available freshwater and created stress over water resources (Srivastava and Ramanathan 2008).

India annually receives about 4000 BCM water, of which approximately 1123 BCM is available for utilization. Of this, about 690 BCM is available as a surface water resource and the rest, approximately 433 BCM, is the groundwater resource. India receives water through 12 major rivers occupying a total catchment area of about 252.8 million hectares (ha) that covers more than 75% of the total area of the country. Indian rivers are classified as the Himalayan rivers, peninsular rivers, coastal rivers, and inland drainage basin.

India receives maximum rainfall mostly through the southwest (SW) monsoon, which accounts for about 75% of the total rainfall received by the country. About 11% of rainfall takes place pre monsoon and about 10% post monsoon. Interannual variability in monsoon onset, seasonal rainfall distribution, and rainfall intensity impact the agriculture and water resources of the country. The phase of the El Niño Southern Oscillation (ENSO) often impacts rainfall amount and distribution: the warm phase (El Niño) tends to result in lower rainfall, both during and beyond the monsoon period. Variations in the onset, withdrawal, and amount of precipitation during the monsoon season affect the water resources, agriculture, power generation, and ecosystems of the country.

Daily rainfall observations during the period 1901–2004 indicate that the frequency of extreme rainfall events (precipitation rate >100 mm/day) has a significant positive trend of 6% per decade. Frequency and duration of rainstorms (synoptic weather systems that have the potential for causing the floods) have also increased during the past 60 years.

## Mineral Resources

India is rich in mineral resources. Of these resources, petrochemicals are mainly responsible for global warming and further influence the rate of climate change. India fulfills some of its basic requirements for petrochemicals, but a large proportion is imported from the Arabian countries. By combustion, petrochemicals emit a significant amount of greenhouse gas to the atmosphere. These GHGs are mainly responsible for global warming and further climate change. Petrochemical products are used in industrial activities, the energy sector, transportation, and domestic requirements. The cement industry also emits greenhouse gas, because limestone, the major raw material of the cement industry, releases $CO_2$ in calcination during clinker formation in the rotary kiln.

$$CaCO_3 \longrightarrow CaO + CO_2 \uparrow$$

Other metallic, nonmetallic, economic, and strategic minerals produce less GHC. Hence, those minerals are not discussed in this chapter.

## Forest, Food, and Agriculture

As per the State of Forest Report, forest and tree cover in the country has increased from approximately 14% in 1950–1951 to around 24.01% in the year 2011–2012, indicating an appreciable approach by India to reduce atmospheric carbon by fixing $CO_2$ through afforestation. The State of Forest Report in 2013 showed the forest cover of the country as approximately 697,898 km$^2$, compared to 692,027 km$^2$ in

2011, an increase of 5871 $km^2$ recorded within 2 years. A study also reported approximately 23% of GHG is emitted through agriculture activities in India (MOEFCC 2015).

Food production, processing, marketing, consumption, and disposal have an impact on the environment because these activities consume energy and natural resources, emitting GHGs (Parashar et al. 2018). The contribution of wetlands, landfill, and other agriculture waste to GHGs during microbial decomposition is also noticeable (Parashar et al. 2019a, b). The global volume of food wastage is estimated at approximately 1.6 gigatonnes (Gt) of 'primary product equivalents,' whereas the total wastage for the edible part of food is about 1.3 Gt (MOEFCC 2015). The global carbon footprint of food wastage, excluding land use change, has been estimated as about 3.3 Gt $CO_2$ equivalent (FAO 2013). Upstream wastage volumes, including production, post-harvest handling, and storage, represent approximately 54% of total wastage, and downstream wastage volumes, including processing, distribution, and consumption, are approximately 46% (MOEFCC 2015).

The forest in India occupies approximately 24.01% of the total land area resource. Forest resources contribute significantly to fulfill the basic needs of rural and urban people throughout the country in the form of food, fuel, wood, and fodder. The forests help in regulating the water cycle, nutrient biogeochemical cycle, and oxygen supply, as well as conserving the soil by reducing soil erosion, and also provide natural habitat for wild animals, insects, birds, reptiles, and other species. The medicinal value for forest resources has been recognized in India from ancient times. A list of medical products worldwide utilizes forest resources. Conservation of biodiversity also helped to reduce atmospheric carbon. Forest resources neutralized approximately 12% of total GHG emitted in India through various anthropogenic activities (MOEFCC 2015).

In India, agricultural activity is mostly dependent on rainfall during the monsoon period. Overdependence of farmers on the monsoon poses uncertainties in crop production and the income of farmers, and sometimes excess floods, as well as drought, affect agriculture activity (Srivastava 2019; Srivastava and Ramanathan 2018b). A published report indicated declines (~18.9% in 2011–2012 to ~17.6% in 2014–2015) in the contribution of agriculture to the national gross domestic product (GDP) may be caused by changes in job prospects or the mobilization of formers to the city from the villages. Climatic uncertainties affect specific crops in different years. India ranks first in the world in total livestock population. The waste released by livestock emits a significant amount of methane to the atmosphere. Hence, a large quantity of waste can be used as raw material for biomass energy. First, animal waste can be used as clean energy, the sludge can be used as biofertilizer, and further release of methane to the atmosphere can be minimized. Second, biomass energy is a renewable source of energy; it reduces the stress on fossil fuels and further reduces the emission of GHG to the atmosphere (Srivastava 2020).

## *Land and Soil*

India possesses approximately 1,945,355 km$^2$ arable land area, which is approximately 56.78% of the total available land resource in India (https://en.wikipedia.org/wiki/Natural_resources_of_India). This area has begun to shrink because of the population explosion and rapid urbanization in India. The Indian government promoted a better infrastructure to reduce the traffic load, which helps in reducing the consumption of fossil fuels and hence reduces the carbon load in the atmosphere. The government also promoted that villagers utilize a renewable source of energy to fulfill their basic energy requirement, which also reduced the emission of GHGs to the atmosphere. Solar and wind energy are promoted on a large scale in the whole country through various social groups, committees, the government, and nongovernment organizations.

Glaciers constitute the land resource having maximum effects on global warming and climate change. Glacier melting is a better indicator of global warming worldwide; Indian glaciers are also affected by global warming. The Indian Space Research Organisation (ISRO) has monitored the advance and retreat of 2018 glaciers across the Himalayan region using satellite data of 2000–2001 and 2010–2011. This study indicated that 1752 glaciers showed no change, 248 glaciers were retreating, and 18 glaciers were advancing. This scenario has raised concern in scientific communities in India, and the government has planned for further inspection of the existing policy on global warming and climate change.

## *Energy*

The consumption of energy in India has been increasing rapidly during the past few decades. Considering the needs of people, industry, and other activities, a large proportion of energy requirements in India is fulfilled by fossil fuels in such forms as coal, petrol, kerosene, diesel, or naphtha. Coal has been used extensively in the production of electricity as an energy source in thermal powerplants. After fractional distillation, petroleum has been used for transportation and other industrial requirements. A study reported approximately 67% GHG is emitted by the energy sector, including the cement industry (MOEFCC 2015). The cement industry uses limestone, which releases $CO_2$ to the atmosphere during calcination, as the raw material; calcination occurs during clinker formation in the rotary kiln. India is the third largest producer of cement in the world, and cement is important for infrastructure, building materials, and development of settlements. Once the infrastructure is properly developed the consumption of cement is also reduced, which also reduces GHG in the atmosphere.

The contribution of renewable energy sources is still less than expectations or requirements. Renewable energy sources used in India include solar, wind, tidal, biomass, and geothermal. Solar energy and wind energy are more successfully used in India for reasons of widespread and easy availability; these sources are more efficient in comparison to other renewable sources of energy. Better technology and widespread awareness regarding renewable energy will help to reduce GHG in the atmosphere, which will also result in a better and healthy environment for the present populations.

## Energy Status of India

The utilization of energy for various activities in India has been reported from ancient times. People have learned to use biomass energy for cooking food, light, and heat. A recently published report stated the total energy production capacity in India is approximately 3254.15 billion kWh. Of this total, ~2287.57 billion kWh (~70.3%) of energy is produced through consumption of fossil fuel, ~64.44 kWh (~1.98%) by nuclear power plants, ~386.63 kWh (~11.88%) by hydroelectric power plants, and ~515.51 kWh (~15.84%) through renewable energy (Table 1.1, Fig. 1.1).

In comparison to European countries, India consumed more fossil fuel to fulfill the energy requirements of the people (Table 1.1), possibly because India has a large population. Details of energy consumption and production as compared between India and European countries are given in Table 1.1 and Fig. 1.2, indicating India needs a massive effort to achieve sustainable growth in energy. The consumption of energy in India, approximately 2,405.82 kWh per capita, is much lower than the per capita energy consumption in European countries, approximately 16,542.38 kWh (Table 1.1). This difference in energy consumption observed between European and Indian society includes both urban and rural populations. Gujarat contributed approximately 25.04% (36,956 MW), Karnataka approximately 13.08% (19,315 MW), and Tamil Nadu approximately 11.17% (16,483 MW) of total renewable energy. The report indicated that access to electricity has increased from about 67% (2010) to about 80% (2020) of the population.

The high consumption of fossil fuel can be minimized through heavy taxation on crude oil, vehicles, and road tax to reduce unnecessary movements of people and

**Table 1.1** Summary of energy consumption and production in India

| Energy source | Total in India (billion kWh) | Percentage in India (%) | Percentage in Europe (%) | Per capita in India (kWh) | Per capita in Europe (kWh) |
|---|---|---|---|---|---|
| Fossil fuels | 2287.57 | 70.3 | 49.2 | 1691.22 | 8125.79 |
| Nuclear power | 64.44 | 1.98 | 7 | 47.64 | 1155.77 |
| Hydroelectric power | 386.63 | 11.88 | 24.1 | 285.84 | 3982.3 |
| Renewable energy | 515.51 | 15.84 | 19.7 | 381.12 | 3278.52 |
| Total production capacity | 3254.15 | 100 | 100 | 2405.82 | 16542.38 |

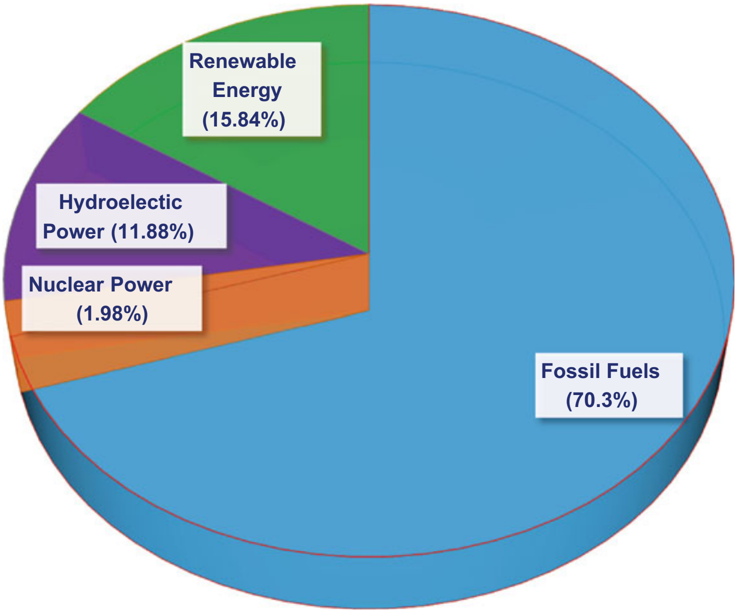


**Fig. 1.1** Total energy production in India

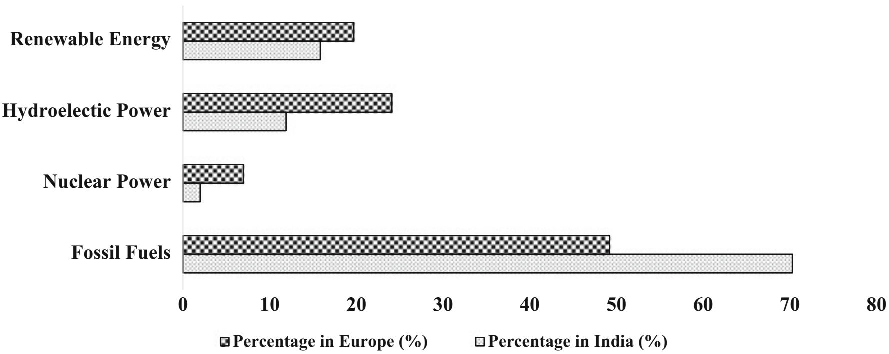


**Fig. 1.2** Comparison chart for energy sources

vehicle use. Effective reduction of fossil fuel consumption thus reduces GHG emission and the impact of global warming on climate change. The government has initiated such steps as promotion of afforestation, an environmental awareness program, conservation of biodiversity, and heavy taxation on petroleum products, vehicles, and roads. Anton (2020) also suggested taxing crude oil can help to mitigate climate change effectively because GHG emission increases global risk by the adverse impact on climate.

## Global Warming and Climate Change

Climate change is most affected in India by the release of GHG during cement production, thermal power plant operation, combustion of fossil fuels, and other pyro-treatment activities. Recently, India has begun various initiatives to reduce carbon in the atmosphere by educating the people, checking the combustion of fossil fuels, and increasing the production of nonconventional energy. Statistics of Indian metropolitan areas show a significant increase in the number of days when maximum temperature was more than 35 °C (Table 1.2). Notably, these data indicated a sharp rise in temperature in coastal cities in comparison to that in towns located in hilly areas. Also shown is an increase in ocean level caused by glacier melting.

The study reported that $CO_2$ contributed approximately 74% of the total greenhouse gases in India, while $CH_4$ contributed approximately 19%, $NO_2$ contributed 5%, and halogenated gases contributed approximately 2%, in the year 2010 (MOEFCC 2015). As per the report, India produced approximately 2,136,841 Gg $CO_2$ equivalent greenhouse gas in the year 2010 (Table 1.3).

The emitted GHG contributed by oxides of carbon was approximately 1,574,362 Gg $CO_2$ equivalent, methane approximately 412,086 Gg $CO_2$ equivalent, oxides of nitrogen approximately 114,365 Gg $CO_2$ equivalent, and halogenated gases approximately 36,028 Gg $CO_2$ equivalent (Table 1.3). Further, other industrial activities released 1.43 Gg $CH_3F$, 2.13 Gg $CF_4$, 0.58 Gg $C_2F_6$, and 0.0042 Gg $SF_6$. All these together account for 36,027.53 Gg $CO_2$ equivalent emissions.

The energy sector contributed approximately 70.7% (1,510,120.76 Gg $CO_2$ equivalent) of total greenhouse gas emitted and the agriculture sector only 18.3% (390,165.14 Gg $CO_2$ equivalent). The industrial sector contributed approximately 8.0% (171,502.87 Gg $CO_2$ equivalent) of total greenhouse gases whereas solid waste

**Table 1.2** Comparison between metro-cities of India

| Cities | Number of days (with maximum temperature >35 °C) | |
|---|---|---|
| | 1959–1968 | 2009–2018 |
| Delhi | 1350 | 1465 |
| Mumbai | 113 | 313 |
| Kolkota | 453 | 449 |
| Chennai | 1009 | 1613 |
| Hyderabad | 1078 | 1137 |
| Bengaluru | 249 | 286 |

**Table 1.3** Composition of emitted greenhouse gas in India (2010)

| Gas | Composition greenhouse gas (Gg $CO_2$ equivalent) |
|---|---|
| Carbon oxide | 1,574,362 |
| Nitrogen oxide | 114,365 |
| Halogenated gases | 36,028 |
| Methane | 412,086 |

landfill areas emitted approximately 3% (65,052.47 Gg $CO_2$ equivalent) in the year 2010. LULUCF (Land Use, Land Use Change, and Forestry) sectors acted as a net sink that offset approximately 12% of the total greenhouse gas emissions.

To minimize the impact of greenhouse emitted during the combustion of fossil fuels, the Indian government set a target for the production of renewable energy. Available information suggests India will be able to produce approximately 175,000 MW electricity through renewable sources by the year 2022: solar energy will contribute approximately 100,000 MW, wind energy approximately 60,000 MW, biomass energy approximately 10,000 MW, and other small hydropower loci approximately 5,000 MW. Afforestation and water conservation programs are promoted in the country through schemes such as the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGA) and the National Afforestation Programme. The schemes launched such as the Green India Mission (GIM), forest restoration, afforestation, agroforestry, and urban forestry have promoted reducing carbon load in the atmosphere. The production of paddy crops also minimizes the production of methane. These agricultural lands have been utilized for another crop with higher economic value.

The National Action Plan on Climate Change (NAPCC) was launched by the government in the year 2008 to address climate change concerns and to promote sustainable development. The NAPCC promotes development activities while addressing climate change. Eight National Missions form the core of the NAPCC, representing multi-pronged, long-term, and integrated strategies for achieving the goals in the context of climate change. Several of the programs described under NAPCC have undertaken various schemes of the government of India, but in the present context require a change in direction, enhancement of scope, and accelerated implementation. Positive response toward the effort has been observed in a few localities on a regional basis.

## Future of India in the Twenty-First Century

The government of India has been promoting the production of energy through renewable sources such as solar energy, wind energy, tidal energy, biomass energy, and geothermal energy since the last century. An appreciable improvement in renewable energy in India has been observed in the past few decades, but a major improvement is still needed, considering other European countries (Fig. 1.2). The Energy Conservation Act and National Electricity Policy came in 2001 and 2005, respectively, for resolving the energy problems in India. The Energy Conservation Act was enacted in 2001 with the objective of energy security through conservation and efficient use of energy. Some of the major provisions of the act include Standard and Labelling of Appliances, Energy Conservation Building Codes, setting up of the Bureau of Energy Efficiency (BEE), and Establishment of Energy Conservation Fund. The National Electricity Policy of 2005 stipulates that progressively the share of electricity from nonconventional sources needs to increase.

Some researchers have reported an increased frequency of heavy rainfall, particularly in central India, in the past 60 years (Rajeevan et al. 2008; Krishnamurthy et al. 2009; Sen Roy 2009; Pattanaik and Rajeevan 2010). Goswami et al. (2006) have reported a decrease in the trend of light rainfall. Further, Krishnan et al. (2013) have reported reduction in moderate to heavy precipitation in the area surrounding the Western Ghats in India.

The data published in worlddata.info suggested renewable sources of energy produced approximately 36% of the total energy in the year 2015 (www.worlddata.info), which indicated a genuine effort of the Indian government in the energy sector. GHG emissions increased by 1301.2 million tonnes, to 1884.3 million tonnes between 2000 and 2010. These results suggested an appreciable effort of the government to resolve the issue of global warming and climate change. Still, serious effort is needed by the people and the government to implement a sustainable approach to minimize GHG in the atmosphere to reduce the impact of climate change. The government has developed the policies, but the common man needs to understand the importance of these policies and to try to reduce the use of fossil fuel: this will be effectively implemented with the proper awareness programs in society through various print media and mass media regarding the impact of GHG. A few localities across the country have shown positive growth that needs to be appreciated as a role model for other regions or localities. The government needs an appropriate policy for every zone considering its socioeconomic conditions along with the geographic and climatic situation of the region. India is a country with a rich diversity of socioeconomic conditions, geography, and climate; hence, implementation of a uniform policy throughout the country is always challenging. Policies on a small scale are needed so that the diversity of socioeconomic conditions, geography, and climate can be considered seriously.

The National Action Plan on Climate Change (NAPCC) was launched in 2008 to address climate change concerns and promote sustainable development. The Ministry of Agriculture of India has taken the major initiative to resolve the issue under the National Initiative on Climate Resilient Agriculture (NICRA) in 2011: it has four main sections of resource management, improving soil health, improving crop production, and livestock to make the farmers self-reliant for adaptation under a changing climate. All these programs help to minimize the emission of GHG in various ways including fixing $CO_2$ from the atmosphere. In summary: the photosynthesis potential of $C_3$ plants is generally lower (~40%) in comparison to $C_4$ plants (Monteith 1978).

Analysis of the annual temperature of India indicated a rise of approximately 0.54 °C in the average temperature of the country in the past century (Table 1.4). A similar pattern of increased temperature will create an explosive situation in India from population growth, overexploitation of natural resources, and further global warming that will impact and seriously affect the whole of human society in the form of climate change and changes in the lifestyle of the people.

The trend of temperature increases as shown in Fig. 1.3 has caused concern for Indian society considering future impact. Climate change is a continuous process that will have effect through changes in nutrient biogeochemical cycles, the

**Table 1.4** Recorded changes in average temperature in India

| Decade | Average temperature (°C) |
|---|---|
| 1900–1910 | 25.26 |
| 1911–1920 | 25.27 |
| 1921–1930 | 25.4 |
| 1931–1940 | 25.38 |
| 1941–1950 | 25.39 |
| 1951–1960 | 25.53 |
| 1961–1970 | 25.44 |
| 1971–1980 | 25.46 |
| 1981–1990 | 25.57 |
| 1991–2000 | 25.73 |
| 2001–2010 | 25.74 |
| 2011–2020 | 25.84 |

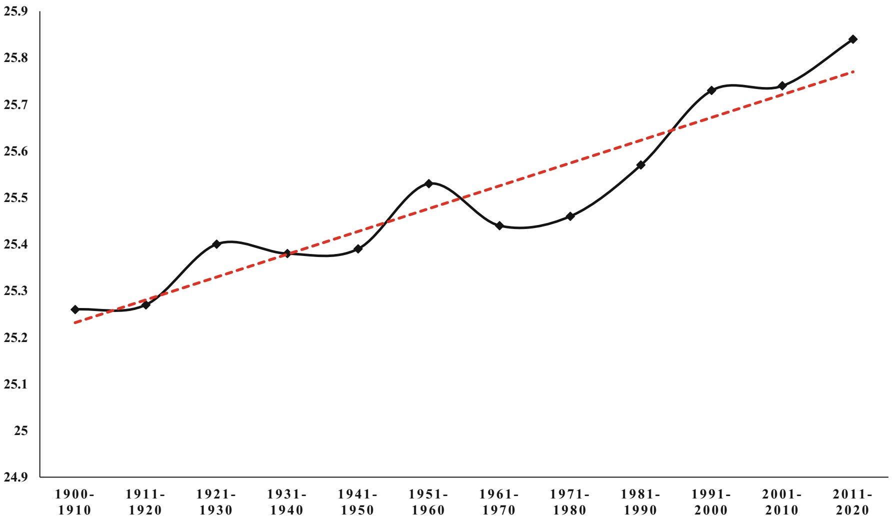


**Fig. 1.3** The change in average temperature in India in the past century

hydrological cycle, the natural habitat of all living beings, and further geographic situations. Hence, every section of society needs a serious approach to resolve these issues and cooperate with the policy implemented by the government of India.

## Conclusion

India is a member of the United Nations Framework Convention on Climate Change (UNFCCC), and it supports approximately 17% of total human populations on the earth. This instrument is highly responsive to control of greenhouse gases and takes remedial measures to minimize greenhouse gas emission. The average annual temperature of India has increased approximately 0.54 °C in the past century. Indian metro-cities have significantly more days when the maximum temperature is more than 35 °C. The most important point about these data is the sharp rise in temperature in coastal cities in comparison to towns in the hilly areas, indicating an increased level of ocean water from climate change.

The government of India has promoted numerous steps to resolve global warming and climate change. It has facilitated the production of renewable sources of energy on a major scale so that the consumption of fossil fuel is minimized, reducing the carbon load in the atmosphere. India has taken steps to fix carbon by increasing plantation: the forest and tree cover in the country has increased from 14% in 1950–1951 to 24.01% in 2011–2012.

India has a rich diversity of socioeconomic conditions, geography, and climate; hence, the implementation of the same policy throughout the country is always challenging. India needs policies on a small scale (zone-wise) so that the diversity of socioeconomic conditions, geography, and climate can be considered seriously. Hence, it is essential that every section of society also participates to resolve these issues and cooperates with the policy implemented by the government of India.

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# Chapter 2
# Regional Assessment of Impacts of Climate Change: A Statistical Downscaling Approach

**Nagraj S. Patil and Rajashekhar S. Laddimath**

**Abstract** Water resource sectors are impacted by industrialization, urbanization, and climate change, making these vital resources more vulnerable and posing substantial challenges to water resources planners. Climate change significantly impacts agricultural production, and water will be a major constraint in the future for food production. Developing countries such as India are more vulnerable, and the ramification of climate change on rain-fed agriculture areas has been affecting the rural population because of their great dependency on agriculture for their livelihood. For understanding how the changes in cardinal and sensitive climate variables such as temperature and precipitation will affect natural resources, and for developing management policies for mitigation and adaption strategies, regional-scale assessments are crucial. This chapter showcases regional assessment of the impacts of climate change by the statistical downscaling technique, the Change Factor method, using the CMIP-5 General Circulation Model data in India with a case study in Bhima sub-basin. Spatial cross-correlation of maximum temperature and precipitation across the Indian Meteorological Department (IMD) gauge grids was captured adequately, and the downscaling satisfactorily captured the cross-correlation between rainfall grids of Bhima sub-basin. Future projections reports, average daily maximum temperature and rainfall are likely to increase in response to climate change under different representative concentration pathway (RCP) scenarios, with maximum changes in RCP 8.5.

**Keywords** Climate change · General Circulation Model · Regional assessment · Change Factor Method · Bhima sub-basin

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M. N. Islam, A. van Amstel (eds.), *India: Climate Change Impacts, Mitigation and Adaptation in Developing Countries*, Springer Climate,
https://doi.org/10.1007/978-3-030-67865-4_2

## Introduction

Water, being the most vital resource, has been under growing demand for ages. As an important natural resource, water is naturally influenced by the environment, weather, geology, and topography. These factors can cause difficulties in evaluating future water resources under a changing climate. Nineteenth-century industrialization has extensively utilized natural resources for construction activities, raising the level of $CO_2$ in the atmosphere, and thus global warming has triggered climate change. The manifest drafted by the experts of the Intergovernmental Panel on Climate Change (IPCC)[1] reports that increase in greenhouse gas (GHG) emission can cause sea level rise, increasing the frequency of storms, heavy rainfall events, seasonal shifts, heat waves, floods, and droughts.

The major consumption of water in India is by the agriculture sector, using 83% of the total freshwater annually. Climate change significantly impacts agricultural production, and water will be a major constraint for food production in the future (Aggarwal 2008). Assessment of impacts of climate change on the agriculture sector has been a thrust area in research around the world. Developing countries such as India are more vulnerable, and the ramification of climate change on rain-fed agriculture areas has been affecting rural populations owing to their great dependency on agriculture for livelihood. Agriculture primarily depends on monsoon and changing precipitation patterns; intensity combined with duration will probably influence the balance in water supply and demand, thus affecting the hydrological cycle and leading to frequent droughts and floods (Gleick et al. 2010). India is the second largest country by population count, with 17% of the world's population but with substantially as little as 4% of world freshwater resources. This available water under increasing demand by various sectors is at high risk of pollution, and its quality is being diminished day by day due to anthropogenic activities. The facts and figures reported by Dhawan (2017) show India is a water-stressed country.

Climate change adaption and mitigation actions require an integrated approach to create a win–win situation among policymakers and stakeholders. Such an integrated approach by Shrestha and Dhakal (2019) for Nepal that proposed an integrated approach at the national level carry an important message. Pasimeni et al. (2019) justify the contribution of urban factors for adaption and mitigation strategies toward changing climate; well recognized by the policymakers, this has led to several policy initiatives. In the context of Indian agriculture, these policy incentives have a vital role in the adoption of climate change strategies, especially in the rain-fed agriculture sectors (Venkateswarlu and Singh 2015). One of the most important impacts of climate change on society will be changes in water availability, particularly at the regional level (Buytaert et al. 2009). Governments in the developing nations have

[1]The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations that is dedicated to providing the world with objective, scientific information relevant to understanding the scientific basis of the risk of human-induced climate change, its natural, political, and economic impacts and risks, and possible response options.