The Impact of Climate Change on Food Security and Agricultural Livelihoods

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By

Vandna Chhabra, Geeta Arora
and Abdul Haris A.

Cambridge
Scholars
Publishing

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This book first published 2024

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-0364-0801-5
ISBN (Ebook): 978-1-0364-0802-2

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PREFACE

As I sit down to write this preface, I am acutely aware of the magnitude of the topic that lies before us—climate change. It is a subject that affects every corner of our planet and every aspect of our lives. It is a challenge that demands our attention, understanding, and action. And it is in this spirit that I present to you this book—an exploration of climate change, its causes, trends, projections, and the wide-ranging impacts it has on our world.

The urgency to address climate change has never been greater. We find ourselves at a critical juncture, where the choices we make today will shape the future of generations to come. This book seeks to shed light on the intricacies of climate change and its consequences across various sectors. It aims to provide a comprehensive understanding of the challenges we face and the opportunities we have to mitigate and adapt to this global crisis.

In the chapters that follow, we embark on a journey through the intricacies of climate change. We start by examining its causes, from the greenhouse effect to the role of greenhouse gases such as carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons. We delve into the projections for climate change in Asia and India, exploring the trends in temperature, rainfall, and extreme weather events. We also take a step back in time to understand the history and evolution of the United Nations Framework Convention on Climate Change, which has played a pivotal role in shaping global efforts to address this issue.

From there, we shift our focus to the impacts of climate change on various sectors. We explore how ecosystems, coastal systems, low-lying areas, and human health are all vulnerable to the changing climate. We delve into the intricate relationship between climate patterns and agriculture, examining how crop growth, water supply, and nutrient cycling are affected. We then turn our attention to food production systems and food security, investigating the implications of climate change on staple crops and the global challenge of ensuring access to nutritious food for all.

But our exploration doesn't stop there. We venture into the realm of horticulture, uncovering the effects of climate change on fruit crops, temperate fruits, vegetables, plantation crops, spices, and flowers. We unravel the complex interplay between climate patterns and the delicate balance of insect pests, diseases, and weeds in agriculture. We also consider the implications of climate change on livestock and fisheries, recognizing the profound impacts on animal health, production, and the livelihoods of communities reliant on aquatic resources.

Throughout these pages, we aim to provide not only a comprehensive understanding of climate change but also a glimmer of hope. We dedicate a chapter to exploring adaptation and mitigation strategies, showcasing the innovative solutions and approaches being implemented around the world. It is our belief that by understanding the challenges and opportunities presented by climate change, we can collectively work towards a sustainable and resilient future.

I would like to express my gratitude to the countless scientists, researchers, and experts whose work has contributed to our understanding of climate change. Their tireless efforts have paved the way for the knowledge we share within these pages. I also extend my deepest appreciation to my colleagues and mentors who have supported me throughout this endeavour.

Finally, I extend my heartfelt thanks to you, the reader. By picking up this book, you have shown a willingness to engage with one of the greatest challenges of our time. I invite you to delve into the chapters that lie ahead, to explore the intricacies of climate change, and to join the global movement towards a sustainable future. Together, we can make a difference.

With hope and determination,

Dr. Vandna Chhabra, Dr. Geeta Arora & Dr. Abdul Haris A.

ACKNOWLEDGMENTS

Writing a book of this magnitude is not a solitary endeavour but a collaborative effort that requires the support, encouragement, and understanding of numerous individuals. It is with deep gratitude that I acknowledge the invaluable contributions of those who have stood by me throughout this journey.

First and foremost, I want to express my heartfelt appreciation to my family. Their unwavering love, patience, and understanding have been the foundation upon which this book was built. Their constant encouragement and belief in me have provided the strength to persevere, even in the face of challenges. I am truly grateful for their unwavering support.

I extend my heartfelt thanks to my friends, whose presence has been a source of inspiration and motivation. Their enthusiasm, insightful discussions, and words of encouragement have fuelled my passion for this project. Their unwavering belief in me and their willingness to lend a listening ear during the highs and lows of the writing process have been invaluable.

I am deeply indebted to my mentors and colleagues who have guided and mentored me throughout this endeavour. Their expertise, wisdom, and constructive feedback have shaped my understanding of climate change and enriched the content of this book. I am grateful for their generosity in sharing their knowledge and for their unwavering support.

I would also like to express my gratitude to the reviewers and experts who provided valuable insights and feedback on the manuscript. Their thoughtful comments and suggestions have helped to refine the content and ensure its accuracy and relevance.

Furthermore, I would like to extend my appreciation to the publishing team who worked tirelessly behind the scenes to bring this book to life. Their dedication, professionalism, and attention to detail have been instrumental in transforming the manuscript into a tangible publication.

Lastly, I want to acknowledge the readers of this book. Your interest and engagement in the topic of climate change are a testament to the importance of this global issue. It is my sincere hope that the knowledge and insights shared within these pages will inspire meaningful conversations and actions towards a sustainable future.

In conclusion, I am humbled and grateful for the support I have received from my family, friends, mentors, colleagues, and the publishing team. Without their encouragement, guidance, and assistance, this book would not have been possible. Their collective contributions have enriched my journey as an author and have made this endeavour immensely rewarding.

Thank you.

INTRODUCTION

Chapter 1 (Climate Change - Causes, Trends, and Projections): This chapter delves into the causes and trends of climate change, exploring concepts like the greenhouse gas effect, global warming, and the various greenhouse gases. It also introduces the impacts of climate change and the role of international initiatives like the UNFCCC.

Chapter 2 (Impacts of Climate Change on Different Sectors): This chapter discusses how climate change affects various sectors, including ecosystems, coastal areas, health, water supply, energy, and society, providing insight into the widespread consequences of climate change.

Chapter 3 (Climate Change Impact on Agriculture): This chapter focuses on the direct and indirect impacts of climate change on agriculture, considering factors like temperature, CO_2, precipitation, and sea-level rise.

Chapter 4 (Climate Change Impact on Food Production Systems and Food Security): This chapter examines the impact of global warming on staple crops like rice, wheat, coarse cereals, and pulses, shedding light on the potential consequences for food security.

Chapter 5 (Impact of Climate Change on Horticulture): This chapter explores the effects of climate change on horticultural crops, including fruits, vegetables, plantation crops, spices, and medicinal plants.

Chapter 6 (Impact of Climate Change on Pests and Diseases): This chapter discusses how climate change influences insect pests, diseases, and weeds, emphasizing the importance of understanding these dynamics for agricultural practices.

Chapter 7 (Impact of Climate Change on Livestock): This chapter delves into the effects of climate change on animal health, livestock reproduction, and factors related to feed and fodder, particularly in the context of poultry.

Chapter 8 (Impact of Climate Change on Fisheries): This chapter highlights the consequences of climate change on fish production, fisheries-based livelihoods, and marine and inland fisheries.

Chapter 9 (Micro-organisms and Climate Change): This chapter explores the role of microorganisms in climate change, specifically their impact on marine and terrestrial ecosystems, as well as soil microbiomes.

Chapter 10 (Adaptation to Climate Change): This chapter focuses on adaptation strategies to mitigate climate change impacts across various sectors, including agriculture, energy, water, and health.

Chapter 11 (Mitigation to Climate Change): This chapter addresses strategies to reduce emissions and mitigate climate change, such as methane and CO_2 mitigation, carbon sequestration, and policies contributing to climate mitigation.

Chapter 12 (Harnessing Indigenous Technical Knowledge of Farmers): This chapter discusses the importance of indigenous knowledge in climate change adaptation and mitigation, offering examples like improved pest management, weather forecasting, and crop insurance.

References: This section provides citations and sources for the information presented in the book.

CHAPTER 1

CLIMATE CHANGE- CAUSES, TRENDS AND PROJECTIONS

If we are to preserve our planet for future generations, we need urgent action to curb new emissions of these heat trapping gases. "Time is running out."
—WMO Secretary-General Michel Jarraud

The climate has changed continuously from time immemorial to the present day. We had ice ages and warmer periods; ice ages have occurred for the last 700 thousand years, and there have been previous periods that appear to have been warmer than the present despite CO_2 levels being lower than they are now. Apart from geological cycles leading to climate change over the ages, human activities have been a major contributor in the recent past, affecting climate. Rapid industrialization, urbanization, deforestation, environmental pollution, and the burning of fossil fuels like oil, natural gas, and especially coal are indeed major sources of human-caused emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs).

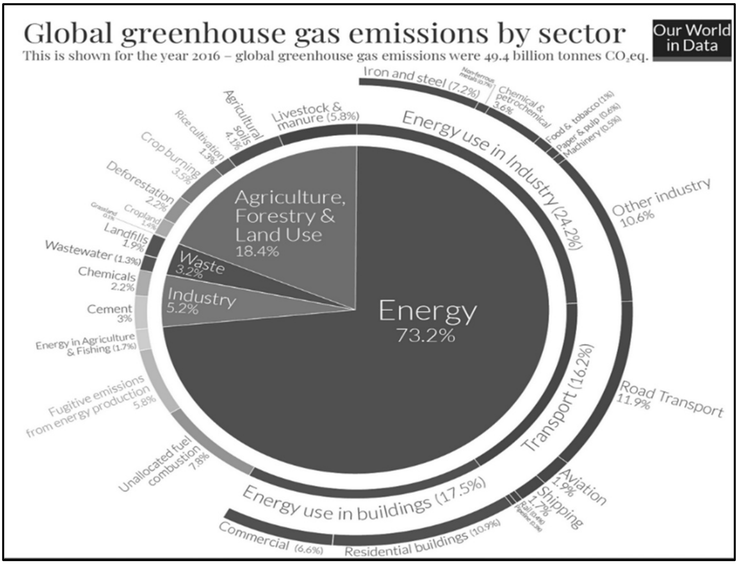
1.1 The Green- house gas effect

The earth's climate depends on the functioning of a natural "greenhouse effect." This effect is the consequence of heat-trapping gases (greenhouse gases) like water vapour, carbon dioxide, ozone, methane, and nitrous oxide, which permit short-wave radiation to pass through but absorb long-wave heat radiated from the earth's surface and lower atmosphere and then reradiate much of the energy back toward the surface. Greenhouse gases are a critical part of our climate system, acting like a blanket and keeping the mean temperature of the earth near about 15oC. Due to the presence of greenhouse gases, these long-wave radiations are trapped in the atmosphere, thus providing warmth to the atmosphere required for sustaining life. Without this natural greenhouse effect, the average surface temperature of the earth would be about 60°F colder. Without GHGs, most regions of the earth would have been too cold for agricultural production as well. However, human activities have been releasing additional heat-trapping gases, intensifying the natural greenhouse effect and thereby changing the earth's climate, leading to global warming.

1.2 Global warming and greenhouse gases

In the 1860s, physicist John Tyndall suggested that slight changes in the atmospheric composition could bring about climatic variations after recognizing the earth's natural greenhouse effect. However, Svante Arrhenius (1896) first speculated that changes in the levels of carbon dioxide in the atmosphere could substantially alter the surface temperature. Worldwide, net emissions of greenhouse gases from human activities increased by 43 percent from 1990 to 2015. Emissions of carbon dioxide, which account for about three-fourths of total emissions, increased by 51 percent over this period, as per the study by USEPA. It has been found that carbon dioxide contributes 60%, methane 15% and nitrous oxide 5% to global warming (IPCC, 2007). China has the highest contribution in emitting greenhouse gases, i.e., about 26%, as compared to the United States (13.4%) and India (6.5%), as per the study during 2018.

The energy sector emitted 73.2% of GHGs and the agriculture, forestry and land use sectors emitted around 18.4%, as reported by Ritchie (2023). The agriculture sector is the largest contributor to global anthropogenic GHGs other than CO_2, accounting for 56% of emissions in 2005. Annual total GHG emissions excluding CO_2 from agricultural production in 2010 were estimated to be 5.2─5.8 $GtCO_2$ eq/yr (Tubiello et al., 2013) and comprised about 10-12% of global anthropogenic emissions. Enteric fermentation and agricultural soils represent together about 70% of total emissions, followed by paddy rice cultivation (9–11%) and biomass burning (7-8%), according to databases of FAOSTAT (2013), U.S.EPA (2006), and EDGAR (JRC/PBL, 2012). Emissions from the agriculture, forest and land use sector (AFOLU) remained similar; however, the share of anthropogenic emissions decreased to 24% in 2010 (IPCC, 2007).



Source: Hanna Ritchie,2020. https://ourworldindata.org/ghg-emissions-by-sector

According to Meehl et al. (2007), "Even if emissions were drastically reduced, global temperatures would remain close to their highest level for at least 1,000 years." India is the world's 5th largest GHG emitter and the 6th largest carbon emitter. India's per capita emission of 1.67 metric tons per year is 23% of the total global average and these emissions are 70% less than the world average.

1.2.1 Carbon dioxide (CO_2)

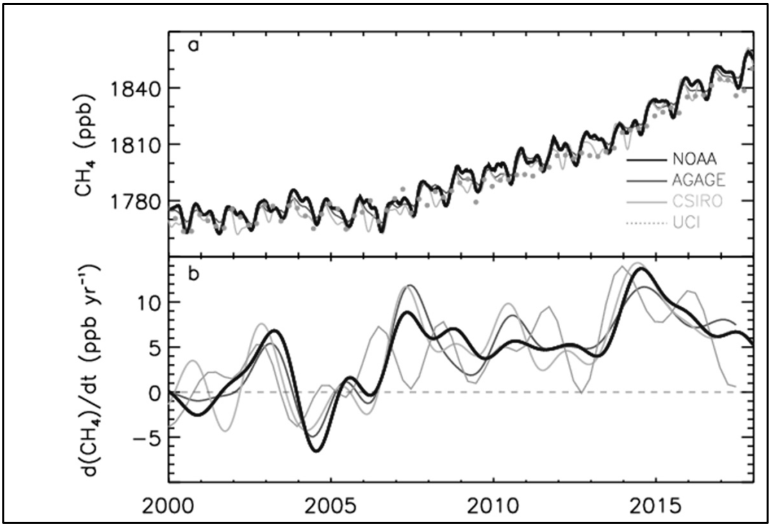
Carbon dioxide concentration has increased due to the burning of fossil fuels, transportation, industrial and household uses. Deforestation provides a source of carbon dioxide and reduces its uptake by trees and other plants. Globally, over the past several decades, about 80 percent of human-induced carbon dioxide emissions came from the burning of fossil fuels, while about 20 percent came from deforestation and associated agricultural practices. Carbon dioxide's lifetime cannot be represented with a single value because the gas is not destroyed over time but instead moves among different parts of the ocean-atmosphere-land system. The ocean surface quickly absorbs some of the excess carbon dioxide, but some will stay in the atmosphere for thousands of years due to the extremely slow process of carbon transfer to ocean sediments. Global emissions of carbon dioxide till 2020 were about 33000 million metric tonnes and other greenhouse gases (i.e., methane, nitrous oxide, and fluorinated gases) are expected to increase by 30 percent over the next three decades.

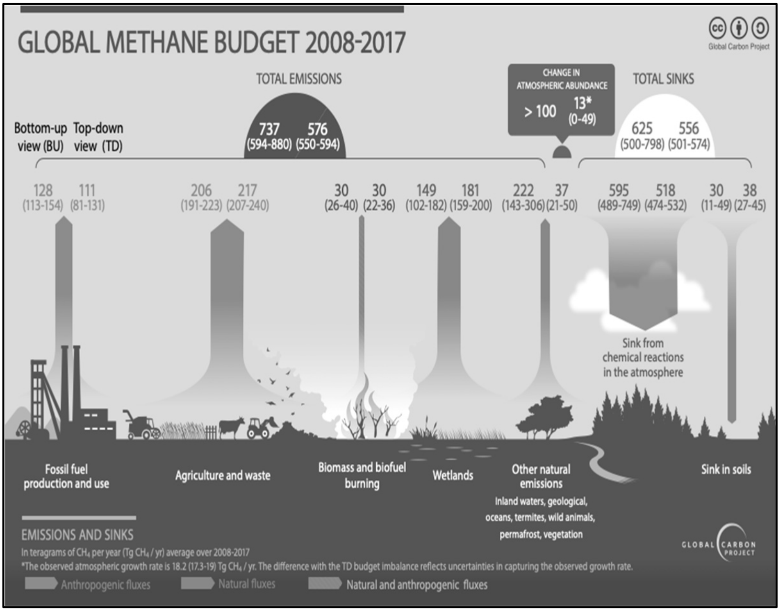
Out of all the GHGs, carbon dioxide (CO_2) is the most important greenhouse gas, having recorded an 80% increase from 21 to 38 gigatonnes (Gt) between 1970 and 2004, which constitutes 77% of total GHG emissions in 2004. The annual per capita CO_2 emission has increased gradually in India from 0.06 to 0.20 metric tonnes from 1950 to 1988 (Mitra 1992). The global warming potential (GWP) is an index to compare the strengths of different GHGs in reusing temperature on a common basis. CO_2 is used as the reference gas to compare the ability of a GHG to trap atmospheric heat. The warming potentials of gases like carbon dioxide, methane and nitrous oxides are 1, 27.8–29.8 and 273 respectively.

It is stated that for the first time, monthly concentrations of carbon dioxide (CO_2) in the atmosphere topped 400 parts per million (ppm) in April throughout the northern hemisphere. This threshold is of symbolic and scientific significance and reinforces evidence that the burning of fossil fuels and other human activities are responsible for the continuing increase in heat-trapping greenhouse gases, thus warming our planet. While the spring maximum values in the northern hemisphere have already crossed the 400-ppm level, the global annual average CO_2 concentration is set to cross this threshold in 2015 or 2016. This should serve as yet another wake-up call about the constantly rising levels of greenhouse gases that are driving climate change.

CO_2 remains in the atmosphere for hundreds of years. Its lifespan in the oceans is even longer. It is the sole greenhouse gas that human activity emits. It was responsible for 85% of the increase in radiative forcing—the warming effect on our climate—over the decade 2002–2012. The amount of CO_2 in the atmosphere has increased on average by 2 parts per million per year for the past 10 years. The northern hemisphere has more anthropogenic sources of CO_2 than the southern hemisphere.

1.2.2. Methane (CH_4) emission





Source: Saunois et al. 2020, ESSD

Over the past 200 years, human activity has doubled the amount of methane in the atmosphere. Methane is the second biggest source of global warming after carbon dioxide and is estimated to be responsible for 23% of all warming caused by greenhouse gases. Methane global emissions were 576 $TgCH_4$/yr (550-594) for 2008-2017 as inferred by an ensemble of atmospheric inversions using an atmospheric constraint. Unlike carbon dioxide, which can survive in the atmosphere for centuries, methane lingers for only around 12 years, but its heat-trapping potential is about 80 times higher than that of carbon dioxide over a 20-year time span. Methane can also further break down into carbon dioxide when it combines with other atmospheric gases, such as oxygen. Methane is generated when organic matter decomposes in an environment with little to no oxygen, for example, underwater or in an animal's intestine as food is digested. Rice crops generate a lot of methane, but livestock rearing remains the biggest contributor within the agricultural sector.

1.2.3. Nitrous oxide emission

Nitrous oxide, GHG in the troposphere is the major source of ozone depletion. Forests, grasslands, oceans, soils, nitrogenous fertilizers, and the burning of biomass and fossil fuels are the sources. Soil, with a contribution of about 65%, is the major contributor to the total nitrous oxide emission. In terms of global warming potential, it is about 298 times more powerful than carbon dioxide. The annual direct and indirect N2O-N emissions from Indian agricultural soils were estimated to be 118.67 Gg (55.5 Tg CO_2 equivalent) and 19.48 Gg (9.1 Tg CO_2 equivalent), respectively, as reported by Bhatia et al., 2013.

1.2.4. Ozone and water vapours

Ozone is a greenhouse gas and is continually produced and destroyed in the atmosphere by chemical reactions. Human activities have increased the ozone concentration through the release of gases like carbon monoxide, hydrocarbons, and nitrogen oxides. Ozone concentrations were projected for 10 regions of the world in 2030 using a coupled general circulation model with interactive chemistry. Modeled ozone concentrations for present conditions have been shown to reasonably agree with surface ozone measurements. The global average population-weighted 8-hr maximum ozone concentration was projected to increase by 9.4 parts per billion per volume (ppbv) compared with a simulation of the concentration in 2000, with the largest increases over South Asia (nearly 15 ppbv) and in the Middle East, Southeast Asia, Latin America, and East Asia.

Water vapour is the most important and abundant greenhouse gas in the atmosphere. The surface warming caused by human-produced increases in other greenhouse gases leads to an increase in atmospheric water vapour, since a warmer climate increases evaporation and allows the atmosphere to hold more moisture. The amount of water vapour in the atmosphere is a direct response to the amount of CO_2 and the other long-lived greenhouse gases, increasing as they do. Increases in water vapour in the upper troposphere and lower stratosphere lead to radiative cooling at these levels and induce warming at the surface. Recent analyses suggest that warming at the earth's surface may be sensitive to parts per million (ppm) by volume changes in water vapour in the lower stratosphere. It has been found that a 10% decrease in stratospheric water vapour between 2000 and 2009 was able to slow the rate at which the global surface temperature increased over this time period by 25%, compared to that which would have occurred as a result of CO_2 and other greenhouse gases.

1.2.5. Chloro-flouro carbons

CFCs are chemically and thermally stable and non-combustible synthetic solvents and are known for raising the amount of dangerous UV (ultraviolet) radiation reaching the surface of the earth. In addition, one of the by-products of the breakdown of ozone by CFCs is carbon dioxide (CO_2), which is a known greenhouse gas. CFCs were banned in the Montreal Protocol (1987) after they were found to be the major cause of a giant hole in Earth's ozone layer. "The IPCC concludes that changes in greenhouse gases - carbon dioxide, methane, nitrous oxide, CFCs, and CFC replacements are the primary drivers of temperature changes over the last 200 years. "While carbon dioxide contributes 65 percent of this, CFCs and CFC-replacements collectively known as synthetic greenhouse gases (SGG) - contribute 10 percent. In a new study at University of Waterloo, Qing-Bin Lu contends that the world has actually been cooling in the years since governments clamped down on aerosol gases, which he believes are the real culprit for climate change. Lu's report challenges the widely held notion that carbon dioxide emissions are the main cause of human-driven climate change and instead suggests that CFCs have been to blame for a trend of anthropogenic global warming from 1970 to about 2002.

1.3 Climate Change and climate variability

Weather is defined as the day-to-day variations in temperature, pressure, humidity, clouds, wind, precipitation, and fog, or the condition of the atmosphere at a particular time and place. Climate is the prevalent long-term weather conditions in a particular area which slowly changes aspects of the atmosphere, hydrosphere, and land surface systems. It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities.

The term "climate change" refers to a change in the climate's state that is discernible by changes in the mean and the variability of its properties that last for an extended period of time, typically decades or longer. Climate change is a shift of climatic conditions to a new equilibrium position, with the values of climatic elements changing significantly. Climatic fluctuation is a situation of temporary deflection that can revert to earlier conditions or be followed by changes in the opposite direction. Climate change may be limited to a specific region or may occur across the Earth.

Climate change is a long-term change in the statistical distribution of weather patterns over periods of time that range from decades to millions of years. It may be a change in the average weather conditions or a change in the distribution of weather events with respect to the average. This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Climate change is a complex problem which has consequences on all aspects of our life. It either impacts or is impacted by poverty, economic development, population growth, sustainable development and resource management. For climate monitoring purposes, a set of climates normal that is stable over a long period is required as a standard. These are reference points used by climatologists to compare current climatological trends to that of the past or what is considered ‘normal’. A normal climate is defined as the arithmetic average of any climate element over a 30-year period. A 30-year period is used, as it is long enough to filter out any interannual variation or anomalies but also short enough to be able to show longer climatic trends.

1.4 Drivers of climate change and variability

Climate change may be due to natural or internal processes, external forcings, or persistent anthropogenic changes in the atmosphere or land use. Global climate change indicates a variation in either the mean state of the climate or in its variability, persisting for several decades or longer. Major characteristics of climate change include a rise in average global temperature, ice cap melting, changes in precipitation, storms, and the increase in ocean temperature leading to a rise in sea level. Climate variability indicates variations in the prevailing condition of the climate on all spatial and temporal scales. Variability may be due to natural internal processes within the climate system or to variations in natural (volcanic eruptions and sunspots) or anthropogenic (human-driven) external forcing. It is worth noting that changes in individual weather events will contribute substantially to changes in climate variability. Common drivers of climate variability include El Nino and La Nina events, which are shifts of warm, tropical Pacific Ocean currents. The immediate drivers that directly affect GHG emissions, namely population, GDP per capita, energy intensity and carbon intensity, are affected, in turn, by underlying drivers that include resource availability, development status and goals, level of industrialization and infrastructure, international trade, urbanization, technological changes, and behavioural choices. Among these, infrastructure, technological changes and behavioural choices appear to be critical, but even though their influences on other drivers is well established, the magnitude of this impact remains difficult to quantify.

1.4.1 El-Nino, La Nina and Southern Oscillation

El Niño refers to warmer-than-normal sea surface temperatures in the eastern tropical Pacific Ocean. La Nina, the reverse of El Niño, indicates periods when the eastern equatorial Pacific is cooler than usual. El Niño and La Niña situations affect the trade winds across the tropical Pacific region, which in turn affect the distribution of ocean temperatures. The fluctuation between El Niño, La Niña and neutral (near average sea surface temperatures) conditions is known as the El Niño-Southern Oscillation (ENSO). With the classical El Nino, the tropical eastern Pacific close to the coast of South America becomes warmer than usual while the western side of the ocean, near Indonesia cools. In recent years, scientists have drawn a distinction between this sort of El Nino and ones where the warming is principally in the central Pacific. The latter, it is argued, has a greater impact on the monsoon, reducing rains over India, than the former. During the evolution of a typical El Nino, as the western side of the tropical Pacific cools and the eastern part warms, trade winds, which blow from east to west over the ocean, weaken considerably and sometimes even reverse direction. This shift in wind pattern, in turn, aids the growth of the El Nino.

But the El Nino that manifested in 2009 was unique, as reported by the scientist at IITM, Pune. That year, from around June to almost October, the entire Pacific basin turned abnormally warm, with no cooling anywhere. In an El Nino with basin-wide warming, the development of such a sea-surface temperature gradient and the accompanying change in winds were disrupted.

El Niño and La Niña influence seasonal temperature and precipitation in many parts of the world via the effects of tropical rainfall on the upper atmosphere. Because of its far-reaching impacts, El Niño grabs headlines around the globe. In 1997-98, a supercharged El Niño event led to drought and massive forest fires in Indonesia, destruction of infrastructure and crops from extreme flooding along the coast of Latin America and livestock and agriculture losses due to heavy rains in Eastern Africa. El Niño events can last up to or longer than a year, so their effects on rainfall around the globe may persist for several seasons, and impacts on agriculture can be widespread. El Niño hits many key agricultural areas across the world. In some years, El Niño can delay or diminish the Indian summer monsoon, putting the livelihoods of hundreds of millions at risk. La Niña conditions in the tropical Pacific have persisted and strengthened as trade winds intensified from mid-July to mid-August 2022.

El Nino Years	Neutral Years	La Nina Years
1897, 1900, 1903, 1906.1915, 1919, 1926, 1931, 1941, 1942, 1958, 1966,1973. 9178, 1980,1983, 1987, 1988, 1992, 1995, 1998, 2003, 2007, 2010, 2016	1896, 1898, 1899,1901-02, 1905, 1907-08, 1912-1914, 1916, 1920-24, 1927-30, 1932-33, 1935-38,1940, 1944-49, 1952-54, 1957, 1959-1961, 1963-65, 1967-70, 1972, 1975, 1977,1979, 1981-82, 1984-86, 1990-91, 1993-94, 1996-97. 2001-02,2004-06, 2009,2013-15, 2017-20	1904, 1909, 1910-11, 1917-18,1925, 1934, 1939, 1943, 1950-51,1955-56, 1962,1971, 1974, 1976,1989, 1999,2000, 2008, 2011, 2012, 2021

1.5 Climate Change projections for Asia and India

The projected increase in temperature for South Asia is in the range of 0.5-1.2°C by 2020, 0.88-3.16°C by 2050 and 1.56-5.44°C by 2080, depending on the scenario of future development. The projections also indicate an increase in the frequency of droughts, floods, and extreme events of temperature and rainfall. Climate models predict that the monsoon will continue to weaken and that the global area affected by drought is likely to increase in the future, with the frequency of heavy precipitation events increasing over most areas. Asia is facing alarming challenges due to climate change and variability, as illustrated by various climatic models predicting the global mean temperature will increase by 1.5◦C between 2030 and 2050 if it continues to increase at the current rate (IPCC, 2019). In arid areas of the western part of China, Pakistan, and India, it is also projected that there will be a significant increase in temperature. During monsoon season, there would be an increase in erratic rainfall of high intensity across the region. In South and Southeast Asia, there would be an increase in aridity due to a reduction in winter rainfall. Due to climatic abnormalities, there will be a 0.1 m increase in sea level by 2,100 across the globe. In Asia, an increase in heat waves, hot and dry days, and erratic and unsure rainfall patterns is projected, while dust storms and tropical cyclones are predicted to be worse in the future (Gouldson et al., 2016).

The retreat of glaciers and permafrost in Asia during recent years is unprecedented as a consequence of warming. The frequency of the occurrence of climate-induced diseases and heat stress in Central, East, South and Southeast Asia has increased with rising temperatures and rainfall variability. Observed changes in terrestrial and marine ecosystems have become more pronounced. Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is likely to decrease due to climate change, along with population growth and a rising standard of living that could adversely affect more than a billion people in Asia by the 2050s. According to the sixth assessment report of the IPCC, higher risks of flood and drought make Asian agricultural productivity highly susceptible to changing climates. Climate change has already adversely affected economic growth and development in Asia.

Projected sea-level rise is very likely to result in significant losses to coastal ecosystems and a million or so people along the coasts of South and Southeast Asia will likely be at risk from flooding. Sea-water intrusion due to sea-level rise and declining river runoff is likely to increase the habitat of brackish water fisheries but coastal inundation is likely to seriously affect the aquaculture industry and infrastructure, particularly in heavily populated mega deltas. The stability of wetlands, mangroves and coral reefs around Asia is likely to be increasingly threatened. Recent risk analysis of coral reefs suggests that between 24% and 30% of the reefs in Asia are likely to be lost during the next 10 years and 30 years, respectively. Significantly longer heat wave durations have been observed in many countries in Asia, as indicated by pronounced warming trends and several cases of severe heat waves. Generally, the frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, and debris and mud flows, while the number of rainy days and