# CLIMATE RISK COUNTRY PROFILE

# INDIA

WORLD BANK GROUP

*Graphic Design:* Circle Graphics, Inc., Reisterstown, MD.

## ACKNOWLEDGEMENTS

This profile is part of a series of Climate Risk Country Profiles that are developed by the World Bank Group (WBG). These profiles synthesize the most relevant data and information on climate change, disaster risk reduction, and adaptation actions and policies at the country level. The profile is designed as a quick reference source for development practitioners to better integrate climate resilience in development planning and policy making. This effort is co-led by Veronique Morin (Senior Climate Change Specialist, WBG) and Ana E. Bucher (Senior Climate Change Specialist, WBG).

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Climate and climate-related information is largely drawn from the Climate Change Knowledge Portal (CCKP), a WBG online platform with available global climate data and analysis based on the latest Intergovernmental Panel on Climate Change (IPCC) reports and datasets. The team is grateful for all comments and suggestions received from the sector, regional, and country development specialists, as well as climate research scientists and institutions for their advice and guidance on use of climate related datasets.

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# FOREWORD

Climate change is a major risk to good development outcomes, and the World Bank Group is committed to playing an important role in helping countries integrate climate action into their core development agendas. The World Bank Group is committed to supporting client countries to invest in and build a low-carbon, climate-resilient future, helping them to be better prepared to adapt to current and future climate impacts.

The World Bank Group is investing in incorporating and systematically managing climate risks in development operations through its individual corporate commitments.

A key aspect of the World Bank Group's Action Plan on Adaptation and Resilience (2019) is to help countries shift from addressing adaptation as an incremental cost and isolated investment to systematically incorporating climate risks and opportunities at every phase of policy planning, investment design, implementation and evaluation of development outcomes. For all IDA and IBRD operations, climate and disaster risk screening is one of the mandatory corporate climate commitments. This is supported by the Bank Group's Climate and Disaster Risk Screening Tool which enables all Bank staff to assess short- and long-term climate and disaster risks in operations and national or sectoral planning processes. This screening tool draws up-to-date and relevant information from the World Bank's Climate Change Knowledge Portal, a comprehensive online 'one-stop shop' for global, regional, and country data related to climate change and development.

Recognizing the value of consistent, easy-to-use technical resources for client countries as well as to support respective internal climate risk assessment and adaptation planning processes, the World Bank Group's Climate Change Group has developed this content. Standardizing and pooling expertise facilitates the World Bank Group in conducting initial assessments of climate risks and opportunities across sectors within a country, within institutional portfolios across regions, and acts as a global resource for development practitioners.

For developing countries, the climate risk profiles are intended to serve as public goods to facilitate upstream country diagnostics, policy dialogue, and strategic planning by providing comprehensive overviews of trends and projected changes in key climate parameters, sector-specific implications, relevant policies and programs, adaptation priorities and opportunities for further actions.

It is my hope that these efforts will spur deepening of long-term risk management in developing countries and our engagement in supporting climate change adaptation planning at operational levels.

**Bernice Van Bronkhorst**
Global Director
Climate Change Group (CCG)
The World Bank Group (WBG)

## KEY MESSAGES

- Historical temperature rise in India has been slightly lower than the global average, however projections of future change are in line with, or slightly above, those expected globally.
- By the end of the century, average temperature in India is projected to increase by 1.1°C–4.1°C over the 1986–2005 baseline, with the rate of warming dependent on the 21st century emissions pathway.
- Projected temperature rises are strongest in the northern regions of India, and annual minimum and maximum temperatures are expected to increase at a greater magnitude than national average temperatures.
- Disaster risk reduction and adaptation should be considered very high priorities in India in order to protect communities from the widespread and diverse increases in projected hazard intensities.
- Intensification of climate extremes is projected in India, with increased drought risk, and increases in the quantity of precipitation during heavy rainfall events.
- Without adaptation measures, extreme river floods are expected to affect an additional 13 to 34 million people by the 2040s and coastal flooding is expected to affect an additional 5 to 18 million people by the 2070s to end of the century.
- Very large potential increases in heat-related ill health, diarrheal disease, and malnourishment are already beginning to impact communities; these threats are projected to intensify.
- Major restructuring of agricultural systems, with consideration of crop range shifts, is likely required in order to respond to the negative outlook for yields, particularly of staple cereal crops.
- Urban areas and key infrastructure will face major pressures, particularly from rising temperatures and water resource management challenges.
- Damage and loss impacts are likely to fall disproportionately on the urban and rural poor, those without assets, and minority groups. Without wide reaching adaptation and disaster risk reduction, inequalities are likely to widen and poverty to prevail.

## COUNTRY OVERVIEW

India is the seventh largest country in the world, and the second most populous, home to over 1.36 billion people. Lying between the Himalayas and the Indian Ocean, India contains diverse ecosystems and cultures. Its geography includes mountainous terrain, northern plains, peninsular plateau, coastal plains, island groups, and deserts, with many different climates, great biodiversity, and rich natural resources.[1]

Approximately 43% of the population is dependent on agriculture as their main employment source, however, its contribution to GDP is declining, with the agriculture sector constituting 16% in 2019. The services sector accounts for 49.4% of GDP, while industry contributes 24.8%.[2] Key issues confronting the Indian government include ensuring equitable and environmentally sustainable growth, fostering faster creation of good quality jobs, addressing environmental stressors such as land degradation, poor air quality and unsustainable groundwater use,

[1] Ministry of Environment and Forests (2012). India Second National Communication to the UNFCCC. Government of India. URL: https://unfccc.int/sites/default/files/resource/indnc2.pdf

[2] World Bank (2021). DataBank – World Development Indicators. [Accessed May 2021]. URL: https://databank.worldbank.org/source/world-development-indicators

as well as strengthening implementation of flagship government programs. As of 2018 an estimated 14% of the population was undernourished (see key indicators in **Table 1**).

Climate change is a major challenge for developing nations like India, threatening to enhance risks already elevated by high levels of social vulnerability and climate variability. Through its 2016 Nationally Determined Contribution (NDC), India is committed to achieving by 2030: a reduction in the emissions intensity of its GDP by 33%–35% below the 2005 levels; the share of renewables in power generation at 40% contingent on technology transfer and availability of finance; and an additional cumulative carbon sink of 2.5–3.0 $GtCO_2e$ by 2030 with increased afforestation and tree cover. Other commitments are to better adapt to climate change by enhancing investments in development programs in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management.

Furthermore, the nation aims to enhance investments in development programs in sectors vulnerable to climate change, particularly agriculture, water resources, coastal economies, and health. India's Second National Communication to the UNFCCC (NC2) (2012) identifies the impacts of climate change for its key sectors agriculture, water resources, coastal areas, energy, and human health.[3] India submitted its Third Biennial Update Report to the UNFCCC February, 2021.

**TABLE 1.** Key Indicators

| Indicator | Value | Source |
|---|---|---|
| **Population Undernourished**[4] | 14.0% (2017–2019) | FAO, 2020 |
| **Proportion of Employed Population Below $1.90 PPP a Day**[5] | 10.7% (2019) | ADB, 2020a |
| **Share of National Wealth Owned by Top 10% of Households**[6] | 77% (2020) | Oxfam, 2020 |
| **Net Annual Migration Rate**[7] | –0.04% (2015–2020) | UNDESA, 2019 |
| **Infant Mortality Rate (Between Age 0 and 1)**[8] | 3.2% (2015–2020) | UNDESA, 2019 |
| **Average Annual Change in Urban Population**[9] | 2.4% (2015–2020) | UNDESA, 2018 |
| **Dependents per 100 Independent Adults**[10] | 48.7 (2020) | UNDESA, 2019 |
| **Urban Population as % of Total Population**[11] | 34.9% (2020) | CIA, 2020 |
| **External Debt Ratio to GNI**[12] | 19.3% (2018) | ADB, 2020b |
| **Government Expenditure Ratio to GDP**[13] | 13.7% (2019) | ADB, 2020b |

3 Ministry of Environment and Forests (2012). India Second National Communication to the UNFCCC. Government of India. URL: https://unfccc.int/sites/default/files/resource/indnc2.pdf
4 FAO, IFAD, UNICEF, WFP, WHO (2020). The state of food security and nutrition in the world. Transforming food systems for affordable healthy diets. FAO. Rome. URL: http://www.fao.org/documents/card/en/c/ca9692en/
5 ADB (2020a). Basic Statistics 2020. URL: https://www.adb.org/publications/basic-statistics-2020 [accessed 17/12/20]
6 Oxfam International (2020). India: Extreme inequality in numbers. URL: https://www.oxfam.org/en/india-extreme-inequality-numbers [accessed 17/12/20]
7 UNDESA (2019). World Population Prospects 2019: MIGR/1. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
8 UNDESA (2019). World Population Prospects 2019: MORT/1-1. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
9 UNDESA (2019). World Urbanization Prospects 2018: File 6. URL: https://population.un.org/wup/Download/ [accessed 17/12/20]
10 UNDESA (2019). World Population Prospects 2019: POP/11-A. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 17/12/20]
11 CIA (2020). The World Factbook. Central Intelligence Agency. Washington DC. URL: https://www.cia.gov/the-world-factbook/
12 ADB (2020b). Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/publications/key-indicators-asia-and-pacific-2020
13 ADB (2020b). Key Indicators for Asia and the Pacific 2020. Asian Development Bank. URL: https://www.adb.org/publications/key-indicators-asia-and-pacific-2020

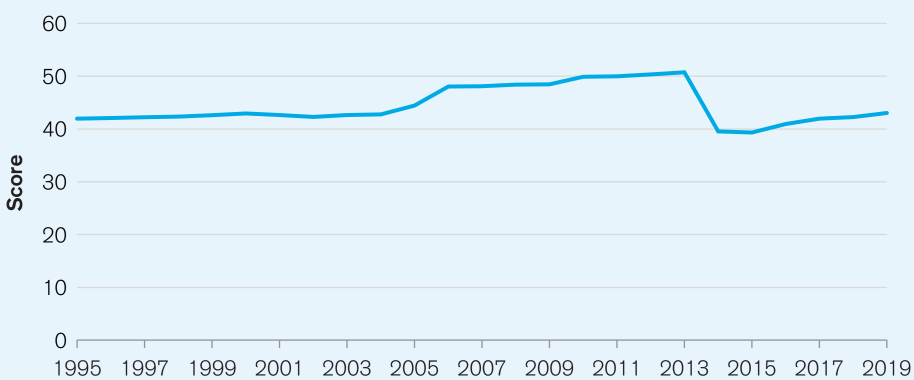
## Green, Inclusive and Resilient Recovery

The coronavirus disease (COVID-19) pandemic has led to unprecedented adverse social and economic impacts. Further, the pandemic has demonstrated the compounding impacts of adding yet another shock on top of the multiple challenges that vulnerable populations already face in day-to-day life, with the potential to create devastating health, social, economic and environmental crises that can leave a deep, long-lasting mark. However, as governments take urgent action and lay the foundations for their financial, economic, and social recovery, they have a unique opportunity to create economies that are more sustainable, inclusive and resilient. Short and long-term recovery efforts should prioritize investments that boost jobs and economic activity; have positive impacts on human, social and natural capital; protect biodiversity and ecosystems services; boost resilience; and advance the decarbonization of economies.

This document aims to succinctly summarize the climate risks faced by India. This includes rapid onset and long-term changes in key climate parameters, as well as impacts of these changes on communities, livelihoods and economies, many of which are already underway. This is a high-level synthesis of existing research and analyses, focusing on the geographic domain of India, therefore potentially excluding some international influences and localized impacts. The core data presented is sourced from the database sitting behind the World Bank Group's Climate Change Knowledge Portal (CCKP), incorporating climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). This document is primarily meant for WBG staff to inform their climate actions. The document also aims to direct the reader to many useful sources of secondary data and research.

Due to a combination of political, geographic, and social factors, India is recognized as vulnerable to climate change impacts, ranked 127th out of 182 countries in the 2020 ND-GAIN Index.[14] The ND-GAIN Index ranks 182 countries using a score which calculates a country's vulnerability to climate change and other global challenges as well as their readiness to improve resilience. The more vulnerable a country is the lower their score, while the more ready a country is to improve its resilience the higher it will be. The higher the score, the higher the rank. Norway has the highest score and is ranked 1st. **Figure 1** is a time-series plot of the ND-GAIN Index showing India's progress.

**FIGURE 1.** The ND-GAIN Index Score (Out of 100) Summarizes a Country's Vulnerability to Climate Change and Other Global Challenges in Combination with Its Readiness to Improve Resilience. It Aims to Help Businesses and the Public Sector Better Prioritize Investments for a More Efficient Response to the Immediate Global Challenges Ahead.




[14] University of Notre Dame (2020). Notre Dame Global Adaptation Initiative. URL: https://gain.nd.edu/our-work/country-index/

# Climate Baseline

## Overview

India's land surface can be divided into six physiographic regions: Himalayan mountains in the north, Peninsular Deccan Plateau, the Indo-Gangetic Plains, Thar Desert in the west, Coastal Plain, and the Islands. All these regions have different climate profiles and vulnerabilities. The country is influenced by the presence of the Himalayas in the northern part of the country and the Thar Desert in the west. The Himalayan Mountains act as a barrier to winds from Central Asia and China, enabling India's climate to be warmer than other countries at similar latitudes. The northern part of the country is characterized as a continental climate with hot summers and cold winters. The coastal regions of the country, however, experience warmer temperatures with little variation throughout the year and frequent rainfall.[15] India's seasonal cycle for the latest climatology, 1991–2020, is shown in **Figure 2**, but this conceals considerable regional variation.

India's monsoon season runs approximately from June to October, arriving later in more northerly regions and delivering over 80% of the territory's annual precipitation. A shorter rainy season occurs during the months of October through December following the summer monsoon and is referred to as the post monsoon season. The southwest monsoon season (June-September) generates average monthly rainfall between 150 millimeters (mm) to 270 mm and the northeast monsoon season (October-December) generates average monthly rainfall between 10 mm and 75 mm. Large inter-annual variability is a key feature of the rainfall regime of India. This is due to both remote and regional climate influences of the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole on the monsoon.[16]

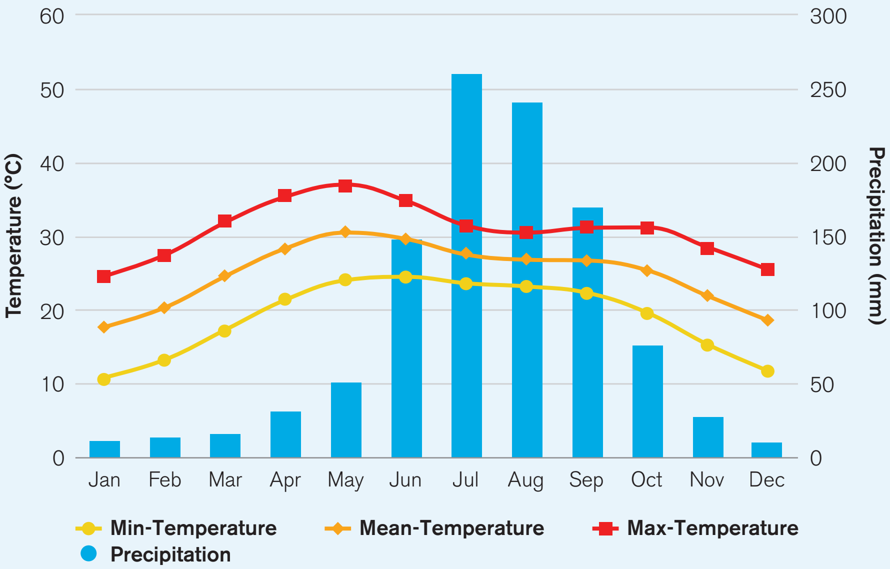
Summer (May–September) temperatures are consistently high across India's territory, with some small exceptions in its most mountainous regions. Winter (November-March) temperatures are more variable, and this variation along with different precipitation patterns determines the many climatic zones of India. The winter season brings dry and clear weather with low humidity and temperature during the months of January and February. To the west are arid and semi-arid climates including the Thar desert region, the driest areas of which experience less than 300 mm of annual precipitation and high inter-annual variability. In contrast, the Southwestern region of India has a wet tropical climate with high annual precipitation commonly well over 1,500 mm. The east coast of India also experiences consistently high temperatures and high precipitation rates, but like much of central India, precipitation is strongly controlled by the monsoon and is highly variable between years. India's central regions experience greater seasonal temperature variation. **Figure 3** shows observed spatial variation for temperature and precipitation across India.

[15] Ministry of Environment and Forests (2012). India Second National Communication to the UNFCCC. Government of India. URL: https://unfccc.int/sites/default/files/resource/indnc2.pdf

[16] Ashok, K., Guan, Z., Saji, N.H. and Yamagata, T. (2004). Individual and combined influences of ENSO and the Indian Ocean dipole on the Indian summer monsoon. Journal of Climate, 17, 3141–3155. URL: http://www.jamstec.go.jp/frsgc/research/d1/iod/publications/ashok_jclim_2004.pdf

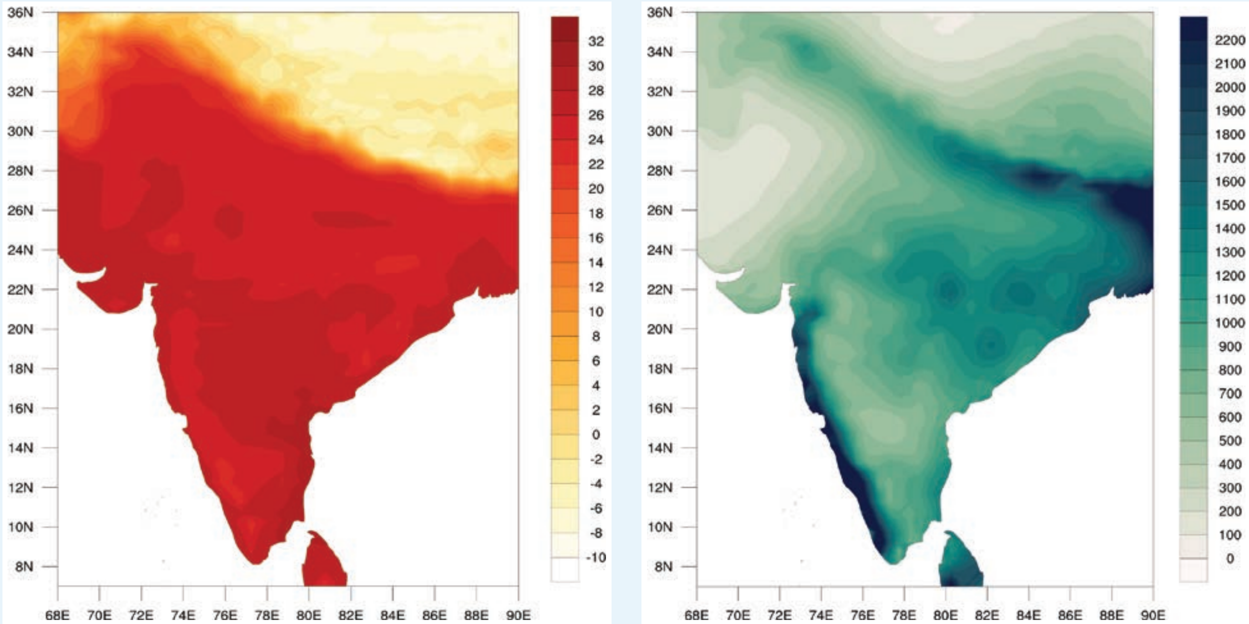
*Annual Cycle*

**FIGURE 2.** Average Monthly Mean, Max and Min Temperatures and Rainfall in India (1991–2020)[17]




*Spatial Variation*

**FIGURE 3.** Annual Mean Temperature (°C) (left), and Annual Mean Rainfall (mm) (right) in India Over the Period 1991–2020[14]




Maps present the coordinates of India: latitude 67°28′12″E – 89°05′29″E and 32°05′53″N – 8°05′40″N.

[17] WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Historical. URL: https://climateknowledgeportal.worldbank.org/country/india/climate-data-historical

## Key Trends

### *Temperature*

India's average annual mean temperature during 1901–2020 showed an increasing trend of 0.62°C/100 years, with significant increasing trend in maximum temperature (0.99°C/100 years) and relatively lower increasing trend (0.24°C/100 years) in minimum temperature.[18] This warming trend is highest during the post-monsoon season (0.88°C/100 years) followed by winter season (0.68°C/100 years). The rise of maximum and minimum temperatures, during the past 30 years, is mostly confined to the northern, central and eastern/north-eastern parts of the country. Temperature increases in India have been observed to be more pronounced in daily maximum temperatures than in daily minimums. Increases in both minimum and maximum temperatures have been observed across the majority of the Indian territory, with the exception of a small pocket of the northwestern region, where cooling has been observed.[19]

The Berkeley Earth Dataset[20] shows that while warming has occurred across all of the Indian territory over the 21st century, India's warming has been below the global average over the same time period. It also shows that the strongest warming has occurred in the northern and northeastern regions.

### *Precipitation*

Historical trends in precipitation are strongly influenced by ENSO, which increases sea surface temperatures and reduces monsoon rainfall in India, as shown in **Figure 4**. Although there is inter-annual variability, the total precipitation during the Indian summer monsoon has remained largely stable over the period 1901–2020 and has shown a weak decreasing trend during the recent few decades. Based on the rainfall data from the India Meteorological Department (IMD) Observational Network,[21] it is found that five states: Bihar, Meghalaya, Nagaland, West Bengal and Uttar Pradesh, have shown significant decreasing trends in Southwest monsoon rainfall during 1989–2018. The annual rainfall over these five states along with the states of Arunachal Pradesh and Himachal Pradesh also show significant decreasing trends. Other states do not show any significant changes in southwest monsoon rainfall during the same period.[22]

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[18] Ministry of Earth Sciences (2020). Statement on Climate of India during 2020. India Meteorological Department – Climate Research and Services. Press Release, 04 January, 2021. URL: https://mausam.imd.gov.in/backend/assets/press_release_pdf/Statement_of_Climate_of_India-2020.pdf

[19] Ministry of Environment, Forest and Climate Change (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. URL: https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

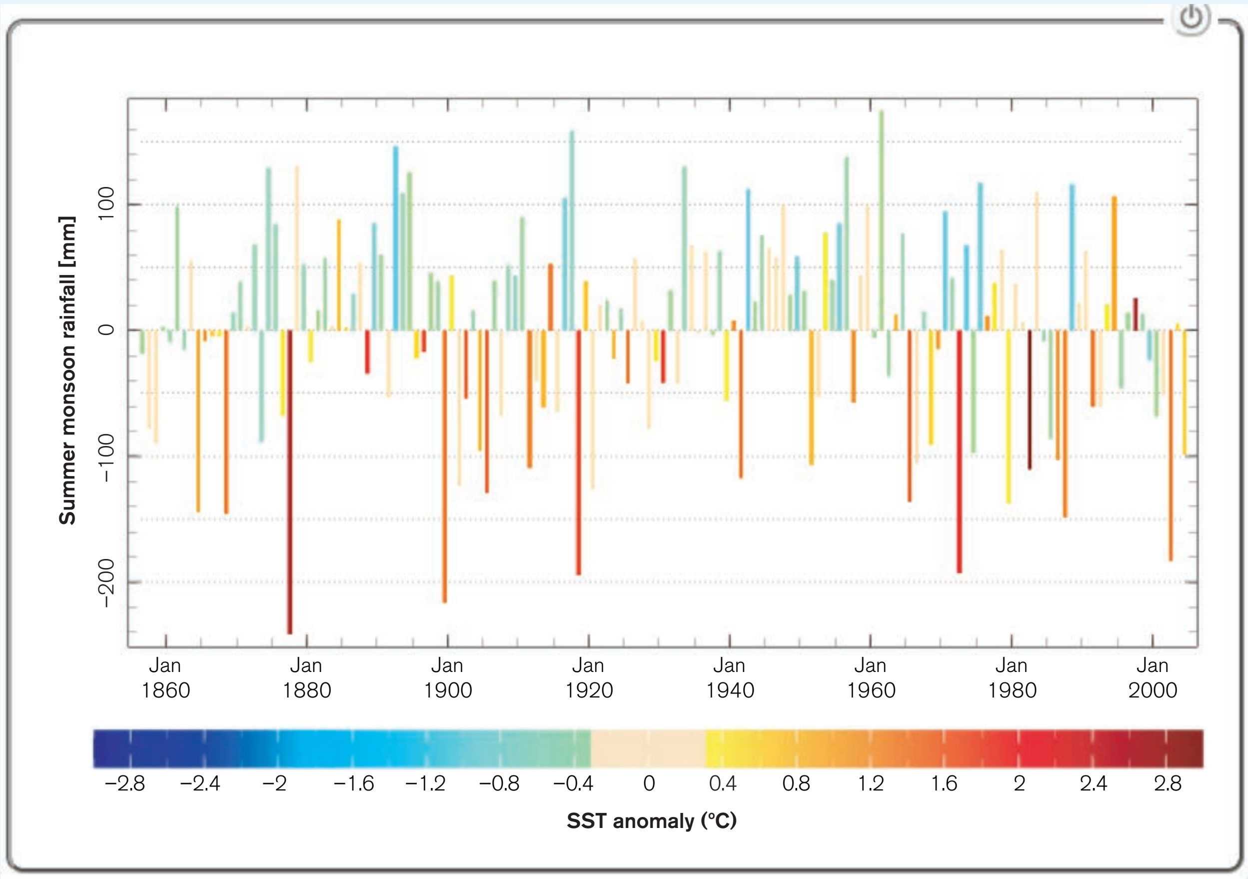
[20] Carbon Brief (2018). Mapped: How every part of the world has warmed – and could continue to. Infographics. [26 September 2018]. URL: https://www.carbonbrief.org/mapped-how-every-part-of-the-world-has-warmed-and-could-continue-to-warm

[21] Ministry of Earth Sciences (2020). Observed Monsoon Rainfall Variability and Changes during Recent 30 years (198902018). India Meteorological Department – Climate Research and Services Division, Pune. URL: https://internal.imd.gov.in/press_release/20200330_pr_778.pdf

[22] Ministry of Environment, Forest and Climate Change (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. URL: https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

There has been a shift in the recent period toward more frequent dry spells (27% higher during 1981–2011 relative to 1951–1980) and more intense wet spells during the summer monsoon season. The frequency of localized heavy precipitation occurrences has increased worldwide in response to increased atmospheric moisture content. Over central India, the frequency of daily precipitation extremes with rainfall intensities exceeding 150 mm per day increased by about 75% during 1950–2015.[23]

**FIGURE 4.** The Historical Relationship Between Summer Monsoon Rainfall in India and El Niño Southern Oscillation (ENSO) Indicated by Sea-Surface Temperature (SST) Anomalies (Higher SST is Associated with ENSO), Figure Reproduced from the IRI Data Library[24]




[23] Krishnan, R. et al. (2020). Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. URL: https://www.springer.com/gp/book/9789811543265

[24] IRI Data Library (2018). International Research Institute for Climate and Society. URL: https://iridl.ldeo.columbia.edu/ [accessed 02/12/2019]

## Climate Futures

The main data source for the World Bank Group's Climate Change Knowledge Portal is the Coupled Model Inter-comparison Project Phase 5 (CMIP5) models, which are utilized within the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), providing estimates of future temperature and precipitation. Four Representative Concentration Pathways (i.e. RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were selected and defined by their total radiative forcing (cumulative measure of GHG emissions from all sources) pathway and level by 2100. In this analysis RCP2.6 and RCP8.5, the low and high emissions pathways, are the primary focus; RCP2.6 represents a very strong mitigation scenario, whereas RCP8.5 assumes a high end emission scenario. For more information, please refer to the RCP Database.

### A Precautionary Approach

Studies published since the last iteration of the IPCC's report (AR5), such as Gasser et al. (2018), have presented evidence which suggests a greater probability that Earth will experience medium and high-end warming scenarios than previously estimated.[25] Climate change projections associated with the highest emissions pathway (RCP8.5) are presented here to facilitate decision making which is robust to these risks.

In India, global climate projections show a significant warming trend for the country. However, the projections in rainfall remain highly variable, with a likely increase in intensity for extreme rainfall events. **Table 2** presents information produced by India's Ministry of Earth Sciences, providing information on historical observations (1951–2014) for temperature and precipitation as well as projections for two RCPs (RCP4.5, RCP8.5) over two distinct time horizons; against the reference period of 1951–2015. It is important to note the difference in the reference periods used for **Table 2** as compared to the reference period (1986–2005) used by CMIP5 and CCKP to derive specific projection indicators.

**TABLE 2.** Change in Surface Air Temperature (TAS, °C) and Precipitation (PR, mm day$^{-1}$) Relative to 1850–1900 for the RCP4.5 and RCP8.5 Scenarios from CMIP5 Models for the Global and the Indian Region During the Historical (1951–2014), Near Future (2040–2069) and Far Future (2070–2099) Period. This Data was Produced by the Ministry of Earth Sciences, Government of India[26]

| | Global Mean Estimates | | | | | Indian Region Estimates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Historical | RCP4.5 | | RCP8.5 | | Historical | RCP4.5 | | RCP8.5 | |
| | 1951–2014 | 2040–2069 | 2070–2099 | 2040–2069 | 2070–2099 | 1951–2014 | 2040–2069 | 2070–2099 | 2040–2069 | 2070–2099 |
| **Average Temperature (°C)** | 0.54 (0.28–0.68) | 2.16 (1.43–2.75) | 2.62 (1.80–3.16) | 2.75 (1.94–3.48) | 4.31 (3.08–5.25) | 0.72 (0.47–1.28) | 2.67 (1.72–3.70) | 3.27 (2.25–4.27) | 3.37 (2.32–4.68) | 5.33 (3.70–6.11) |
| **Precipitation (mm)** | 0.01 (–0.02–0.40) | 0.09 (0.05–0.16) | 0.13 (0.09–0.18) | 0.12 (0.07–0.20) | 0.20 (0.11–0.30) | -0.06 (–0.36–0.28) | 0.10 (–0.32–0.33) | 0.23 (–0.13–0.49) | 0.22 (–0.09–0.43) | 0.28 (–0.31–0.68) |

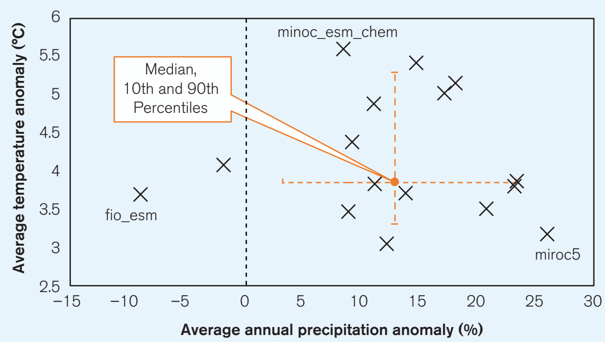
[25] Gasser, T., Kechiar, M., Ciais, P., Burke, E. J., Kleinen, T., Zhu, D., . . . Obersteiner, M. (2018). Path-dependent reductions in CO2 emission budgets caused by permafrost carbon release. Nature Geoscience, 11, 830–835. URL: https://www.nature.com/articles/s41561-018-0227-0?WT.feed_name=subjects_climate-sciences

[26] Krishnan, R. et al. (2020). Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. URL: https://www.springer.com/gp/book/9789811543265

### *Model Ensemble*

Climate projections presented in this document are derived from datasets available through the CCKP, unless otherwise stated. These datasets are processed outputs of simulations performed by multiple General Circulation Models (GCM) (for further information see Flato et al., 2013).[27] Collectively, these different GCM simulations are referred to as the 'model ensemble'. Due to the differences in the way GCMs represent the key physical processes and interactions within the climate system, projections of future climate conditions can vary widely between different GCMs, this is particularly the case for rainfall related variables and at national and local scales. The range of projections from 16 GCMs for annual average temperature change and annual precipitation change in India under RCP8.5 is shown in **Figure 5**. Spatial representation of future projections of annual temperature and precipitation for mid and late century under RCP8.5 are presented in **Figure 6**.

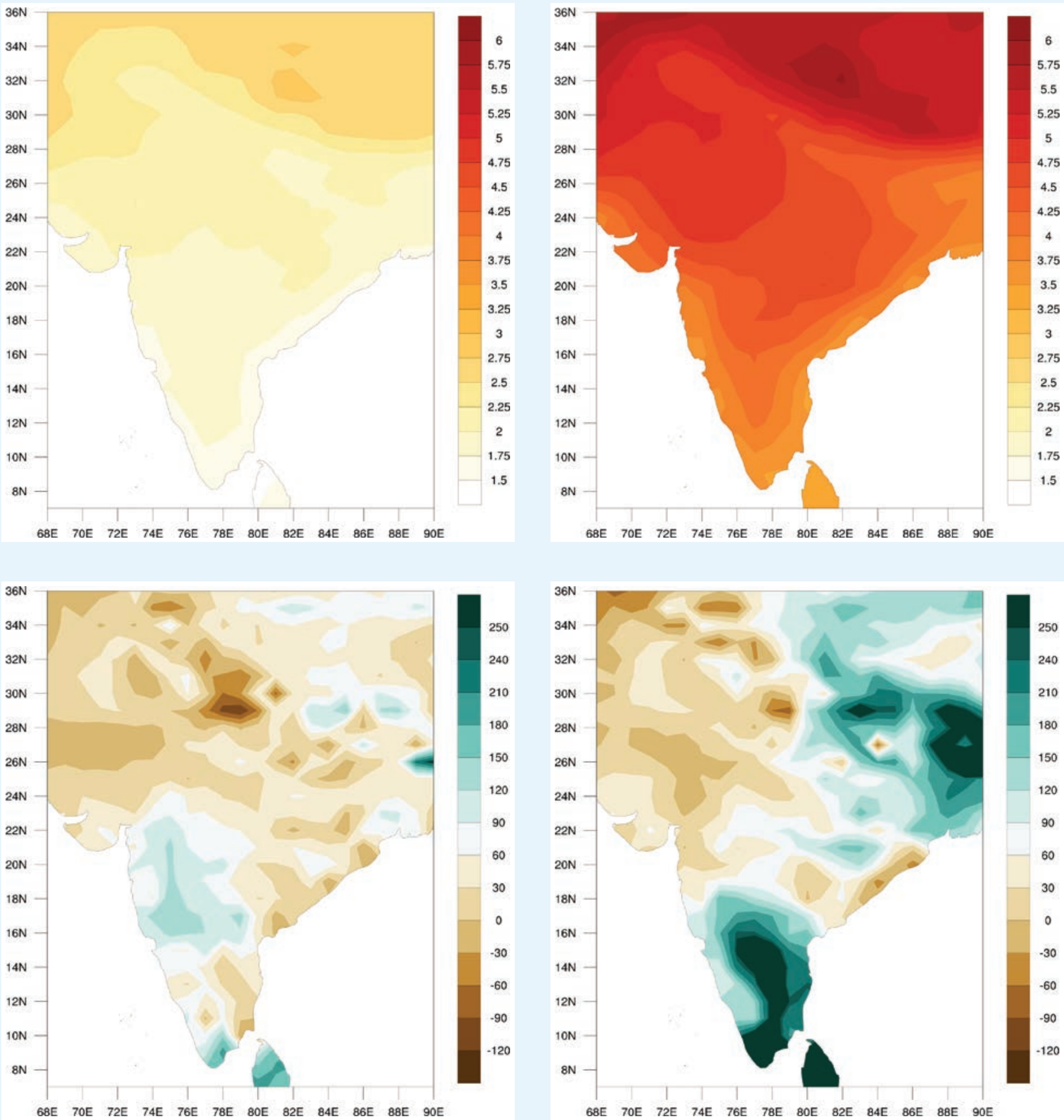
**FIGURE 5.** 'Projected Average Temperature Anomaly' and 'Projected Annual Rainfall Anomaly' in India. Outputs of 16 Models Within the ensemble Simulating RCP8.5 Over the Period 2080–2099. Models Shown Represent the Subset of Models Within the ensemble Which Provide Projections Across All RCPs and Therefore are Most Robust for Comparison.[21] Models at the Extremities are Labelled




[27] Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S. C., Collins, W., . . . Rummukainen, M. (2013). Evaluation of Climate Models. Climate Change. (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 741–866. URL: http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

### *Spatial Variation*

**FIGURE 6.** CMIP5 Ensemble Projected Change (32 GCMs) in Annual Temperature (top) and Precipitation (bottom) by 2040–2059 (left) and by 2080–2090 (right) Relative to 1986–2005 Baseline Under RCP8.5[28]




Maps present the coordinates of India: latitude 67°28′12″E – 89°05′29″E and 32°05′53″N – 8°05′40″N.

[28] WBG Climate Change Knowledge Portal (CCKP 2021). India. Climate Data. Projections. URL: https://climatedata.worldbank.org/CRMePortal/web/water/land-use-/-watershed-management?country=IND&period=2080-2099

### *Temperature*

Projections of future temperature change are presented in three primary formats. Shown in **Table 2** are the changes (anomalies) in daily maximum and daily minimum temperatures over the given time period, as well as changes in the average temperature. **Figures 7** and **8** display the annual and monthly average temperature projections. While similar, these three indicators can provide slightly different information. Monthly and annual average temperatures are most commonly used for general estimation of climate change, but the maximums and minimums can explain more about how daily life might change in a region, affecting key variables such as the viability of ecosystems, health impacts, productivity of labor, and the yield of crops, which are often disproportionately influenced by temperature extremes.

Temperatures in India are projected to increase by approximately 4.5°C by the 2090s, under the RCP8.5 emissions pathway, and around 1.2°C on the RCP2.6 emissions pathway. These changes are similar to the global average.[29] Warming is stronger in annual minimum and maximum temperatures than in the average. Notably, under all emissions pathways, the rise in annual minimum temperatures is around 18%–21% higher than the rise in average temperatures. Warming on higher emissions pathways is strongly biased towards the winter and pre-monsoon months (**Figure 8** and **Table 3**). With the exception of the RCP2.6 emissions pathway, the net increase by the 2080s and the 2090s tends to be 20%–30% higher in the months from January to May than during the monsoon months of June, July and September.

**FIGURE 7.** Projected Average Annual Temperature in India Under RCP2.6 (Blue) and RCP8.5 (Red). The Values Shown Represent the Median of the Multi-Model Ensemble with the Shaded Areas Showing the 10–90th Percentiles (Historical Reference Period, 1986–2005).[30]

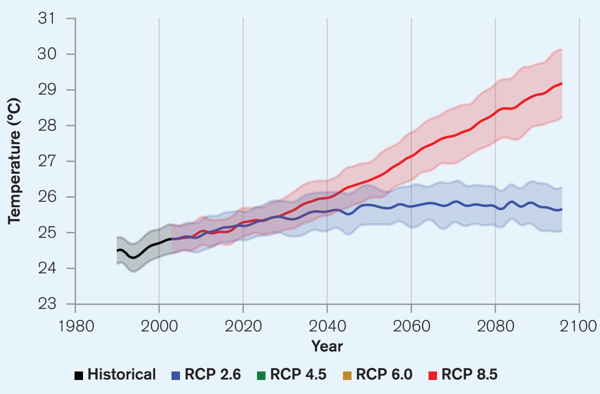
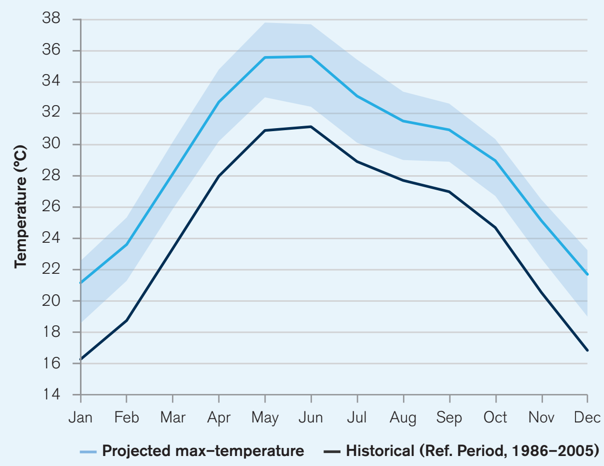



**FIGURE 8.** Projected Mean Monthly Temperature in Relation to the Historical Reference Period, 1986–2005, Across the Seasonal Cycle, for India for the period 2080–2099 under RCP8.5. The Value Shown Represents the Median of the Model Ensemble with the Shaded Areas Showing the 10th–90th Percentiles.[25]




[29] Kirtman, B., Power, S. B., Adedoyin, A. J., Boer, G. J., Bojariu, R., Camilloni, I., . . . Wang, H.-J. (2013). Near-term Climate Change: Projections and Predictability. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 953–1028). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter11_FINAL.pdf

[30] WBG Climate Change Knowledge Portal (CCKP 2021). India Water Sector Dashboard. URL: https://climatedata.worldbank.org/CRMePortal/web/water/land-use-/-watershed-management?country=IND&period=2080-2099

### *Precipitation*

Considerable uncertainty characterizes projections of local long-term future precipitation trends in India, this uncertainty is compounded by a poor understanding of the relationship (teleconnections) between ENSO and the monsoon, and the impact climate change may have on this relationship. The intensity of sub-daily extreme rainfall events (**Figure 9**) appears to be increasing with temperature, a finding supported by evidence from different regions of Asia.[31] Future changes in the seasonality of monthly precipitation at the national level are also highly uncertain under all emissions scenarios. While the ensemble median would point to a small increase in annual precipitation driven by increases in the monsoon months of July, August, and September, uncertainty reflected in the standard deviation is high and the projections are not robust.

Jayasankar et al. (2015) attempt to provide more robust analysis on changes in Indian Summer Monsoon rainfall through the creation of sub-groups of Global climate models and statistically analyzing the performance of those groups.[32] The best performing sub-group points towards a slight reduction in the frequency of light precipitation events which is offset by an increase in the frequency of high and extreme precipitation events, leading to a net increase in average daily monsoon precipitation of 0.74 ± 0.36 mm/day. This finding is broadly supported by Sharmila et al. (2015).[33] Another study, also utilizing a subset of GCMs and analyzing annual trends, Li et al. (2016) suggested Northern India may experience a slight reduction in average annual precipitation by 2041–2060.[34]

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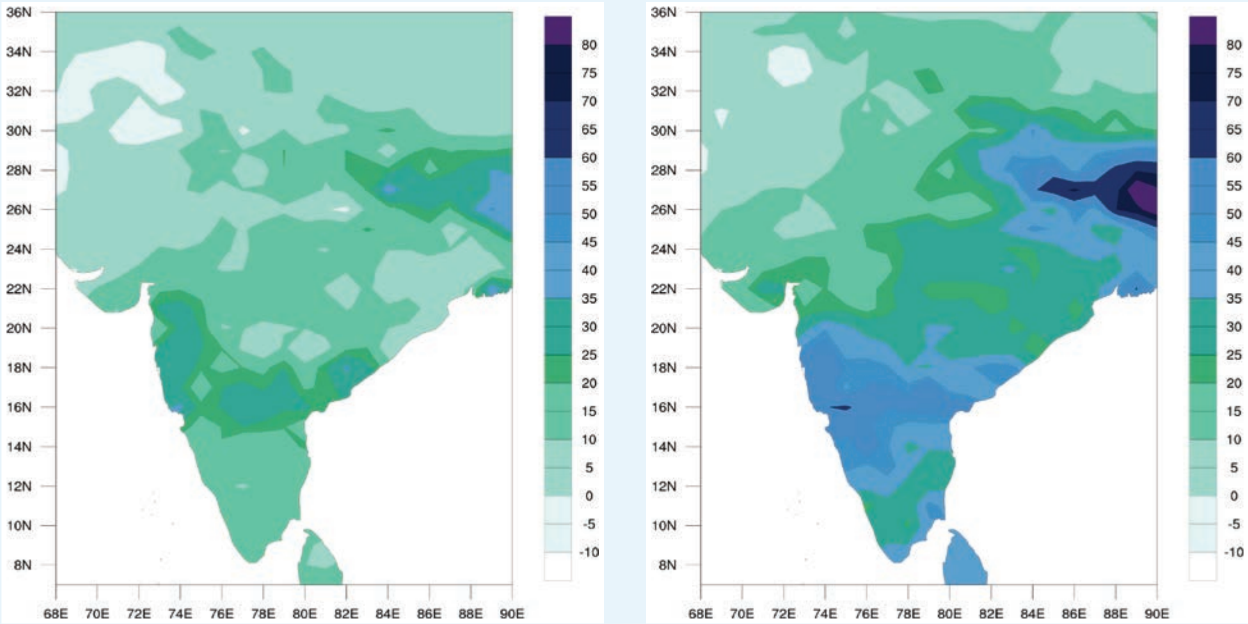
[31] Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E. J., Lenderink, G., Roberts, N. (2014). Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics, 52, 522–555. URL: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014RG000464

[32] Jayasankar, C., Surendran, S., Rajendran, K. (2015). Robust signal of future projections of Indian Summer Monsoon rainfall by IPCC AR5 climate models: Role of seasonal cycle and interannual variability. Geophysical Research Letters: 42: 3513–3520. URL: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2015GL063659

[33] Sharmila, S., Joseph, S., Sahai, A.K., Abhilash, S., Chattopadhyay, R. (2015). Future projection of Indian summer monsoon variability under climate change scenario: An assessment from CMIP5 climate models. Global and Planetary Change: 124: 62–78. URL: https://ui.adsabs.harvard.edu/abs/2015GPC...124...62S/abstract

[34] Li, Q., Wang, S., Lee, D.K., Tang, J., Niu, X., Hui, P., Gutowski, W.J., Dairaku, K., McGregor, J.L., Katzfey, J. and Gao, X. (2016). Building Asian climate change scenario by multi-regional climate models ensemble. Part II: mean precipitation. International Journal of Climatology, 36, 4253–4264. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.4633

**FIGURE 9.** Projected Change in the Maximum 5-Day Rainfall (mm) Over India for the Period 2040–2059 (left) and 2080–2099 (right) for Emissions Pathways RCP8.5 Compared to the 1986–2005 Baseline[35]




Maps present the coordinates of India: latitude 67°28′12″E – 89°05′29″E and 32°05′53″N – 8°05′40″N.

## CLIMATE RELATED NATURAL HAZARDS

India faces some of the highest disaster risk levels in the world, ranked 32nd out of 191 countries by the 2019 INFORM Risk Index[36] (**Table 3**). India has very high exposure to flooding (ranked jointly 13th), including, riverine, flash, and coastal, as well as high exposure to tropical cyclones and their associated hazards (ranked jointly 14th) and drought (ranked jointly 24th). Disaster risk in India is also driven by its social vulnerability. India's vulnerability ranking (44th) is driven by its high levels of socioeconomic deprivation. India scores markedly better in terms of its coping capacity. The section which follows, analyses climate change influences on the exposure component of risk in India. As seen in **Figure 1**, the ND-GAIN Index presents an overall picture of a country's vulnerability and capacity to improve its resilience. In contrast, the Inform Risk Index identifies specific risks across a country to support decisions on prevention, preparedness, response and a country's overall risk management.

[35] WBG Climate Change Knowledge Portal (CCKP 2021). India Climate Projections. URL: https://climateknowledgeportal.worldbank.org/country/india/climate-data-projections

[36] European Commission (2019). INFORM Index for Risk Management. India Country Profile. URL: https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk

**TABLE 3.** Selected Indicators from the INFORM 2019 Index for Risk Management for India. For the Sub-Categories of Risk (e.g. "Flood") Higher Scores Represent Greater Risks. Conversely the Most at-Risk Country is Ranked 1st. Global Average Scores are Shown in Brackets

| Flood (0–10) | Tropical Cyclone (0–10) | Drought (0–10) | Vulnerability (0–10) | Lack of Coping Capacity (0–10) | Overall Inform Risk Level (0–10) | Rank (1–191) |
|---|---|---|---|---|---|---|
| 8.4 [4.5] | 7.2 [1.7] | 6.2 [3.2] | 4.9 [3.6] | 4.3 [4.5] | 5.4 [3.8] | 32 |

## Heat Waves

India regularly experiences some of the world's highest maximum temperatures, with an average monthly maximum of around 30°C and an average maximum of 36°C. The CORDEX multi-Regional Climate Model ensemble mean projects that for all India averaged frequency of summer heat waves, will increase to about 2.5 events per season by the mid-twenty-first century (2040–2069), with a further slight rise to about 3.0 events by the end-twenty-first century (2070–2099) under the medium (RCP4.5) emission scenario. The average total duration of summer heat waves is projected to increase to about 15 and 18 days per season during the mid- and end-twenty-first century respectively under this future scenario. The CORDEX ensemble mean projects that India averaged frequencies of summer heat waves will increase to about 3.0 and 3.5 events per season during the mid- and end-twenty-first century, respectively under the high (RCP8.5) emission scenario. The future rise in heat wave frequencies under this high emission scenario is marginally higher than the increase in the number of summer events under the RCP4.5 scenario for the corresponding periods. The average total duration of summer heat waves in India under the RCP8.5 scenario is assessed to be substantially higher than that under RCP4.5 scenario, with about 25 and 35 heat wave days per season during the mid- and end-twenty-first century respectively. The projected CORDEX ensemble mean change in the frequency of heat waves for the mid- and end-twenty-first century under RCP8.5 scenario relative to the historical reference period (1976–2005) are higher over the north-west region (more than 3 days per summer season) compared to other parts of India.[37]

Heat wave probability increases are projected to be strongest along India's west coast. While heat waves refer to the periodic occurrence of exceptionally high heats, the incidence of permanent (chronic) heat stress is likely to increase significantly in India under all emissions pathways.[38] Matthews et al. (2017) use Kolkata as an example, suggesting that the deadly conditions experienced during the 2015 heat wave may be experienced annually under 2°C of global warming.[33] Other cities where exposure to chronic heat stress is projected to be significant include Mumbai, Delhi, Chennai, Ahmedabad, Surat, Hyderabad, Pune, and Bangalore.

[37] Krishnan, R. et al. (2020). Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. URL: https://www.springer.com/gp/book/9789811543265

[38] Matthews, T., Wilby, R.L. and Murphy, C. (2017). Communicating the deadly consequences of global warming for human heat stress. Proceedings of the National Academy of Sciences, 114, 3861–3866. URL: https://www.pnas.org/content/pnas/114/15/3861.full.pdf

## Drought

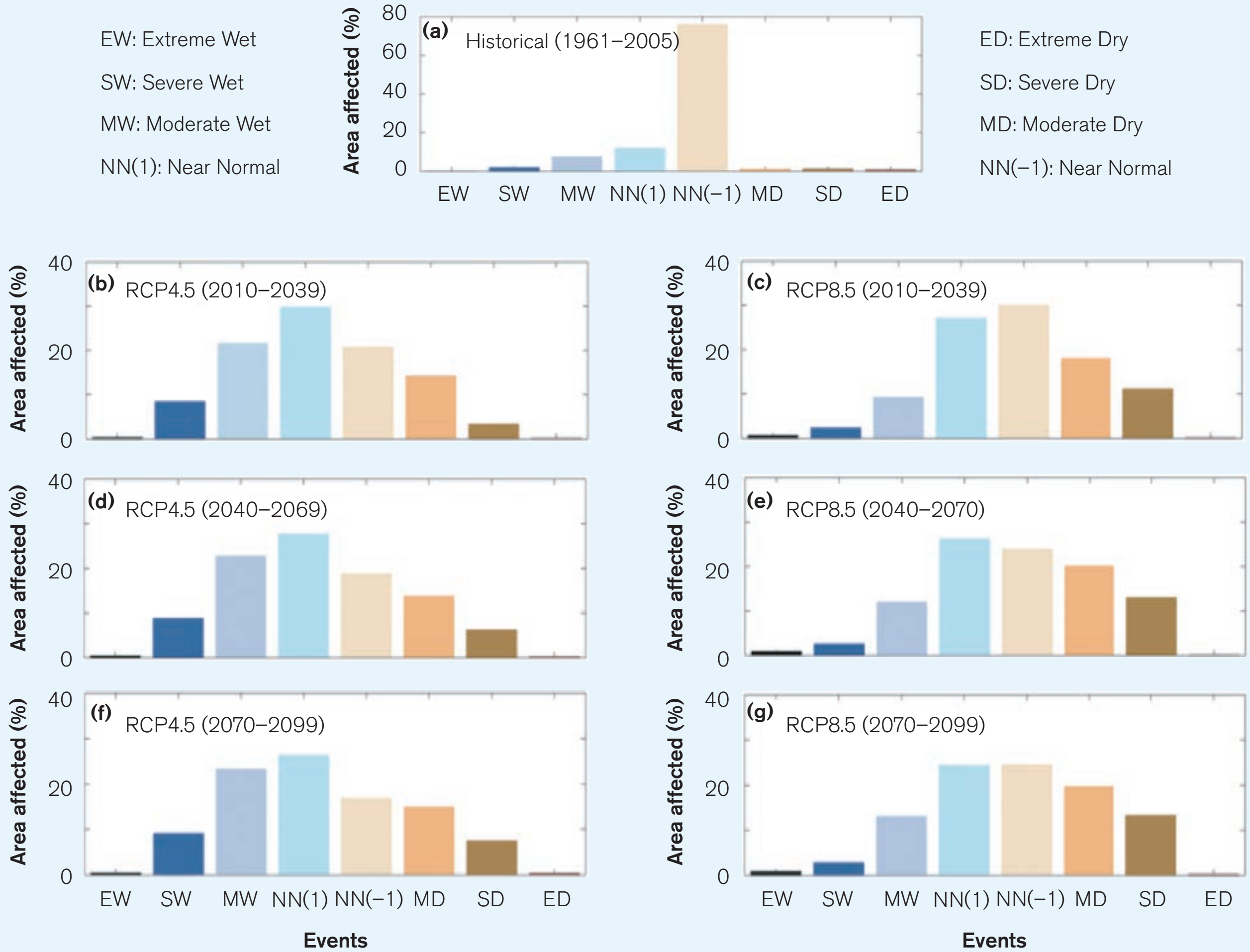
Two primary types of drought may affect India, meteorological (usually associated with a precipitation deficit) and hydrological (usually associated with a deficit in surface and subsurface water flow, potentially originating in the region's wider river basins). At present, India faces an annual median probability of severe meteorological drought of approximately 3%, as defined by the Standardized Precipitation Evaporation Index (SPEI) of less than –2. Drought has historically occurred most frequently in the Indo-Gangetic Plain region. One study suggested that between 2001–2013, approximately 19% of India's population was exposed to drought (in this case drought was categorized as a Normalized Difference Drought Index of >0.6).[32]

Naumann et al. (2018) provide a global overview of changes in drought conditions under different warming scenarios.[39] The research suggests that in South Asia there will be an increase in the frequency of drought events, with what is currently a 1 in 100-year event returning approximately every 40 to 50 years under 1.5°C–2°C of warming, and every 20 years under 3°C of warming. CCKP model ensemble projections also suggest annual probability of severe drought could see a slight increase across much of India but for many regions, southern and eastern India in particular, statistical confidence is not high and therefore projections should be treated with caution. Most confidence can be found in northwestern India under RCP8.5, with annual median probability growing over the 21st century to 23%. The most eastern and southern tips of India are also projected to see an increase in the length of less severe dry spells on this emissions pathway.

Specific studies have looked in greater detail at potential future changes, particularly in the Indian Summer Monsoon which brings the large majority of precipitation. The common finding is a trend towards fewer wet days, but more frequent and more intense extreme wet and dry events on all emissions pathways (see Sharmila et al., 2015).[28] **Figure 10** presents research on the Indo-Gangetic plain region showing an increase in the occurrence of extreme climate events, with a heavier trend towards floods under lower emissions pathways and droughts under higher emissions pathways.

[39] Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R. A., Carrao, H., . . . Feyen, L. (2018). Global Changes in Drought Conditions Under Different Levels of Warming. Geophysical Research Letters, 45(7), 3285–3296. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2017GL076521

**FIGURE 10.** Area of the Indo Gangetic Plain Affected by Extreme Climate Events for the Historical Period (1961–2005), and Different Time Periods Under Emissions Pathways RCP4.5 and RCP8.5[40]




## Flood

The World Resources Institute's AQUEDUCT Global Flood Analyzer[41] can be used to establish a baseline level of river flood exposure. As of 2010, assuming protection for up to a 1 in 25-year event, the population annually affected by river flooding in India is estimated at 4.8 million people and the expected annual impact on GDP at $14 billion. Development and climate change are both likely to increase these figures. The climate change component can be isolated and by the 2030s is expected to increase the annually-affected population by 9.3 million people, and impact GDP by $62 billion, under the RCP8.5 emissions pathway (AQUEDUCT Scenario B).

[40] Nath, R., X. Cui, D. Nath, H. F. Graf, W. Chen, L. Wang, H. Gong, and Q. Li (2017). CMIP5 multi-model projections of extreme weather events in the humid subtropical Gangetic Plain region of India, Earth's Future, 5, 224–239. p. 237. doi: 10.1002/2016EF000482. URL: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2016EF000482

[41] WRI (2018). AQUEDUCT Global Flood Analyzer. URL: https://floods.wri.org/# [Accessed: 22/11/2018].

Work by Paltan et al. (2018) demonstrates that even under lower emissions pathways consistent with the Paris Climate Agreement, almost all Asian countries face an increase in the frequency of extreme river flows.[42] What would historically have been a 1 in 100-year flow, will become a 1 in 50-year or 1 in 25-year event in most of South, Southeast, and East Asia. There is good agreement among models on this trend. India's three major northern river basins, the Indus, the Ganges and the Brahmaputra all receive a contribution from snow and glacier meltwater. A review by Nepal and Shrestha (2015) suggests that snow melt and glacier loss due to warming may result in increased winter flows and reduced summer flows.[43] Increased peak flows are likely to contribute to increased flood risk. Research suggests these increases may be further compounded by future land use changes within these major river basins.[44]

Floods are on average the greatest source of annual losses to disaster in India. UNISDR estimates that a combined GDP impact of all types of flood at $7 billion every year.[45] This estimate is notably lower than that made by the AQUEDUCT model, potentially reflecting a model bias, but also potentially linked to the underreporting of damage and loss due to lower-level flood events. According to Guhathakurta et al. (2011) flood hazard increased across a majority of India during the 20th century.[17] The implications of trends toward more intense extreme precipitation events are serious for potential future flood events. Work by Willner et al. (2018) suggests the median increase in the population affected by an extreme (90th percentile) flood by the mid 2030s and 2040s is in the order of 22 million people (**Table 4**).[46] This increase is centered most heavily in the regions of Bihar (7.5 million newly affected), Uttar Pradesh (3.8 million) and West Bengal (3.2 million), and all of the Indo-Gangetic Basin. The magnitudes of flood disasters are highly dependent on exposure of assets and people to hazards and existing socioeconomic and physical vulnerabilities, and further research is required to understand climate change-enhanced flood risk at a more localized level.

**TABLE 4.** Estimated Number of People in India Affected by an Extreme River Flood (Extreme River Flood is Defined as Being in the 90th Percentile in Terms of Numbers of People Affected) in the Historic Period 1971–2004 and the Future Period 2035–2044. Figures Represent an Average of All Four RCPs and Assume Present Day Population Distributions[41]

| Estimate | Population Exposed to Extreme Flood (1971–2004) | Population Exposed to Extreme Flood (2035–2044) | Increase in Affected Population |
|---|---|---|---|
| **16.7 Percentile** | 1,168, 337 | 14,579,246 | 13,410,909 |
| **Median** | 3,711,037 | 24,970, 671 | 21,259, 634 |
| **83.3 Percentile** | 10,554,091 | 45,418, 272 | 34,864, 181 |

42 Paltan, H., Allen, M., Haustein, K., Fuldauer, L., & Dadson, S. (2018). Global implications of 1.5°C and 2°C warmer worlds on extreme river flows Global implications of 1.5°C and 2°C warmer worlds on extreme river flows. Environmental Research Letters, 13. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aad985/pdf

43 Nepal, S. and Shrestha, A.B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. International Journal of Water Resources Development, 31, 201–218. URL: https://www.tandfonline.com/doi/full/10.1080/07900627.2015.1030494

44 Tsarouchi, G. and Buytaert, W. (2018). Land-use change may exacerbate climate change impacts on water resources in the Ganges basin. Hydrology and Earth System Sciences, 22, 1411–1435. URL: https://www.hydrol-earth-syst-sci.net/22/1411/2018/hess-22-1411-2018.pdf

45 UNISDR (2014). PreventionWeb: Basic country statistics and indicators. URL:https://www.preventionweb.net/countries [accessed 14/08/2018].

46 Willner, S., Levermann, A., Zhao, F., Frieler, K. (2018). Adaptation required to preserve future high-end river flood risk at present levels. Science Advances: 4:1. URL: https://advances.sciencemag.org/content/4/1/eaao1914

### Cyclones

Cyclone activity remains a large contributor to disaster risk in India, notably along the east coast. Climate change trends are expected to interact with cyclone hazards in complex ways, and known risks include the action of sea-level rise to enhance the damage caused by cyclone-induced storm surges, and the possibility of increased windspeed and precipitation intensity. Storm surges and cyclones have also been known to induce episodes of rapid coastal erosion and further research is needed to understand the vulnerability of India's coastline to this threat (see Mujabar and Chandrasekar, 2013).[47]

Modelling of climate change impacts on cyclone intensity and frequency conducted across the globe point to a general trend of reduced cyclone frequency and increased intensity and frequency of the most extreme events.[48] Research assessing historical cyclone activity in the Bay of Bengal is broadly in line with this expectation. Balaguru et al. (2014) report increased intensity of tropical cyclone activity in the Bay of Bengal over the period 1981–2010, representing an increased threat to communities living along India's east coast.[49] Further research is required to better understand potential changes in cyclone seasonality and routes, and the potential for cyclone hazards to be experienced in unprecedented locations. The risks of coastal impacts related to cyclone and storm surge should be seen in the context of large projected growth in the population of India living in low elevation coastal zones.[50]

# CLIMATE CHANGE IMPACTS

## Natural Resources

### Water

India's main water sources consist of precipitation on the Indian territory and flows, many of which are trans-boundary, originating in neighboring mountain regions. Many of the flows originating in the Himalayas are fed by glacier melt water. Glaciers serve to smooth flows, providing a reliable water source during the dry season. As such, the potential loss of glaciers as a result of climate change and warming is expected to be a significant threat to water resources in India.[51] Precipitation is concentrated in the monsoon season during June to September/October. The unreliability of precipitation, dynamics of social vulnerability, and proliferation of chronically water scarce regions mean that an

[47] Mujabar, P.S. and Chandrasekar, N. (2013). Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. Natural Hazards, 69, 1295–1314. URL: https://ideas.repec.org/a/spr/nathaz/v69y2013i3p1295-1314.html

[48] Walsh, K., McBride, J., Klotzbach, P., Balachandran, S., Camargo, S., Holland, G., Knutson, T., Kossin, J., Lee, T., Sobel, A., Sugi, M. (2015). Tropical cyclones and climate change. WIREs Climate Change: 7: 65–89. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.371

[49] Balaguru, K., Taraphdar, S., Leung, L. R., & Foltz, G. R. (2014). Increase in the intensity of post-monsoon Bay of Bengal tropical cyclones. Geophysical Research Letters, 41(10), 3594–3601. URL: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL060197

[50] Neumann, B., Vafeidis, A.T., Zimmermann, J. and Nicholls, R.J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. PloS one, 10, e0118571. URL: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0118571

[51] Pritchard, H. D. (2017). Asia's glaciers are a regionally important buffer against drought. Nature, 545(7653), 169–174. URL: https://www.ncbi.nlm.nih.gov/pubmed/28492255

estimated 180 million people are already living in chronic (year-round) and severe water scarcity at any given time in India.[52,53] Glacier loss and increases in precipitation extremes have the potential to exacerbate this issue.

The irrigation sector accounts for 83% of India's national fresh water consumption. Changes in key climate variables, namely, temperature, precipitation, and humidity, may have significant long-term implications for the quality and quantity of water for agricultural use. The Government of India's Drought Management Plan suggests an estimated 33% of the nation's landmass is chronically drought prone, with a further 35% having some drought exposure.[54] The projected reduction in the frequency and regularity of wet days, and a decline in dry season runoff, will likely put additional strain on India's agricultural systems and any adverse impact on water availability would threaten food security and the viability and health of ecological assets. The fundamental shift is expected to also affect groundwater supplies, which are already stressed in the northwest and southern areas.[55] An estimated 200,000 people die every year in India due to inadequate water, sanitation and hygiene. In 2016, per person disease burden due to unsafe water and sanitation, was 40 times higher than in China and 12 times higher in Sri Lanka. Pressure on reservoirs and changes to runoff dynamics may also affect power generation in India's hydropower sector. For example, in early 2016, after two years of below average rainfall, India's 91 reservoirs were at just 17% of capacity, leaving 300 million people with water shortages.

## Coastal Zone

India has a long coastline of over 8,000 km, with flat coastal terrain, shallow continental shelf, high population density, geographical location and physiological features of its coastal areas thereby making it extremely vulnerable to cyclones and its associated hazards. Currently, sea levels along the Indian coast are rising. The long-term average of sea level rise is estimated at approximately 1.7 mm/year. However, these are changing at different rates along the Indian coast.[56] Sea levels have risen globally because of the continental ice melt and thermal expansion of ocean water in response to global warming. Sea-level rise in the North Indian Ocean (NIO) occurred at a rate of 1.06–1.75 mm per year during 1874–2004 and has accelerated to 3.3 mm per year in the last two and a half decades (1993–2017), which is comparable to the current rate of global mean sea-level rise. At the end of the twenty-first century, steric sea level in the NIO is projected to rise by approximately 300 mm relative to the average over 1986–2005 under the RCP4.5 scenario, with the corresponding projection for the global mean rise being approximately 180 mm.[57]

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[52] Mekonnen, M., Hoekstra, A. (2016). Four billion people facing severe water scarcity. Science Advances: 2:2. URL: https://advances.sciencemag.org/content/2/2/e1500323

[53] *'Severe water scarcity' is defined as a situation where human demand for 'blue water' (i.e. freshwater) is two or more times greater than blue water availability*

[54] Government of India. (2017) Drought Management Plan. Ministry of Agriculture and Farmers welfare. URL: http://agricoop.nic.in/

[55] Chakraborti, D., Mukherjee, S.C., Pati, S., Sengupta, M.K., Rahman, M.M., Chowdhury, U.K., Lodh, D., Chanda, C.R., Chakraborti, A.K. and Basu, G.K. (2003). Arsenic groundwater contamination in Middle Ganga Plain, Bihar, India: a future danger? Environmental Health Perspectives, 111, 1194–1201. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1241574/

[56] Ministry of Environment, Forest and Climate Change (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. URL: https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

[57] Krishnan, R. et al. (2020). Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. URL: https://www.springer.com/gp/book/9789811543265

Sea surface temperature (SST) of the tropical Indian Ocean has risen by 1°C on average during 1951–2015, markedly higher than the global average SST warming of 0.7°C, over the same period. Ocean heat content in the upper 700 m (OHC700) of the tropical Indian Ocean has also exhibited an increasing trend over the past six decades (1955–2015), with the past two decades (1998–2015) having witnessed a notably abrupt rise. During the twenty-first century, SST and ocean heat content in the tropical Indian Ocean are projected to continue to rise.[58]

Given India's long coastline with many low-lying and densely populated areas, areas are exposed to the slow-onset threat of land loss and erosion due to sea-level rise and also the rapid-onset threat of storm surges, particularly associated with tropical cyclone activity. A growing evidence base assesses the vulnerability of India's coastline to erosion driven by sea-level rise, with studies in regions such as Karnataka state,[59] Tamil Nadu,[42] Andhra Pradesh,[60] and Odisha.[61]

India's coast includes a number of river deltas identified as among the most vulnerable to climate change-induced sea-level rise worldwide. Examples include the Indian portion of the Ganges-Brahmaputra-Meghna Delta, the Mahanadi, the Krishna, the Godavari, and the Brahmani. Collectively these river deltas hold more than 1,200 $km^2$ of land at less than 2 m above sea-level. India also has around 1,238 large and small islands which are also highly vulnerable to the impact of climate change such as sea level rise, rising ocean temperatures, and changing rainfall patterns. Not only are these areas low-lying, and at risk due to sea-level rise and storm surges, but in many areas, human influences are accelerating land-subsidence and the net rate of sea-level rise.[62] River delta regions are areas of high agricultural productivity, important to national food security.

58 Krishnan, R. et al. (2020). Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. URL: https://www.springer.com/gp/book/9789811543265

59 Dwarakish, G. S., Vinay, S. A., Natesan, U., Asano, T., Kakinuma, T., Venkataramana, K., . . . Babita, M. K. (2009). Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state, west coast of India. Ocean & Coastal Management, 52(9), 467–478. URL: https://www.deepdyve.com/lp/elsevier/coastal-vulnerability-assessment-of-the-future-sea-level-rise-in-udupi-xARCjJtl2c

60 Rao, K. N., Subraelu, P., Rao, T. V., Malini, B. H., Ratheesh, R., Bhattacharya, S., . . . Ajai. (2009). Sea-level rise and coastal vulnerability: An assessment of Andhra Pradesh coast, India through remote sensing and GIS. Journal of Coastal Conservation, 12(4), 195–207. URL: https://www.academia.edu/2484456/Sea-level_rise_and_coastal_vulnerability_an_assessment_of_Andhra_Pradesh_coast_India_through_remote_sensing_and_GIS

61 Kumar, T. S., Mahendra, R. S., Nayak, S., Radhakrishnan, K., & Sahu, K. C. (2010). Coastal Vulnerability Assessment for Orissa State, East Coast of India. Journal of Coastal Research, 263(May), 523–534. URL: http://indiaenvironmentportal.org.in/files/Coast%20Orissa.pdf

62 Syvitski, J., Kettner, A., Overeem, I., Hutton, E., Hannon, M., Brakenridge, R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., Nicholls, R. (2011). Sinking deltas due to human activities. Nature Geoscience: 2:681–686. URL: http://www.searchanddiscovery.com/pdfz/documents/2011/70094overeem/ndx_overeem.pdf.html

By the 2070s through to the end of the century, it is estimated that without adaptation, approximately 18 million people will be exposed to sea-level rise induced flooding every year (**Table 5**). In addition to the risk of inundation, sea-level rise and storm surges contribute to the salinization of coastal aquifers, important sources of fresh water for human use.

**TABLE 5.** The Average Number of People Experiencing Flooding Per Year in the Coastal Zone in the Period 2070–2100 Under Different Emissions Pathways (Assumed Medium Ice-Melt Scenario) and Adaptation Scenarios for India[63]

| Scenario | Without Adaptation | With Adaptation |
|---|---|---|
| **RCP2.6** | 5,497, 650 | 8,690 |
| **RCP8.5** | 18,264,640 | 15,630 |

With its long and diverse coastline, India faces a complex set of challenges in effectively adapting to sea-level rise and other coastal climate changes, alongside a rapidly changing development context. Multi-disciplinary approaches will be required, including operationalizing nature-based solutions to coastal erosion. Guidance on tackling these challenges has been set out in a collection of publications on climate resilient coastal protection developed by a collaboration of the Government of India,and other stakeholders.[64]

## Fisheries and Marine Biodiversity

Climate change and human resource exploitation represent a dual threat to fisheries. Changes in temperature, dissolved oxygen, and acidity associated with climate change all impact plankton productivity with cascading effects up the food web. In addition, the loss of coral reefs and the diminishing of their role in the marine ecosystem, fishery productivity and marine biodiversity are threatened.[65] An additional factor for consideration is the potential for marine heat waves. Research has identified the seas around India, notably its western coast, as a global hotspot for climate change impacts on marine heat waves. Marine heat waves are projected to extend their spatial footprint and to grow in duration and intensity.[66] Even under lower emissions pathways (RCP4.5) increases in heat wave duration and intensity are likely to exceed anything experienced by marine ecology within the recent historical record (**Figure 11**).

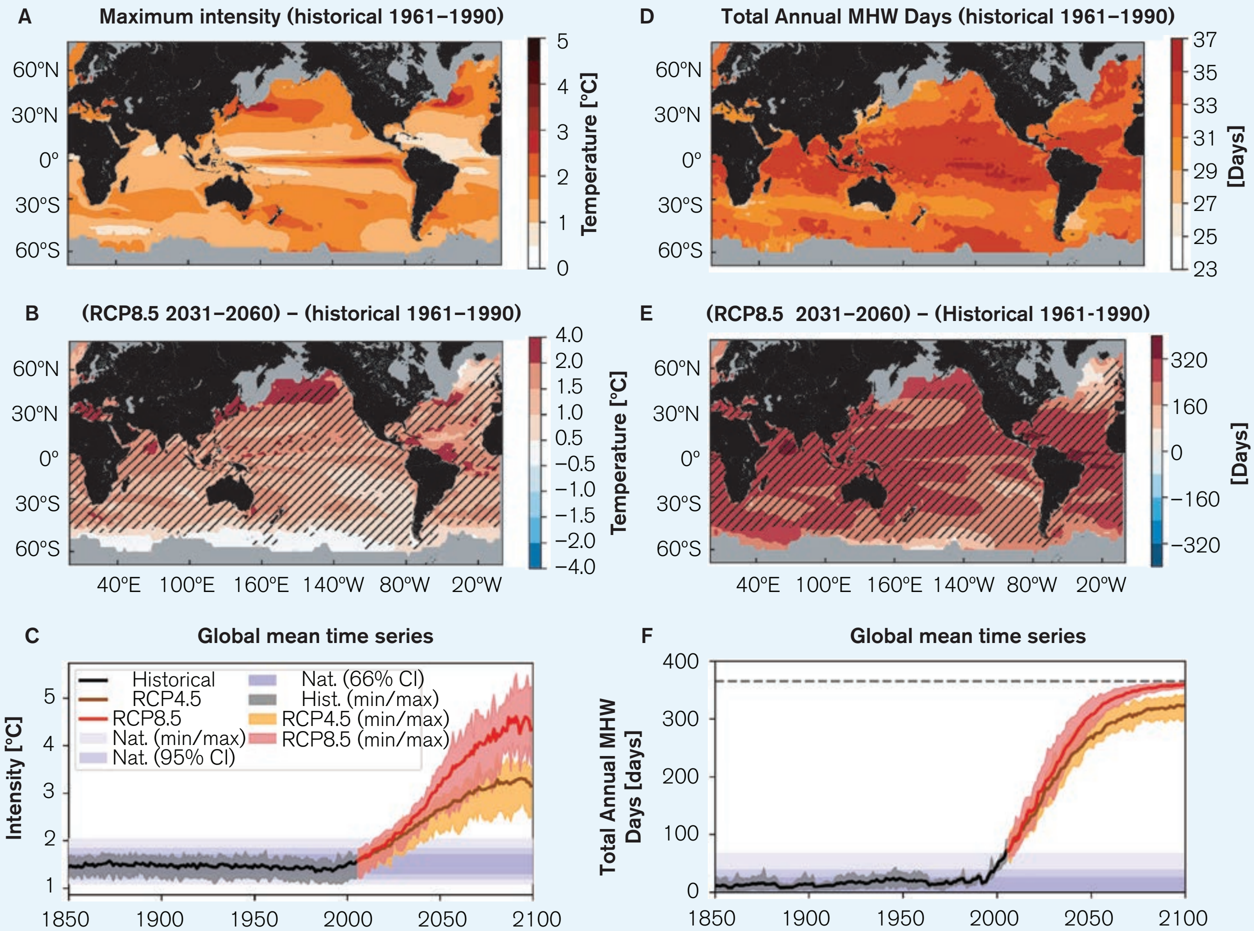
[63] UK Met Office (2014). Human dynamics of climate change: Technical Report. Met Office, UK Government. URL: https://www.metoffice.gov.uk/weather/learn-about/climate-and-climate-change/climate-change/impacts/human-dynamics/index

[64] Government of India et al. (2019). Climate change adaptation guidelines for coastal protection and management in India. URL: http://cwc.gov.in/cpdac/guidelines

[65] FAO (2019). Impacts of climate change on fisheries and aquaculture. Food and Agriculture Organization of the United Nations. URL: http://www.fao.org/3/i9705en/i9705en.pdf

[66] Frölicher, T. L., Fischer, E. M., & Gruber, N. (2018). Marine heatwaves under global warming. Nature, 560(7718), 360–364. URL: https://www.ncbi.nlm.nih.gov/pubmed/30111788

**FIGURE 11.** Projected Changes to Marine Heatwaves (MHWs). (A,D) Multi-Model Mean MHW Properties from the Historical Runs Over 1961–1990. (B,E) Change Between RCP8.5 Run (Averaged Over 2031–2060) and Historical Run (Averaged Over 1961–1990). Hatching Indicates that All Models Agree About the Sign of Change (Corresponding to a 1% Significance Level Based on Binomial Distribution). (C,D) Annual Time Series for Historical (Black), RCP4.5 (Brown), and RCP8.5 (Red) Runs. The Gray, Red and Brown Shaded Regions Show the Maximum Range Between Individual Model Runs. The Blue Shaded Areas Show the Expected Range of Natural Variability Based on a 66% Confidence Interval (Darkest Blue), 95% Confidence Interval (Medium Blue), and Full Min-to-Max Range (Lightest Blue) of the HistoricalNat Runs (1850–2005). Results for Intensity are Shown on the Left (A,B,C) and for Total MHW Days on the Right (D, E, F).[67]




[67] Oliver, E. C. J., Burrows, M. T., Donat, M. G., Sen Gupta, A., Alexander, L. V, Perkins-Kirkpatrick, S. E., . . . Smale, D. A. (2019). Projected Marine Heatwaves in the 21st Century and the Potential for Ecological Impact. Frontiers in Marine Science, 6, 734. https://doi.org/10.3389/fmars.2019.00734.

Declines and changes to marine productivity threaten both livelihoods and subsistence on India's extensive coastline. Barange et al. (2014) identify India as being particularly at risk on the global stage, projecting a potential decline in fish catch due to climate change of almost 10% by the 2050s (this estimate based on the SRES scenario A1B).[68] More recent modelling by the FAO suggests declines of between 10% and 17% by 2050 depending on the emissions scenario.[69] Notably, the coastal and marine sector is a source of valuable fish protein not only for the growing Indian population but also contributes to the global food basket and is a key export commodity for India. The country produced 3.8 million metric tonnes of seafood during 2017, valued at $11.27 billion at the retail level. The fisheries sector supports around 930,000 active and part-time fishers, one of the largest workforce of fishers in the world. Declines in resource availability, and the costs of adapting livelihoods to a new climate and new marine ecosystems are likely to fall hardest on India's poorest communities. Fishing communities around Mumbai are revealing showing the struggles already being faced by more vulnerable groups, noting particularly the challenges faced when small-scale operators lack financial capital.[70]

## Biodiversity and Soil Degradation

India has fragile ecosystems that are highly vulnerable to climate change such as the Himalayan region, western ghats. India's National Mission on Sustaining Himalayan Ecosystem identifies the importance of continuity and enhancing the monitoring of the Himalayan ecosystem, in particular, the state of glaciers and the impact of changes in the glacial mass and its subsequent impact on river flows. It is also identified, under the Mission, to empower local communities through Panchayati Raj institutions, so as to assume greater responsibility for the management of natural resources.[71]

Climate change represents a major threat to biodiversity and abundance of wild species, compounding a global ecological crisis already being driven by other human development impacts. One of the key impacts of climate change will be to force species range shifts. Broadly speaking, moving suitable habitat ranges away from the equator, and upslope. This feature has been demonstrated with the iconic example of the Asian elephant. Research has suggested that under the highest emissions pathway (RCP8.5) the suitable habitat area for the Asian elephant in India and southern Nepal could shrink by as much as 42%, with serious, but less severe, losses under lower emissions pathways.[72] Not only is total habitat size an issue, but also habitat connectivity, efforts will be required to ensure populations can relocate to newly suitable areas, in the process, new conflicts with human society could result. Similar issues of past and future species range shifts and habitat loss have been documented across a wide range of species, for example in fruit trees.[73] Changes are not always negative, some species are expected to experience habitat expansion, such as the Peafowl in Southern India,[74] but careful monitoring and research will be required in order manage the redistribution of pests and invasive species.

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[68] Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., . . . Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Climate Change, 4(3). URL: https://www.nature.com/articles/nclimate2119.pdf

[69] FAO (2019). Impacts of climate change on fisheries and aquaculture. Food and Agriculture Organization of the United Nations. URL: http://www.fao.org/3/i9705en/i9705en.pdf

[70] Senapati, S., & Gupta, V. (2017). Socio-economic vulnerability due to climate change: Deriving indicators for fishing communities in Mumbai. Marine Policy, 76, 90–97. DOI: https://doi.org/10.1016/j.marpol.2016.11.023

[71] Ministry of Environment and Forests (2012). India Second National Communication to the UNFCCC. Government of India. URL: https://unfccc.int/sites/default/files/resource/indnc2.pdf

[72] Kanagaraj, R., Araujo, M. B., Barman, R., Davidar, P., De, R., Digal, D. K., . . . Goyal, S. P. (2019). Predicting range shifts of Asian elephants under global change. Diversity and Distributions, 25(5), 822–838. DOI: 10.1111/ddi.12898

[73] Pramanik, M., Paudel, U., Mondal, B., Chakraborti, S., & Deb, P. (2018). Predicting climate change impacts on the distribution of the threatened Garcinia indica in the Western Ghats, India. Climate Risk Management, 19, 94–105. DOI: https://doi.org/10.1016/j.crm.2017.11.002

[74] Jose V, S., & Nameer, P. O. (2020). The expanding distribution of the Indian Peafowl (Pavo cristatus) as an indicator of changing climate in Kerala, southern India: A modelling study using MaxEnt. Ecological Indicators, 110, 105930. DOI: https://doi.org/10.1016/j.ecolind.2019.105930

Climate change also poses risks to soil, the most fundamental component of terrestrial ecosystems. Research suggests that a large proportion of India's land surface is already experiencing processes which lead to land degradation. Ajai et al. (2009) suggest as much as 32% of the country's area is affected by issues such as salinization, alkalization, water logging, and wind erosion.[75] While land management practices play a very large role, climate change is likely to further to exacerbate these issues, particularly through dryland expansion and desertification processes. Work by Huang et al. (2016) suggests India's central regions are most at risk. Shifts in ecological zones and in particular shifts towards less productive landscapes represent a threat to the biodiversity of India's ecosystems and its agricultural output.[76] Additionally, most of the Himalayan glaciers are retreating and the rates of retreat have probably accelerated in the past few decades, but the observed tendencies are not regionally uniform. The mean rate of retreat is 14.2±12.9 ma –1, but with high levels of uncertainty in the estimates.[77]

# Economic Sectors

## Energy

Climate change is projected to impact both energy supply and demand. On the supply side, the main effects would be on electricity generation, although oil and gas production would also be affected indirectly due to changes in relative economics of fuels under a climate change regime. Hydropower generation is the energy source that is most likely to be impacted because it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting). Reduced flows in rivers and higher temperatures reduce the capabilities of electric generation; high temperatures also reduce transmission capabilities. Increased cloudiness can reduce solar energy production despite the availability of generation capacity. Wind energy production would be reduced if wind speeds increase above or fall below the acceptable operating range of the technology. Changes in photosynthesis and growing conditions could affect the production of biomass-based energy. Energy demand side would also be similarly affected in sectors, specifically, residential, commercial, and transport. Changes in space cooling and heating requirements, and water pumping needs would be the main drivers of energy demand changes.[78]

## Agriculture

Climate change will influence food production via direct and indirect effects on crop growth processes. Direct effects include alterations to carbon dioxide availability, precipitation and temperature. Indirect effects include impacts on water resource availability and seasonality, soil organic matter transformation, soil erosion, changes in pest and disease profiles, the arrival of invasive species, and a decline in arable areas due to the submergence and salinization of coastal lands, and desertification. On an international level, these impacts are expected to damage key staple crop

[75] Ajai, R. R., Arya, A. S., Dhinwa, P. S., Pathan, S. K., & Ganesh Raj, K. (2009). Desertification/land degradation status mapping of India. Current Science, 97(10), 1478–1483. URL: https://www.indiawaterportal.org/articles/desertification-and-land-degradation-status-mapping-india-paper-isro

[76] Huang, J., Yu, H., Guan, X., Wang, G., & Guo, R. (2016). Accelerated dryland expansion under climate change. Nature Climate Change, 6(2), 166–171. URL: https://www.nature.com/articles/nclimate2837

[77] Ministry of Environment, Forest and Climate Change (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. URL: https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

[78] Ministry of Environment and Forests (2012). India Second National Communication to the UNFCCC. Government of India. URL: https://unfccc.int/sites/default/files/resource/indnc2.pdf

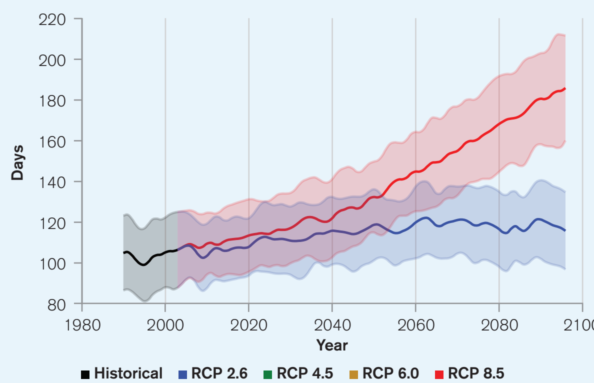
yields, even on lower emissions pathways. Tebaldi and Lobell (2018) estimate 5% and 6% declines in global wheat and maize yields, respectively even if the Paris Climate Agreement is met and warming is limited to 1.5°C.[79] Shifts in the optimal and viable spatial ranges of certain crops are also inevitable, though the extent and speed of those shifts remain dependent on the emissions pathway.

A further, and perhaps lesser appreciated influence of climate change on agricultural production is through its impact on the health and productivity of the labor force. Work by Dunne et al. (2013) suggests that global labor productivity during peak months has already dropped by 10% as a result of warming, and that a decline of up to 20% might be expected by the 2050s under the highest emissions pathway (RCP8.5).[80] Increased heat stress will also impact livestock rearing, affecting both productivity levels and the viable range of species and varieties. Thermal humidity index is projected to increase in all the regions, especially in the months of May and June, leading to stress to the livestock and hence a reduction in milk production.[81] In combination, it is highly likely that the above processes will have a considerable impact on national food consumption patterns both through direct impacts on internal agricultural operations, and through impacts on the global supply chain.

Nearly two-thirds of India's population depends directly or indirectly on the agricultural sector for their livelihoods. As nearly 60% of the cultivated area is rain-fed agriculture (i.e. without irrigation), the agricultural production is strongly influenced by climate variability and particularly the behavior of the south-west monsoon. The productivity of crops varies greatly over space and time, with the primary determinant being the patterns of monsoon rainfall, a factor which is sufficiently influential as to be detectable in regional economic productivity.

The food and nutritional security of India currently depends, to a great extent, on the production of cereals, primarily wheat and rice. Almost one third of India's land area is utilized for cereal production, generating almost 300 million tons per year, as of 2017.[82] The general trend in precipitation seen in climate models, indicates fewer wet days, more intense extreme events, and an increase in the number of very hot days (**Figure 12**) is likely to have a negative impact on Indian food security. Estimates between models vary greatly, but some models reported by the FAO (2015) identify large deficits in India's ability to meet internal demand for cereals, in the order of several

**FIGURE 12.** Projected Annual Average Number of Hot Days (>35°C) in India Under Two Emissions Pathways, RCP2.6 (Blue) and RCP8.5 (Red) The Values Shown Represent the Median of the Multi-Model Ensemble with the Shaded Areas Showing the 10–90th Percentiles (Historical Reference Period, 1986–2005).[25]




[79] Tebaldi, C., & Lobell, D. (2018). Differences, or lack thereof, in wheat and maize yields under three low-warming scenarios. Environmental Research Letters: 13: 065001. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aaba48
[80] Dunne, J. P., Stouffer, R. J., & John, J. G. (2013). Reductions in labor capacity from heat stress under climate warming. Nature Climate Change, 3(6), 563–566. URL: http://www.precaution.org/lib/noaa_reductions_in_labour_capacity_2013.pdf
[81] Sirohi, S., & Michaelowa, A. (2007). Sufferer and cause: Indian livestock and climate change. Climatic Change, 85(3), 285–298. URL: https://link.springer.com/article/10.1007%2Fs10584-007-9241-8
[82] World Bank (2020). Cereal Production (metric tons): India. World Bank data portal. URL: https://data.worldbank.org/

million-ton shortage.[83] As reported in Chapter 7 of the IPCC's AR5 report (2014), studies suggest a negative outlook particularly for production of wheat, maize, sorghum, and rice, all major staples. Notably, the increase in the frequency of very hot days during the growing seasons of wheat and maize in central India is expected to result in significant yield declines, even on lower emissions pathways.[59] Some mitigation may be achieved through enhancement of crop varieties, improved management practices, and infrastructure, but it is likely that large-scale range shifts of appropriate crop and climate combinations are likely to take place. Some crops in India, such as banana, are likely to be no longer be viable in their current region of plantation due to temperature rises.[62]

## Urban

The industrial and service sector economies contained within India's many large urban conglomerations are central to the nation's success, providing livelihoods to a large and rapidly growing population and supporting state revenue generation. These potential impacts of climate change are complex for India's urban landscapes. Specifically, unplanned urbanization has led to increased vulnerability to natural disasters; overburdened drainage, frenzied and unregulated construction, buildings constructed without paying any heed to the natural topography and hydro-geomorphology lead to higher instances of urban flooding. Climate change impacts such as rising average temperatures and more frequent extreme weather events will only add to this vulnerability. Increasing urban population and incomes have also led to increased generation of solid and liquid waste by households and industry; due to inadequate treatment and disposal, these become significant sources of GHG emissions, nearly 4% of the total emissions of the country. Many of the changes in natural hazard exposure will be relevant in urban areas, particularly in coastal zones. Increasing heat stress represents another major impact. Research has established a reasonably well constrained relationship between heat stress and labor productivity, household consumption patterns, and (by proxy) household living standards.[84]

The effects of temperature rise and heat stress in urban areas are increasingly compounded by the phenomenon of the Urban Heat Island (UHI) effect. Dark surfaces, residential and industrial sources of heat, an absence of vegetation, and air pollution[85] can push temperatures higher than those of the rural surroundings, commonly anywhere in the range of 0.1°C–3°C in global mega-cities.[86] For example, Borbora and Das (2014) document UHI of over 2°C in Guwahati city.[87] As well as impacting on human health (see Communities) the temperature peaks that will result from combined UHI and climate change, as well as future urban expansion, are likely to damage the productivity of the industrial and service sector economies, both through direct impacts on labor productivity, but also through the additional costs of adaptation. Research suggests that on average, a one-degree increase

83 FAO (2015). Climate change and food systems: Global assessments and implications for food security and trade. Food and Agriculture Organization of the United Nations (FAO), Rome. URL: http://www.fao.org/3/a-i4332e.pdf

84 Mani, M., Bandyopadhyay, S., Chonabayashi, S., Markandya, A., Mosier, T. (2018). South Asia's Hotspots: The Impact of Temperature and Precipitation changes on living standards. South Asian Development Matters. World Bank, Washington DC. URL: https://openknowledge.worldbank.org/bitstream/handle/10986/28723/9781464811555.pdf?sequence=5&isAllowed=y

85 Cao, C., Lee, X., Liu, S., Schultz, N., Xiao, W., Zhang, M., & Zhao, L. (2016). Urban heat islands in China enhanced by haze pollution. Nature Communications, 7, 1–7. URL: https://www.nature.com/articles/ncomms12509

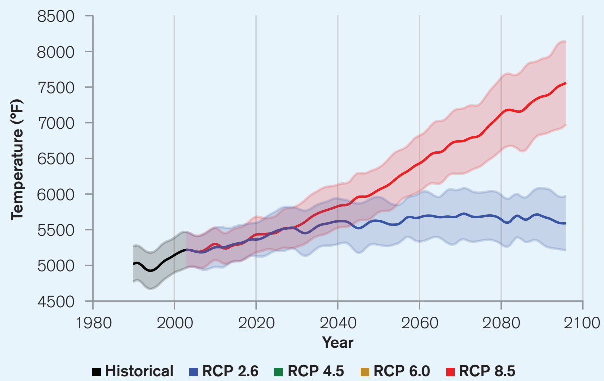
86 Zhou, D., Zhao, S., Liu, S., Zhang, L., & Zhu, C. (2014). Surface urban heat island in China's 32 major cities: Spatial patterns and drivers. Remote Sensing of Environment, 152, 51–61. URL: https://www.researchgate.net/publication/263283084_Surface_urban_heat_island_in_China's_32_major_cities_Spatial_patterns_and_drivers

87 Borbora, J. and Das, A.K. (2014). Summertime urban heat island study for Guwahati city, India. Sustainable Cities and Society, 11, 61–66. URL: https://www.semanticscholar.org/paper/Summertime-Urban-Heat-Island-study-for-Guwahati-Borbora-Das/ca25a670478e4119d84ab1894d519ab7619fc7af

in ambient temperature can result in a 0.5%–8.5% increase in electricity demand.[88] Notably this serves business and residential air-cooling systems. This increase in demand places strain on energy generation systems which is compounded by the heat stress on the energy generation system itself, commonly due to its own cooling requirements, which can reduce its efficiency.[89]

With average summer temperatures already reaching over 30°C in many of India's population centers, rising temperatures, particularly at the levels projected by higher emissions pathways, represent major risks to human and ecosystem health, as well as economic productivity. As shown in **Figure 13**, a substantial increase in the amount of required building cooling is projected, placing demands either on energy systems or on health systems depending on the efficacy of the response. Infrastructure will likely come under pressure, both from temperatures and the increased risk of riverine (fluvial) and surface water (pluvial) flooding.

**FIGURE 13.** Historic and Projected Annual Cooling Degree Days in India (Cumulative Degrees Above 65°F) Under RCP2.6 (Blue) and RCP8.5 (Red). The Values Shown Represent the Median of the Multi-Model Ensemble with the Shaded Areas Showing the 10–90th Percentiles[25] (Historical Reference Period, 1986–2005).




A further consideration relating to rising urban temperatures is its interaction with air pollution. Many of India's cities suffer with extremely high levels of air pollution, indeed, 16 Indian cities feature in the top 50 cities by annual mean concentrations of particulate matter (PM10) pollution in the World Health Organization's Global Urban Ambient Air Pollution Database.[90] This feature has significant harmful public health effects, including increased mortality rates, as demonstrated globally,[91] and in Indian cities such as Delhi.[92] A key climate concern is the interaction between air quality and rising temperatures. While the research base is complex and sometimes inconsistent, the current weight of scientific evidence suggests higher temperatures amplify the negative health affects of poor air quality.[93] This highlights a significant health risk to India's urban populations in particular.

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[88] Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review. Energy and Buildings, 98, 119–124. URL: https://pdfs.semanticscholar.org/17f8/6e9c161542a7a5acd0ad500f5da9f45a2871.pdf

[89] ADB (2017). Climate Change Profile of Pakistan. Asian Development Bank. URL: https://www.adb.org/sites/default/files/publication/357876/climate-change-profile-pakistan.pdf

[90] WHO (2016). Global Urban Ambient Air Pollution Database URL: https://www.who.int/airpollution/data/cities-2016/en/

[91] Anenberg, S. C., Achakulwisut, P., Brauer, M., Moran, D., Apte, J. S., & Henze, D. K. (2019). Particulate matter-attributable mortality and relationships with carbon dioxide in 250 urban areas worldwide. Scientific Reports, 9(1), 11552. DOI: 10.1038/s41598-019-48057-9

[92] Maji, S., Ahmed, S., Siddiqui, W. A., & Ghosh, S. (2017). Short term effects of criteria air pollutants on daily mortality in Delhi, India. Atmospheric Environment, 150, 210–219. URL: https://www.sciencedirect.com/science/article/abs/pii/S1352231016309281?via%3Dihub

[93] Lou, J., Wu, Y., Liu, P., Kota, S. H., & Huang, L. (2019). Health Effects of Climate Change Through Temperature and Air Pollution. Current Pollution Reports, 5(3), 144–158. DOI: https://doi.org/10.1007/s40726-019-00112-9

Another aspect to note is that many of the steps required for reducing greenhouse gas emissions also act to reduce air pollution, i.e. provide a 'co-benefit', an example includes the shift away from fossil fuel-burning private vehicles. One study has suggested that the necessary steps required to limit global warming to 2°C would progressively reduce the number of premature deaths resulting from air pollution in India, and in 2050 could be sufficient to prevent as many 450,000 premature deaths.[94]

# Communities

## Poverty and Inequality

Of the total geographical area in India, approximately 70% of the area is under arid, semi-arid, and dry sub-humid regions. The western parts of Rajasthan and Kutch are arid, and might be regarded as chronically drought affected and the region spanning the Indo-Gangetic Plain also experiences frequent drought and water shortage. The coasts of India are regularly affected by cyclones, and associated impacts such as high winds, rainfall and storm surge. The East Coast is especially vulnerable to cyclonic storms and the states of Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal are significantly affected. India is also affected by frequent floods, leading to loss of life, poverty and spread of disease, as well as agricultural, property, and infrastructural losses. In economic terms, flooding is the most significant contributor to the average annual losses in India, accounting for approximately $7.4 billion, or 76%, of the total $9.8 billion annual loss estimated by UNISDR (2014).[40] However, as discussed above, other models suggest the UNISDR estimate may be a significant underestimate, linked to underreporting and lack of consideration of very low-level hazard impacts. Multiple factors amplify disaster risk in India, notably social vulnerability, with almost 150–200 million people remaining undernourished and high levels of exposure driven by unplanned development in risk-prone zones.

Recent progress on tackling poverty can be measured in India through reductions achieved in the percentage of the population who are undernourished (from 20.5% in 2004–2006 to 14.0% in 2017–2019).[95] However, other indicators point to the continued vulnerability of the Indian population, such as estimates that approximately one billion people face some form of water scarcity at least one month every year[47] and that high levels of multidimensional poverty prevail (41% in 2011/12).[96] The most impacted will be the marginal farmers, the coastal communities, low-income families, and forest communities with an inordinate higher impact on women and girl children and under privileged groups. Many of the climate changes projected are likely to disproportionately affect the poorest groups in society. As discussed, Bihar, Uttar Pradesh, and West Bengal face particularly significant increases in flood risk. A ranking of 19 of India's states conducted in 2011 estimated that these states are among the lowest on the Human Development Index, ranked 18th (Bihar), 13th (Uttar Pradesh), and 9th (West Bengal), respectively.[97] In addition,

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[94] Xie, Y., Dai, H., Xu, X., Fujimori, S., Hasegawa, T., Yi, K., . . . Kurata, G. (2018). Co-benefits of climate mitigation on air quality and human health in Asian countries. Environment International, 119, 309–318. DOI: 10.1016/j.envint.2018.07.008

[95] FAO, IFAD, UNICEF, WFP, WHO (2020) The state of food security and nutrition in the world. Transforming food systems for affordable healthy diets. FAO. Rome. URL: http://www.fao.org/documents/card/en/c/ca9692en/

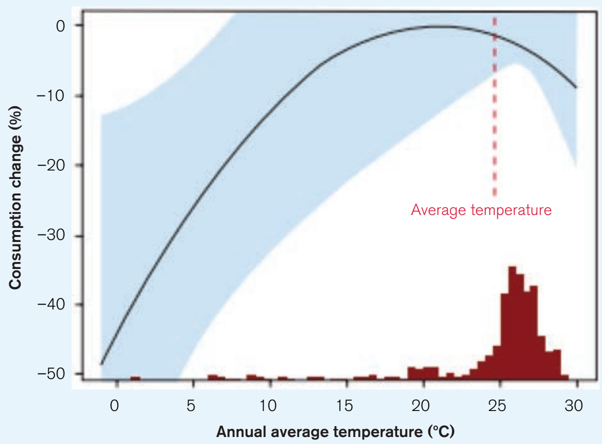
[96] OPHI (2018). Global MPI Winter 2017/2018. URL: https://ophi.org.uk/multidimensional-poverty-index/global-mpi-2016/ [accessed 20/08/2018].

[97] Suryanarayana, M.H., Agrawal, A., Seeta Prabhu, K. (2016). Inequality-adjusted Human Development Index: States in India. Indian Journal of Human Development: 10: 157–175. URL: https://journals.sagepub.com/doi/abs/10.1177/0973703016675793

heavy manual labor jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress.[98] Poorer businesses are least able to afford air conditioning, an increasing need given the projected increase in cooling days, and poorer farmers and communities are least able to afford local water storage and irrigation infrastructure and hence are most vulnerable to water stress. One lens through which to view the impact of change is through the correlation of consumption patterns with temperature. Work by Mani et al. (2018) describes this relationship, and particularly the way consumption (used as an indicator of living standards) drops off past a certain threshold temperature.[63]

Income levels, and aspects of multidimensional poverty and inequality restrict consumption levels in India. However, the work by Mani et al. (2018) also suggests that India's average temperature is already higher than the optimal level for maximum productivity (**Figure 14**) and that further increases, through their impact on the productivity of labor (particularly linked to health issues), may further reduce consumption and living standards.[63] Mani et al. (2018) identify a particular hotspot in central India, predominantly spanning Madhya Pradesh and Chhattisgarh, where declines in living standards due to temperature increases are expected to be strongest. The southern and coastal regions are less affected by declines in living standards associated with temperature increases, although these regions face different risks (such as storm surge) which will damage living standards.

**FIGURE 14.** The Relationship Between Temperature and Consumption in India, Shaded Areas Represent 90% Confidence Intervals. Black Line Shows the Relationship Between Temperature and Consumption and the Optimum Temperature (Around 21°C) at which No Consumption is Lost.[99]




## *Gender*

An increasing body of research has shown that climate-related disasters have impacted human populations in many areas including agricultural production, food security, water management and public health. The level of impacts and coping strategies of populations depends heavily on their socio-economic status, socio-cultural norms, access to resources, poverty as well as gender. Research has also provided more evidence that the effects are not gender neutral, as women and children are among the highest risk groups. Key factors that account for the differences between women's and men's vulnerability to climate change risks include: gender-based differences in time use; access to assets and credit, treatment by formal institutions, which can constrain women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change.[100]

[98] Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016). Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. Annual Review of Public Health: 37: 97–112. URL: https://www.ncbi.nlm.nih.gov/pubmed/26989826

[99] Mani, M., Bandyopadhyay, S., Chonabayashi, S., Markandya, A., Mosier, T. (2018). South Asia's Hotspots: The Impact of Temperature and Precipitation changes on living standards. South Asian Development Matters. World Bank, Washington DC. p. 5, c. URL: https://openknowledge.worldbank.org/bitstream/handle/10986/28723/9781464811555.pdf?sequence=5&isAllowed=y

[100] World Bank Group (2016). Gender Equality, Poverty Reduction, and Inclusive Growth. URL: http://documents1.worldbank.org/curated/en/820851467992505410/pdf/102114-REVISED-PUBLIC-WBG-Gender-Strategy.pdf

## Human Health

### *Nutrition*

In 2015, the World Food Program estimated that, without adaptation action, the risk of hunger and child malnutrition on a global scale could increase by 20% by the 2050s.[101] Even with adaptation action, it is likely that excess deaths will result. Further research is required to better understand the potential implications in India. The FAO (2015) estimates that around one third of the population is at risk of not being able to meet their protein requirements. Emerging evidence suggests the impact of increased $CO_2$ on the nutritional content of cereals is likely to reduce the protein and mineral content; see FAO (2015) for further analysis.[62] The increased risk of climate-related disasters such as drought and storm surge threaten food production and hence food security and consumption, river delta regions are particularly important regions for agricultural production and are especially exposed to climate hazards. Work by Springmann et al. (2016) has assessed the potential for excess, climate-related deaths associated with malnutrition.[102] The authors identify two key risk factors which are expected to be the primary drivers: (i) a lack of fruit and vegetables in diets, and (ii) health complications caused by increasing prevalence of people underweight. India will be particularly affected in absolute terms, with 26% of all global deaths caused by this reduction in food availability projected to occur within the country. They also project that there could be approximately 104 climate-related deaths per million linked to lack of food availability in India by mid-century under RCP8.5. This estimate does not include the impact of the potential climate-related changes to the nutritional content of food identified by FAO.[62]

### *Heat-Related Mortality*

Research has placed a threshold of 35°C (wet bulb ambient air temperature) on the human body's ability to regulate temperature, beyond which even a very short period of exposure can present risk of serious ill-health and death.[103] Temperatures significantly lower than the 35°C threshold of 'survivability' can still represent a major threat to human health. Climate change will push global temperatures closer to this temperature 'danger zone' both through slow-onset warming and intensified heat waves. The potential for heat wave events which result in mass mortality, such as the event seen across India in 2015 which resulted in at least 2,500 deaths, will grow. The Heat Index risk is of particular concern for southern India through the end of the century. India has large, densely populated, and vulnerable populations facing high risk of heat-related mortality. Studies suggest even just a 0.5°C increase in mean summer temperatures may increase the probability of a mass heat-related mortality event (i.e. an event resulting in greater than 100 deaths) from 13% to 32%.[104] Considerably larger magnitudes of temperature increase are projected for India under all emissions pathways. Work by Honda et al. (2014), which utilized the CMIP3 projections (A1B), estimates that without adaptation, annual excess heat-related deaths in the South Asian region, will increase by 160% by 2030 and 276% by 2050.[105] Murari et al. (2015) highlight the significant benefits of achieving a lower

[101] WFP (2015). Two minutes on climate change and hunger: A zero hunger world needs climate resilience. The World Food Program. URL: https://docs.wfp.org/api/documents/WFP-0000009143/download/

[102] Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H. C. J., Gollin, D., . . . Scarborough, P. (2016). Global and regional health effects of future food production under climate change: a modelling study. The Lancet: 387: 1937–1946. URL: https://www.ncbi.nlm.nih.gov/pubmed/26947322

[103] Im, E. S., Pal, J. S., & Eltahir, E. A. B. (2017). Deadly heat waves projected in the densely populated agricultural regions of South Asia. Science Advances, 3(8), 1–8. URL: https://advances.sciencemag.org/content/3/8/e1603322

[104] Mazdiyansi, O., Aghakouchak, A., Davis, S., Madadgar, S., Mehran, A., Ragno, E., Mojtaba, S., Sengupta, A., Ghosh, S., Dhanya, C.T., Niknejad, M. (2017). Increasing probability of mortality during Indian heat waves. Science Advances: 3:6. URL: https://www.ncbi.nlm.nih.gov/pubmed/28630921

[105] Honda, Y., Kondo, M., McGregor, G., Kim, H., Guo, Y-L, Hijioka, Y., Yoshikawa, M., Oka, K., Takano, S., Hales, S., Sari Kovats, R. (2014). Heat-related mortality risk model for climate change impact projection. Environmental Health and Preventive Medicine 19: 56–63. URL: https://www.ncbi.nlm.nih.gov/pubmed/23928946

emissions pathway, suggesting that by the 2070s and 2090s, there will be approximately double the number of heat-related deaths under RCP8.5 in contrast to RCP2.6.[106]

Further regional-level analysis of potential growth in heat-related mortality has been conducted by the World Health Organization.[107] The research reports heat-related deaths in absolute terms based on UN population projections and the A1B climate change scenario, this reflects only one of many plausible futures. Under these conditions (and without adaptation) the WHO model suggested an additional 22,000 heat-related deaths by the 2030s and an additional 63,000 by the 2050s in the South Asia Region. These deaths are heavily concentrated in the Indo-Gangetic Basin. See Matthews et al. (2017) for further analysis of the potential risks to India's many large urban areas of chronic heat stress induced by climate change.[33] Cities at risk include Kolkata, Mumbai, Delhi, Chennai, Ahmedabad, Surat, Hyderabad, Pune, and Bangalore.

### *Disease*

Research indicates that projected climate changes are likely to extend the range and window of transmission of key vector-borne diseases considerably, notably in the case of malaria and dengue fever. Recent efforts have been successful in reducing the proliferation of these diseases but preparations will nevertheless be needed to mitigate the potential spread of disease into new areas, such as the region of Himachal Pradesh.[108] Climate change pressures, such as increased incidence of extreme rainfall and flooding, as well as higher temperatures, represent environmental drivers of leptospirosis suggesting increased future transmission risks.[109] These pressures may also increase the risk of other water-borne disease, such as diarrheal disease. Diarrheal disease is a very significant health risk to children in India. UNICEF estimates that around 100,000 children under five years of age died as a result of diarrheal disease in 2016.[110] This represents around 9% of under five deaths in India, and just under 20% of the global total attributable to diarrheal disease. Modelling by WHO estimates the change in the number of diarrheal deaths in individuals under fifteen years of age, is projected to increase by around 5–15% by the 2030s and to increase by around 10–20% by the 2050s.[79]

## Migration

Research by the World Bank Group suggests that South Asia will experience an estimated 17 to 36 million internal climate migrants by 2050 as a result of slow-onset climate changes due to rising temperatures, agricultural challenges, and changing precipitation patterns, among others.[111] The range in this estimate reflects different future development pathways with differing levels of emissions reduction and inequality in development outcomes. Under

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[106] Murari, K. K., Ghosh, S., Patwardhan, A., Daly, E., & Salvi, K. (2015). Intensification of future severe heat waves in India and their effect on heat stress and mortality. Regional Environmental Change, 15(4), 569–579. URL: https://research.monash.edu/en/publications/intensification-of-future-severe-heat-waves-in-india-and-their-ef

[107] WHO (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. World Health Organization. URL: https://apps.who.int/iris/bitstream/handle/10665/134014/9789241507691_eng.pdf?sequence=1&isAllowed=y

[108] Dhiman, R., Pahwa, S., Dhillon, G.P.S., Dash, A. (2010). Climate change and threat of vector-borne disease in India: Are we prepared? Parasitology Research: 106: 763–773. URL: https://www.ncbi.nlm.nih.gov/pubmed/20155369

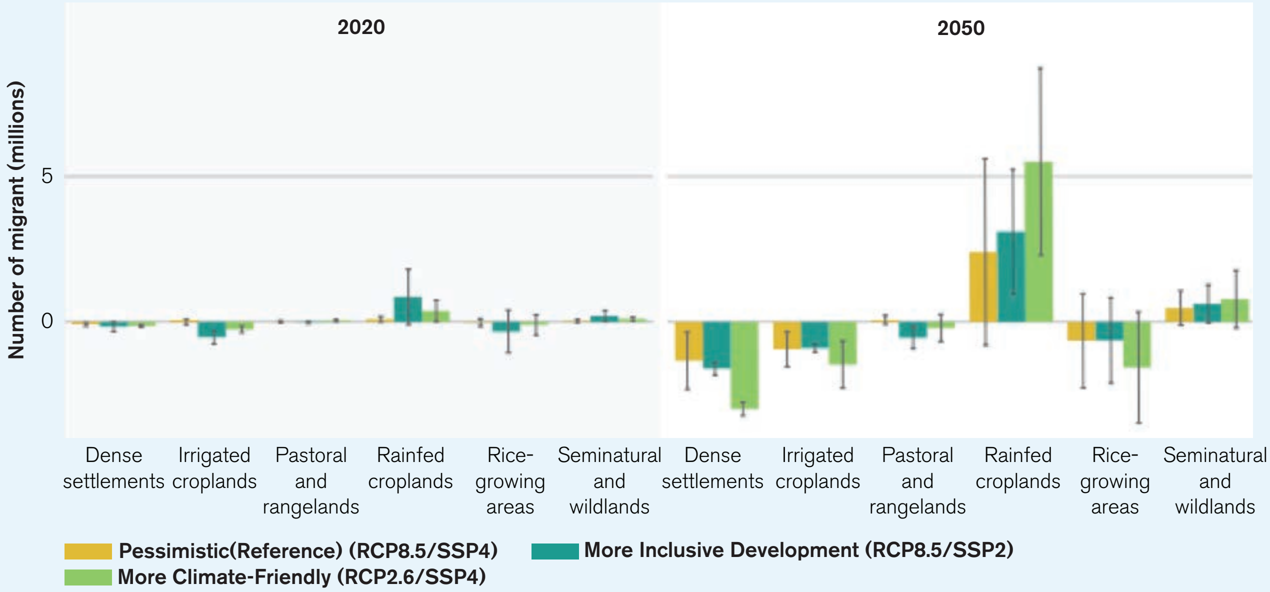
[109] Lau, C. L., Smythe, L. D., Craig, S. B., & Weinstein, P. (2010). Climate change, flooding, urbanization and leptospirosis: Fuelling the fire? Transactions of the Royal Society of Tropical Medicine and Hygiene, 104(10), 631–638. URL: https://www.ncbi.nlm.nih.gov/pubmed/20813388

[110] UNICEF (2019). Data: Diarrhoeal Disease. URL: https://data.unicef.org/topic/child-health/diarrhoeal-disease/ [accessed 29/01/2019].

[111] Rigaud, K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McClusker, B., Heuser, S., Midgley, A. (2018). Groundswell: Preparing for internal climate migration. World Bank Group, Washington DC. URL: http://documents.worldbank.org/curated/en/846391522306665751/pdf/124719-v2-PUB-PUBLIC-docdate-3-18-18WB-ClimateChange-Final.pdf

all scenarios, the poorest and most climate-vulnerable communities are likely to be hardest hit. Without significant mitigation action, beyond mid-century, the climate-induced migration rate is likely to accelerate considerably. It is expected that 'hotspots' of in and out-migration are likely to form. The highlands between Chennai and Bangalore are likely to become particular hotspots of in-migration, as well as some parts of northwest India[83]. Out-migration is expected to be strongest from the northern regions of the Indo-Gangetic plain, the corridor between Delhi and Lahore, and coastal metropolitan areas around Mumbai and Chennai. As shown in **Figure 15**, the large majority of migrants are expected to come from communities dependent on rain-fed croplands for their livelihoods (see Rigaud et al., 2018 for detailed discussion).

**FIGURE 15.** Projected Net Climate Migration In and Out of Livelihood Zones in South Asia Under Three Scenarios (2020 and 2050), Positive Values Indicate Outmigration, from Rigaud et al. (2018)[112]




Rigaud et al (2018) establish migration as an effective adaptation strategy, if well planned and supported by upskilling and job creation and conducted with sensitivity to the impacts on the communities already living in receiving areas.[83] Climate-induced migration remains a poorly understood area, and investment is needed to understand push and pull factors, where hotspots may form, and how communities might be supported in different local contexts. Research can support governance which embeds migration across sectoral planning.

[112] Rigaud, K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McClusker, B., Heuser, S., Midgley, A. (2018). Groundswell: Preparing for internal climate migration. World Bank Group, Washington DC. p. 95. URL: http://documents.worldbank.org/curated/en/846391522306665751/pdf/124719-v2-PUB-PUBLIC-docdate-3-18-18WB-ClimateChange-Final.pdf

## National Adaptation Policies and Strategies

- Third Biennial Update Report (2021)
- Second Biennial Update Report (2018)
- National Disaster Management Plan (2016)
- Intended Nationally Determined Contribution (INDC) (2016)
- First Biennial Update Report (2015)
- Second National Communication (2012)
- National Action Plan on Climate Change (2008)
- Initial National Communication (2004)
- State Action Plans on Climate Change

## Climate Change Priorities of the WBG

### *WBG Country Partnership Framework*

According to the WBG's Country Partnership Framework (CPF) with India (FY18–FY22) the World Bank Group will support the Government of India's climate mitigation and adaptation efforts across the portfolio. The WBG will support India's efforts to address climate change through a mix of climate-focused operations and across CPF objectives. In addition, the WBG will work with the private sector to support the development of market mechanisms to tap private sector financing and knowhow to tackle India's climate change-related challenges (**Table 6**).[113]

**TABLE 6.** The World Bank Group Will Support India Across Several CPF Objectives and Interventions.

| Focus Area | Objectives | Interventions |
|---|---|---|
| **Promoting Resource-Efficient Grow** | 1. Promote more resource-efficient, inclusive, and diversified growth in the rural sector.<br>2. Improve the livability and sustainability of cities in select states.<br>3. Improve management systems for controlling air pollution.<br>4. Increase access to sustainable energy.<br>5. Improve disaster risk management. | • Facilitate large increases in renewable power generation.<br>– A $220 million loan and an $80 million guarantee to support the India Energy Efficiency Scale-Up Program;<br>– Installing 175 GW of RE capacity by 2022, including 750 MW Rewa solar park in Madhya Pradesh; and<br>– Partnering with the State Bank of India to provide US$625 million financing for up to 40MW of grid-connected rooftop solar generation.<br>• Promotion of electrification of transport.<br>• Adopting climate resilient agricultural practices.<br>– Climate smart agriculture in Tamil Nadu and Maharashtra.<br>• Disaster preparedness efforts will include technical support to develop resilient infrastructure.<br>• IFC will lead key, innovative, proof-of-concept climate change interventions with the private sector. |

[113] World Bank Group (2018). India - Country Partnership Framework for the Period FY18-FY22 (English). Washington, D.C.: World Bank Group. URL: http://documents.worldbank.org/curated/en/277621537673420666/India-Country-Partnership-Framework-for-the-Period-FY18-FY22.

CLIMATE RISK COUNTRY PROFILE

# INDIA

WORLD BANK GROUP