CLIMATE CHANGE AND INDIA
ADAPTATION GAP (2015)
A Preliminary Assessment

Authors

Amit Garg | Vimal Mishra | Hem H. Dholakia

IIM AHMEDABAD

Indian Institute of Technology Gandhinagar

CEEW Council on Energy, Environment & Water

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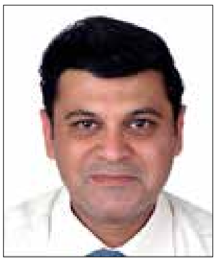
November 2015

When citing this report the following citation should be used:

Amit Garg, Vimal Mishra and Hem Dholakia, 2015. *Climate Change and India: Adaptation Gap (2015) - A Preliminary Assessment.* Working paper of Indian Institute of Management Ahmedabad (IIMA) W.P. No. 2015-11-01.

About the Authors



Amit Garg is Professor at the Indian Institute of Management Ahmedabad (IIMA). He specializes in energy, climate change and sustainable development issues. His current research interests include greenhouse gas emission estimation and projections, carbon finance, energy policy, vulnerability assessment and adaptation policy due to climate change, and aligning climate change with sustainable development. He has co-authored six books, 20 international research reports and published extensively in international peer-reviewed journals. Prof Garg was awarded Distinguished Young Professor Award for Excellence in Research at IIMA in 2010. He was also a member of the Nobel Peace Prize winning IPCC team in 2007. The Prime Minister of India Dr Manmohan Singh felicitated Prof Garg for his outstanding contribution to climate change research.

amitgarg@iimahd.ernet.in, +91 79 66324952

Vimal Mishra is an Assistant Professor in the Civil Engineering Discipline at Indian Institute of Technology (IIT) Gandhinagar. Before joining IIT Gandhinagar, he completed PhD from Purdue University and Postdoctoral Fellowship from the University of Washington, Seattle. Dr. Mishra received National Environmental Science Fellowship from the Ministry of Environment and Forest (MoEF) and Varahamihir Earth Science Fellowship from the Ministry of Earth Sciences (MoES), Government of India. He was also awarded with JSPS postdoctoral fellowship, Purdue Climate Change Research Center Fellowship, and German Academic Exchange Fellowship (DAAD) previously. He is an active reviewer of Nature, Nature Climate Change, Scientific Report, Geophysical Research Letters, Water Resources Research and many other scientific journals. He was awarded the Research Excellence Award by IIT Gandhinagar in 2015.

vmishra@iitgn.ac.in, +91 9687944337

Hem H. Dholakia is a Research Associate with the Council of Energy, Environment and Water. His research addresses the linkages between energy, environment, human health and public policy. Specifically, it understands health impacts of urban air pollution, heat and cold waves to develop mitigation strategies and adaptation measures. He was the recipient of the Young Scientist Summer Award in 2012 at the International Institute of Applied Systems (IIASA), Austria. Hem has published six papers in International peer-reviewed journals; contributed to two book chapters as well as the LIMITS (2014) India report. In addition, he is the co-author of a book titled "Energy-Emissions Trends and Policy Landscape in India". Hem holds a PhD from the Indian Institute of Management (Ahmedabad); Master's in Exercise Science from University of Brighton (UK) and Bachelor's in Physiotherapy from Seth G.S. Medical College.

hem.dholakia@ceew.in, +91 9999042464

अशोक लवासा
ASHOK LAVASA, IAS

सत्यमेव जयते

सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
Secretary
Government of India
Ministry of Environment, Forest and Climate Change

Foreword

India is a Party to the United Nations Framework Convention on Climate Change (UNFCCC). The objective of this multilateral treaty is to stabilize the concentrations of greenhouse gases of anthropogenic origin in the atmosphere at safer level. The Government of India has recently submitted India's Intended Nationally Determined Contributions (INDCs) to the UNFCCC towards implementation of the commitments enshrined in the Convention. Indian INDCs highlight India's concerns due to adverse impacts of climate change being faced now and in future by the Indian people, natural resources and ecosystems, other living beings, and various infrastructure. India has been contributing positively and constructively to the UNFCCC objectives through the National Action Plan on Climate Change (NAPCC), its several missions as well as the State Action Plans.

The current scientific assessments on the impact of the projected climate change suggest that developing countries are likely to be more adversely affected. India was third most affected country in 2013 due to climate risk as per the briefing paper- Global Climate Risk Index 2015. The UNEP Adaptation Gap Report (2014) had concluded that "even if global greenhouse gas emissions are cut to the level required to keep global temperature rise below 2°C this century, the cost of adapting to climate change in developing countries is likely to reach two to three times the previous estimates of $70-100 billion per year by 2050".

At the national level, the assessment of vulnerability and adaptation needs to be carried out comprehensively. There is an urgent need of enhancing capacity in this area. Moreover, there is also a need to comprehensively map the current adaptation measures, gaps and policy actions required in future. I am happy to note this initiative of mapping adaptation gap for India taken within the programme framework of the INDCs and NAPCC.

Supporting and enhancing sustainable development of 1.25 billion people is at the heart of Indian adaptation gap filling strategy. The fruits of development should not be lost due to increasing adaptation gap in future. Developed countries have to come forward under the principle of common but differentiated responsibilities and respective capabilities as enshrined in the Convention, to provide new and additional financial resources and technology transfers for filling India's adaptation gap.

I commend the authors of this working document "Climate Change and India: Adaptation Gap (2015)" for putting together various financial, technological and capacity building needs of India, as well as documenting the Indian efforts to manage the adverse impacts of climate change being faced by India. The contents of the contributions presented here reflect the deep insight of authors on this complex subject.

I am sure that the working document will serve as a useful reference to all concerned and interested users, both nationally and internationally in providing an updated status of knowledge on the subject. It, being a working document, provides an opportunity to the experts to give comments and share feedback.

Issue of climate change is complex, especially the concept of adaptation. The preliminary assessment enshrined in this working document is also intended to generate an informed debate with a view to crystallizing and refining the extant knowledge and understanding on adaptation needs in India. I trust that the publication will be of interest to all concerned.

(Ashok Lavasa)

Place: New Delhi
Date: November 24, 2015

इंदिरा पर्यावरण भवन, जोर बाग रोड़, नई दिल्ली-110 003 फोन : (011) 24695262, 24695265, फैक्स : (011) 24695270

INDIRA PARYAVARAN BHAWAN, JOR BAGH ROAD, NEW DELHI-110 003 Ph. : (011) 24695262, 2465265, Fax : (011) 24695270
E-mail : secy-moef@nic.in, alavasa@nic.in, Website : moef.gov.in

सुशील कुमार
अपर सचिव
SUSHEEL KUMAR, IAS
Additional Secretary

सत्यमेव जयते

भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
नई दिल्ली - 110003
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FORESTS & CLIMATE CHANGE
NEW DELHI-110003

Preface

It is unequivocally recognized that climate change is the most significant global environmental challenge of this century. Notwithstanding the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, the scientific assessments have continued to warn about plausible futures with varying degrees of climate change. There is now a growing recognition of the vulnerability of natural and human systems to the projected future climate changes and the need for developing strategies to adapt to the changing climate. The multilateral negotiations till date have however paid greater attention to the control of greenhouse gas emissions that cause the climate change. The prominence of emissions mitigation in global negotiations has obscured the importance of vulnerability and adaptation, loss and damage.

In this context, it is important to note that in the Copenhagen Commitments (2009), the world leaders agreed to keep the increase in global temperature below 2 degrees Celsius between pre-industrial times and 2100, on the basis of equity and in the context of sustainable development, enhancing the long-term cooperative action to combat climate change. The Cancun Agreement (2010) strengthened this resolve to limit the global temperature increase below 2 degrees Celsius over the pre-industrial levels. The Durban Outcome (2011) stressed that, even if the two-degree scenario is met, developing countries, especially the poorest and most vulnerable, will still need much more support to adapt to the change that is already embedded in the global climate system. The Warsaw Agreement (2013) resolved to bind nations together into an effective global effort to reduce emissions rapidly enough to chart humanity's longer-term path out of the danger zone of climate change, while building adaptation capacity. The last Conference of Parties (COP) at Lima (COP-20, 2014) agreed on elevating adaptation onto the same level as the curbing and cutting of greenhouse gas emissions.

The present working document analyses changes in climatic patterns observed in India, and projects future climate change using high resolution projections from a multi-model ensemble. The authors have studied the proactive measures that the Government of India is taking to adapt to the adverse impacts of climate change.

Adaptation gap is perceived as a dynamic concept in this working document. The analysis has highlighted financial, technological, institutional and capacity building needs to fill the adaptation gaps for India.

I appreciate the commitment of the authors and am sure that the document would be of interest to various international and national audiences for further research in the area. I also hope that it would receive constructive criticism from experts that would help in refining the document further.

(Susheel Kumar)

इंदिरा पर्यावरण भवन, जोर बाग रोड, नई दिल्ली-110 003 फोन : 011-24695242, फैक्स : 011-24695260
INDIRA PARYAVARAN BHAWAN, JOR BAGH ROAD, NEW DELHI-110 003 Ph. : 011-24695242, Fax : 011-24695260
E-mail : asmef.susheel@gov.in

Acknowledgements

"Climate Change and India: Adaptation Gap (2015)" was conceived to understand the adaptation to climate change India is already doing, and would have to do in future under projected climate change. This work was possible due to the support and inputs of several people. The future climate change projections also include analysis of the latest modeling data released by NASA.

The authors acknowledge senior officials of Ministry of Environment, Forest and Climate Change for providing policy focus to our research enquiry, engagement and encouragement.

The authors acknowledge data availability from the CMIP5 models and the CORDEX South Asia regional climate models (RCMs). Authors acknowledge help from Bridget Thrasher (NASA NEX) in statistical downscaling and bias correction of the CMIP5 model output. Preparation of visuals from Reepal Shah, PhD student with the Indian Institute of Technology Gandhinagar, is greatly appreciated. The authors are grateful for the research assistance provided by Jaypalsinh Chauhan, Bhushan Kankal, Parmeswaran Iyer and Shrutika Parihar. Part of this work was presented at the Vulnerability and Adaptation workshop in New Delhi on October 28, 2015 and benefited from inputs from several Indian experts.

While numerous researchers and officials provided excellent support and encouragement to the research leading to this report, the responsibility for the contents solely rests with the authors.

Authors

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Executive Summary

Climate change is projected to have severe adverse impacts on India's population, natural eco-systems, and socio-economic parameters. India's vulnerability to climate change impacts is profound since around 650 million Indians are dependent on rain-fed agriculture for their livelihoods; around 250 million Indians live along a 7500 km of coastline that is at high risk due to sea level rise and extreme weather events; many of the 10,000-odd Indian glaciers are receding at a rapid rate; and deforestation is happening.

India is concerned about climate change impacts.

India occupies 2.4% of the global land area, supports 17% of the global population and contributes less than 4% of global greenhouse gas emissions. Sustainable development is at the core of Indian planning process and India has been making huge efforts for enhancing the quality of life of her people including sustained poverty alleviation efforts. The number of people below poverty line has declined from 469 million to about 388 million during 2005 to 2010. Even then roughly three-fourths of Indian population lives below a daily income of US$ 2 (PPP). This also highlights the extent of number of people who are vulnerable to adverse impacts of a changing climate.

India has submitted the Intended Nationally Determined Contributions to UNFCCC on October 1, 2015 highlighting a strong GHG mitigation plan until 2030 and also providing a glimpse into national vulnerability to adverse impacts of climate change across regions and sectors. According to IPCC AR5, adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. The below 2^{o}C target also unequivocally includes reducing the combined and cumulative risks of mitigation and adaptation actions. The Lima COP-20 (2014) agreed on elevating adaptation onto the same level as the curbing and cutting of greenhouse gas emissions. This report analyzes the climate change that is already occurring in India, projected future climate change, the proactive measures Government of India is taking to adapt to the adverse impacts of climate change, and the Adaptation Gap that is ever increasing.

India has experienced substantial changes in mean and extreme climate during the period of 1951-2013. For instance, mean annual air temperature has increased in many regions of the country. Other than the mean annual air temperature, prominent increase was observed in the number of hot days, night-time temperature, and growing degree days during the period of 1951-2013. Figure 1 indicates the regions that are experiencing temperatures equivalent to various RCPs currently. Based on our analysis, around 36 districts (5.5% of land area or ~36 million people) are observing temperatures equivalent to Representative Concentration Pathway 8.5(warming of 4°C+)., 65 districts (11% of land area or ~65 million people) RCP6 (warming of 3°C-4°C), 346 districts (59% of land area or ~704 million people) RCP4.5(warming of 2°C -3°C) and the remaining 190 (24.5% of land area or ~405 million people) districts RCP2.6 (warming of 2°C). The RCP are internationally accepted scenarios to project climate change. Similary for precipation, these numbers are 63% area for RCP 8.5, 2.6% area for RCP 6, 24% area for RCP 4.5 and 11% area for RCP 2.6. 35 districts are facing the highest risk facing due to enhanced temperature now (following profiles similar to RCP 8.5). These are Aizawl, Baran, Bhilwara, Bundi, Cachar, Champhai, Chandel, Chittaurgarh, Churachandpur, Darrang, Dhalai, East Garo Hills, East Kameng, Guna, Hailakandi, Jaipur, Jhalawar, Karimganj, Kolasib, Kota, Lalitpur, Lawngtlai, Lunglei, Mamit, North Tripura, Papum Pare, Sagar, Saiha, Sawai Madhopur, Serchhip, Sheopur, Shivpuri, Sivasagar, South Tripura and West Tripura. There are 408 districts for similar profile for precipitation and this are spread across various states of India. 22 districts which are following RCP 8.5 profile for both temperature and precipitation together are Aizawl, Baran, Bhilwara, Bundi, Cachar, Champhai, Chandel, Chittaurgarh, Churachandpur, Dhalai, East Garo Hills, Hailakandi, Jhalawar, Karimganj, Kolasib, Kota, Lunglei, Mamit, North Tripura, Serchhip, South Tripura and West Tripura.

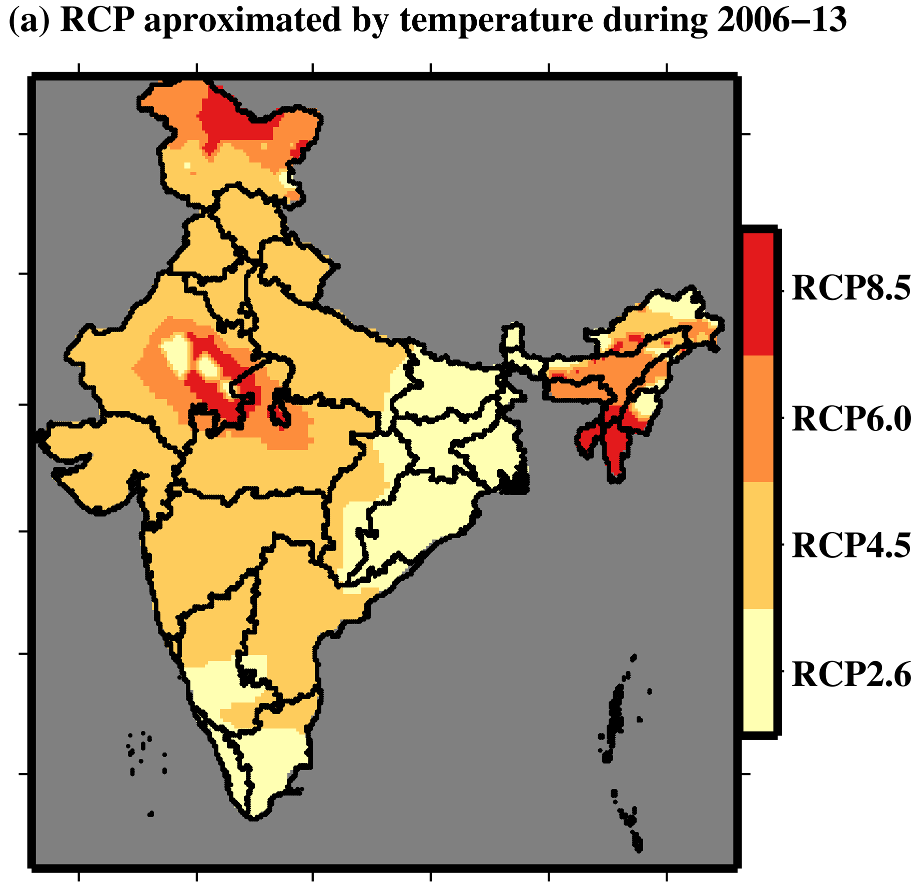


Figure 1: Representative Concentration Pathway (RCP) approximated during 2006-2013 based on change in mean annual temperature for each grid cell.

The monsoon season precipitation declined in many regions (western ghats, Gangetic Plain, and central India) during the period of 1951-2013. The monsoon season precipitation became more erratic leading to some of the most severe and widespread droughts during the recent decades (very severe in 2002, 2009, and 2015). The increased frequency of droughts pose challenges to food security and water management in India. Droughts during the monsoon season of 2015 led to water crisis in many regions of the country (notably Maharashtra, Karnataka, and Uttar Pradesh). Additionally, the monsoon season droughts that have increased during the recent decades posed tremendous socioeconomic challenges in many regions of the country.

High resolution (0.25 degree) downscaled and bias corrected climate change projections showed that India is projected to experience 1-1.5°C increase in mean annual air temperature in the Near (2016-2045) term climate. On the other hand, multimodel ensemble mean annual air temperature is projected to increase by 2-3 °C by the Mid-21st century. Multimodel ensemble mean projections indicate that India is projected to witness substantial increases in night-time temperature and growing degree days, which may have profound implications for agriculture and crop production.

Moreover, frequency of temperature extremes (hot days and hot nights) is projected to increase significantly under the projected future climate.

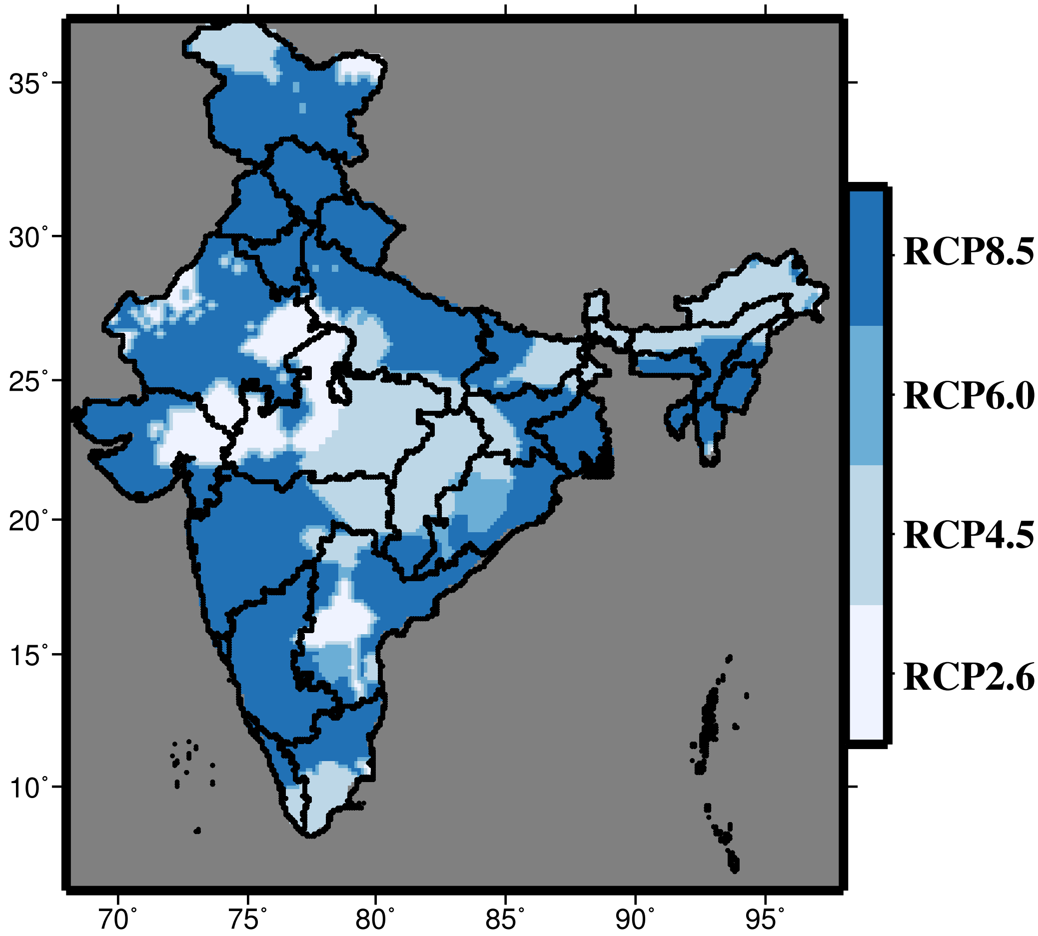


Figure 2: RCP path already followed for precipitation during 2006-2013.

Projected increase in extreme precipitation events may cause enormous damage to infrastructure and also result in flooding, which in turn may affect crop production and other socioeconomic aspects in India. Meteorological droughts are projected to decline under the future climate due to increase in the monsoon season precipitation. However, frequency of droughts is projected to increase in the Near (2016-2045) term under the RCP 4.5 scenario. Results indicated that despite projected increase in air temperature, drought risks in India under the future climate cannot be ignored. Moreover, the soil moisture variability that affected agricultural production is likely to be changed by the projected warming in India in the non-monsoon season, which will pose challenges for irrigation water management under the projected future climate.

We find that the Government of India is consistently committing resources through the annual Union Budgets towards public spending on climate change adaptation. We observe that over the last ten years, the overall budget outlay has increased by a factor of four (from 2003-04 to 2014-15). On the other hand, development and adaptation related outlays have increased by a factor of five. This implies that rate of growth of government allocation to development and building adaptive capacity has been increasing steadily over the years, much faster than that of overall annual budgets. The public spending on adaptation last year was INR 2130 billion i.e. 12% of the budget for the year (~2% of GDP). Various state governments contributed another INR 3100 billion through their state budget for similar activities. In addition to the overall development expenditure for enhancing adaptation to climate change, we identified twenty-one (from a total of sixty-six) Central Government Schemes that are directly related to climate change adaptation. The total commitment for these 21 schemes (actual expenditure as per revised estimates for 2013-14) was INR 740 billion during 2013-14 or 0.7% of GDP. The total spending therefore on developing adapting capacity & adaptation was INR 5970 billion (around US $ 91.8 billion) in 2013-14. The Loss and Damage from extreme events were estimated additional at US $ 5-6 billion in that year.

The report identifies preliminary financial, technology, knowledge gaps in adaptation, as well as capacity building and institutional needs.

Our analysis highlighted the deep financial, technological, institutional and capacity building needs to fill the Adaptation gap for India. The financial needs could be upto US $ 360 billion in 2030 and beyond in case we ride RCP 8.5 pathway. In real terms, the Adaptation gap for India could be over a trillion US$ from now until 2030. It could increase substantially beyond 2030. Technologies needed for adaptation could be both simple and advance. We provide a preliminary listing of the same. Climate change projections for India showed that the new and robust adaptation strategies will be required in the sectors of agriculture, water resources, and public health under the future climate. New approaches to assess projected losses in economy and infrastructure are needed that can be used to estimate adaptation gap at local scale.

The adaptation dividend would not be visible to India until 2040 by our assessment. That is, whatever global action on GHG mitigation, India would have to rely more of enhanced adaptation efforts to keep the adverse impacts of climate change within acceptable limits for the vast vulnerable populations and eco-systems. Of course India is standing with the global community on GHG mitigation and has promised a strong action on mitigation through her INDCs, including one of the most ambitious renewable energy programmes in the world. However supporting and enhancing sustainable development of 1.25 billion people is at the heart of Indian adaptation gap filling strategy. The fruits of development should not be lost due to increasing Adaptation Gap in future. Developed countries have to come forward, under Common but Differentiated responsibilities paradigm (CBDR), to provide additional financial resources and technology transfers for filling India's Adaptation Gap. As decided in the last COP at Lima (2014), adaptation has to be elevated onto the same level as the curbing and cutting of greenhouse gas emissions.

Chapter 1

Introduction and Framework

Electricity access and affordability is a major adaptation concern

1. Introduction and Framework

1.1 Introduction

According to the Copenhagen Commitments (2009) by world leaders, "to achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below $2^{O}C$, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change. We recognize the critical impacts of climate change and the potential impacts of response measures on countries particularly vulnerable to its adverse effects and stress the need to establish a comprehensive adaptation programme including international support". The Cancun Agreement (2010) strengthened this resolution to limit the global temperature increase below $2^{O}C$ over the pre-industrial levels. The Durban Outcome (2011) stressed that, even if the two-degree scenario is met, developing countries, especially the poorest and most vulnerable, will still need much more support to adapt to the change that is already embedded in the global climate system. The Warsaw Agreement (2013) agreed to bind nations together into an effective global effort to reduce emissions rapidly enough to chart humanity's longer-term path out of the danger zone of climate change, while building adaptation capacity. The Lima COP 20 (2014) agreed on elevating adaptation onto the same level as the curbing and cutting of curbing greenhouse gas emissions. Manuel Pulgar-Vidal, the Minister of the Environment of Peru and the COP-20 President, said "Lima has given new urgency towards fast tracking adaptation and building resilience across the developing world—not least by strengthening the link to finance and the development of national adaptation plans" (http://newsroom.unfccc.int/lima/lima-call-for-climate-action-puts-world-on-track-to-paris-2015/).

Climate change is projected to have severe adverse impacts on India's population, natural eco-systems, and socio-economic parameters. India's vulnerability to climate change impacts is profound since around 650 million Indians are dependent on rain-fed agriculture for their livelihoods; around 250 million Indians live along a 7500 km of coastline that is at high risk due to sea level rise and extreme weather events; many of the 10,000-odd Indian glaciers are receding at a rapid rate; and deforestation is happening. India occupies 2.4% of the global land area, supports 17% of the global population and contributes less than 4% of global greenhouse gas emissions. Sustainable development is at the core of Indian planning process and India has been making huge efforts for enhancing the quality of life of her people including sustained poverty alleviation efforts. The number of people below poverty line has declined from 469 million to about 388 million during 2005 to 2010. Even then roughly three-fourths of Indian population lives below a daily income of US$ 2 (PPP). This also highlights the extent of number of people who are vulnerable to adverse impacts of a changing climate.

India is much concerned about climate change impacts.

According to IPCC AR5, adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. The below $2^{o}C$ target also unequivocally includes the combined and cumulative risks of mitigation and adaptation actions. These risks however are over different time scales – with adaptation risks being faced now.

For instance, the global insurance industry, the largest industry in the world at total direct premiums of about 4.8 trillion US$ in 2014 (over double the Indian GDP), had insured losses due to natural disasters in the United States alone in the first half of 2015 at $12.6 billion, well above the $11.2 billion average in the first halves of 2000 to 2014, according to a July 2015 presentation by Munich Re and the Insurance Information Institute (http://www.iii.org/fact-statistic/catastrophes-us). In Canada, claims on the insurance industry reached $3.2-billion in 2013, after floods, hail and ice storms caused devastating damage across the country, (http://www.theglobeandmail.com/report-on-business/economy/severe-weather-leads-to-record-32-billion-in-insurance-payouts/article16405099/). This is roughly twice the next highest year on record and a tenfold increase from the losses sustained a decade ago. Similarly in the UK, the wettest winter on record is likely to result in £446 million being paid in insurance claims to customers whose homes, businesses, and vehicles were flooded during the two-month period 23 December 2013 to 28 February 2014 (https://www.abi.org.uk/News/News-releases/2014/03/6-7-million-a-day-in-insurance-claims-from-customers-hit-by-the-recent-flooding).

The estimate for a single heavy rain event in Uttarakhand, India in 2013 is estimated cost US $ 1.1 billion economic losses (EMDAT, 2015).

The subsequent sections provide a framework to assess the Adaptation Gap.

1.2 What is Adaptation to climate change?

The changing climate is posing unprecedented challenges to existing human and economic activities, natural ecosystems, and man-made ecosystems in many ways. *Firstly*, it is creating new risks for their existence as well as safe and economically viable operations. For instance, infrastructure assets are planned with some visibility of magnitude and type of potential climate-induced risks (Hallegatte, 2009). However due to climate change, new dimensions are being added to the risk profile of these assets. Climate is changing the conceptual basis of risks and some specific risks may become more critical for the asset in future, which are either not visible today or do not hold importance in the basket of risks that the asset currently faces (Stern, 2007). *Secondly,* climate change appears to exacerbate the existing risks faced today. For example, higher variability in the Indian monsoons and temperature profiles temporally and spatially could make certain crops uncultivable in present form at locations where they are being cultivated presently. Similarly floods and droughts could become more uncertain and severe. *Thirdly*, climate change threatens the usable life span of assets, products and even services. Regulatory or product and technology risks could make the asset redundant sooner than the planned lifespan or physical risks could reduce the usable life of the asset (Peter & Grimm, 2008). Tourism services face major uncertainty due to changing weather conditions and unpredictable weather at tourist destinations during peak tourist seasons. *Finally,* it creates allied risks that arise out of disruptions in network of infrastructure such as supply chain risks (Schenker-Wicki, Inauen, & Olivares, 2010).

In human systems, the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities is normally termed as Adaptation. In natural systems, this process of adjustment to actual climate and its effects, and human interventions that may facilitate adjustment to expected climate is called Adaptation. Adaptation is supposed to reduce risks and enhance resilience of natural and man-made systems towards adverse impacts of climate change.

Risks can only be managed and cannot be completely eliminated. The palliative financial burden, as discussed in subsequent chapters and demonstrated through an example of Uttrakhand tragedy in north India during June 2013, could be huge and economic implications can only be evaluated till the first or the second order and therefore the total indirect palliative impacts may be lower than the actual losses that many sectors and regions may face. Therefore, the choice of right adaptation practices may not always be easy to determine as the costs are unambiguous. The preventive costs may therefore many a times appear to be infructuous. Further, the concave nature of (preventive and palliative) adaptation cost curve could also mean that the relationships between prevention costs and palliative damage costs due to an event may be directly related or inversely related, depending upon the type of investment and its purpose under discussion. For instance, construction of a dam to avoid drought is a preventive mechanism and some expenditure would be required for the same. But if drought does happen subsequently, one may have to spend on palliative damages as well. The palliative costs may be high at times due to food grain prices going up on supply-demand shortages etc. It may appear that the expenditure on building the dam was infructuous in the first place as it did not prevent droughts from occurring. This also shows a direct relationship between preventive and palliative costs as expenditure is required to restore the damages due to an event for which some preventive expenditure was already made. On the other hand, the same dam may also be used as a flood prevention mechanism. In such a situation, if it does present floods from occurring, palliative costs would be minimum, indicating an inverse relationship between preventive and palliative costs.   Consequently, it becomes important to plan for potential climate-induced risks keeping in view the other factors like the time frame for results in case of a particular adaptive practice or costs for inducing the adaptive measure, what all types of risks the practice covers etc.

According to IPCC AR5 report of WG-2, benefits from adaptation therefore can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. However economic impact estimates completed over the past 20 years vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and many other factors. With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income (±1 standard deviation around the mean; medium evidence, medium agreement). Losses are more likely than not to be greater, rather than smaller, than this range (limited evidence, high agreement). Additionally, there are large differences between and within countries. Losses accelerate with greater warming (limited evidence, high agreement) (IPCC, 2014).

1.3 What is Adaptation Gap?

The UNEP Adaptation Gap (2014) defines it generically as the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts, and reflecting resource limitations and competing priorities. Developing countries such as India have national targets on development with poverty alleviation, education, health, energy, water, and provision of infrastructure being among the top priorities. These are mostly aligned with the Millennium Development Goals (MDGs) for 1990-2015 and also the Sustainable Development Goals for 2015-2030. Resource limitations and competing priorities put constraints on achieving these goals. Changing climate dynamically interacts with these goals and may or may not adversely impact them. Adaptation gap therefore is perceived as a dynamic concept in this report.

Strong mitigation actions today could reduce the climate change induced impacts on various systems after a few years. Uncovered mitigation gap today, could therefore lead to a larger adaptation gap in longer-term. However it should also be noted that any mitigation action today will not be able to fill the adaptation gap in short to medium-terms, which have been caused by unbridled GHG emissions from Annex-1 countries in the past. It would only reduce the adaptation gap in the longer-term. That is the adaptation dividend of current mitigation actions would be realized in future. Therefore common but differentiated responsibility (CBDR) paradigm of climate actions under UNFCCC does not only require more mitigation by developed countries now so that the world does not face much adverse consequences in future, but also more support by them to developing and least developed countries to fill their present adaptation gaps.

Apart from this time gap between mitigation induced impact reductions achieved in future and impacts occurring now that would need adaptation, adaptation is also locale specific as against a more global character of mitigation. One million tons of GHG emissions mitigated in a developed country would have the same mitigating effect of one million tons of GHG emissions mitigated in a developing country due to fungibility of mitigation actions. But one million litres of additional potable water made available to a water-affluent location will have much less positive externalities than one million litres of potable water made available to a water-starved region. Adaptation actions, and therefore actions to reduce Adaptation Gap, have to be very locale specific.

The most vulnerable communities and systems, in all probabilities, would not have contributed to their present climate misery due to their almost miniscule GHG emissions in the past. They may not be even aware of the global reasons of the climate impacts they have to face today and tolerate without any choice. Therefore tolerable impacts[1] should ideally not be included as part of the adaptation that is already occurring for they may be involuntary, and should ideally be included in the Adaptation Gap. Someone is already paying to bridge this gap – may be the individuals concerned themselves or their governments – both should not be ideally doing it under a Common But Differential Responsibility (CBDR) paradigm. Examples for involuntary tolerated adaptation could be the adverse impacts due to changed excessive heat wave patterns in a developing country.

We define the various adaptation needs through a risk coverage paradigm, rather than a simple gap based relationship.

1.4 Adaptation Gap and Adaptation Dilemma

We consider the decisions on how much climate change impact risks are acceptable and how much are not acceptable. The unacceptable risks constitute Adaptation Gap (Figure 1.1). Therefore determining the right balance between preventive and palliative adaptation measures determines the Adaptation Gap. For any society, there remains a range of risks that are acceptable. What constitutes as acceptable risk is a function of several factors that include level of development, preparedness, resources, norms and values that any society places on goods, services and human life. Beyond this range of acceptable risks, societies are faced with the possibility of being impacted in an unacceptable way. Such impacts have damage costs associated with them and are typically unacceptable to a society.

Risk coverage depends upon resources available and competing priorities. The unacceptable risks may be due to lack of understanding of those risks currently, or lack of available resources to cover those risks, or due to a conscious decision to tolerate those risks, or a combination of these. *The Adaptation Gap is basically risks that one would like to cover but is unable to cover.* Tolerated risks are therefore generally considered part of the Adaptation Gap if they indicate forced and involuntary choices. The risk coverage process induces *Adaptation Dilemma* that is how much risks are acceptable and how much are not. The latter may or may not be covered given the resources available and their opportunity costs.

Climate change adaptation measures heavily depend on the risk perceptions and management strategy to cover these risks. Managing all risks through adaptation could be an expensive proposition. For instance, according to the 12th Five-Year Plan of the Government of India (2013), adaptation costs for new infrastructure could be in the range of 3–10 per cent of the total

[1]Sometimes including some Acceptable risks as well since the boundary between acceptable and unacceptable risks depends upon individuals and their circumstances. This is the concept of Adaptation Dilemma, discussed later.

investment, although for certain sectors and locations this may be higher. The number for existing infrastructure is likely to be as high as 25 per cent of their present construction costs (Planning Commission, 2013), and could therefore run into trillions of dollars. We discuss these issues in subsequent chapters.

Excessive adaptation and prior over estimation of risks leads to a *type 1* or *α error*. It means that one plans for some event but it does not take place. In our earlier example, this could be building a dam for drought prevention, but the drought does not happen. The decision to build a dam may therefore be looked as infructuous in hindsight, since it could be difficult to estimate potential losses that could have occurred if a drought would have happened, especially depending upon its intensity and time of occurrence, both of which are hypothetical in this case.

On the other hand, under investment in risk mitigation and adaptation strategies leads to a *type 2* or β error, that is, one does not plan for an event to occur, but it occurs. In the example above, one does not built any dams thinking that no droughts or floods would occur, but they do occur. The palliative damages could be very high in such a situation. Under adaptation means that risk assessment may have been inadequate.

Therefore, nations invest in mitigating risk e.g. building a wall to prevent flooding associated with sea level rise. These investments are borne by individual actors, groups of individuals or governments as preventive costs. However, it often happens that not all risk can be covered. This uncovered risk can be classified into three types – uncovered risk, residual risk and intolerable risk. Each of these risks is associated with an increasing set of palliative damage costs and requires different mechanisms to mitigate the same. The first would generally have a palliative cost. These could be transferred to a third party but at a high premium, which may not be acceptable to the affected party since *α error* exists. The residual risks are generally involuntary and have damage costs. The Intolerable risks have huge costs, including deaths and migrations. The decision about the quantum of risk to be covered (i.e. acceptable versus unacceptable) and the associated resource investment is termed as the 'Adaptation Dilemma'. The policy dilemma therefore is how much to invest a priory in adaptation. Climate proofing natural or manmade systems does not mean that all possible risks are eliminated; it just implies that they have been made more resilient towards climate-induced risks. Thus the adaptation dilemma revolves around choosing an acceptable level of risk from a wide spectrum and covering the unacceptable risks appropriately.

1.5 Adaptation Gap is a dynamic concept

It must also be recognised that the Adaptation Gap is dynamic in nature and is based upon possible future transitions – both climate change parameters and resilience of the population and various eco-systems. Future climatic parameters could shift towards right with a changed mean, a changed distribution, or a combination of both. For instance, current rainfall distribution may just shifts towards right (Figure 1.2) retaining its distribution pattern. If we assume that the resilience of populations and various eco-systems do not change over time, then the Adaptation Gap would increase in future. In case the distribution also changes with much higher variance (Figure 1.3), the Adaptation Gap could be much larger in future. Therefore, gap analysis must be a periodic exercise based on the most recent science.

Moreover as various RCPs could manifest in future, the Adaptation Gaps would be different under alternate RCPs. For instance, the Adaptation gap under RCP 8.5 scenario would be much more than that under an RCP 2.6 scenario.

Since nations have to hedge for the worst possible impacts, the adaptation policies and measures may have to be ready for RCP 8.5 extremes. This also means that more and more resources have to be committed to adaptation and as per CBDR, more and more resources have to flow to developing countries and emerging economies from developed countries.

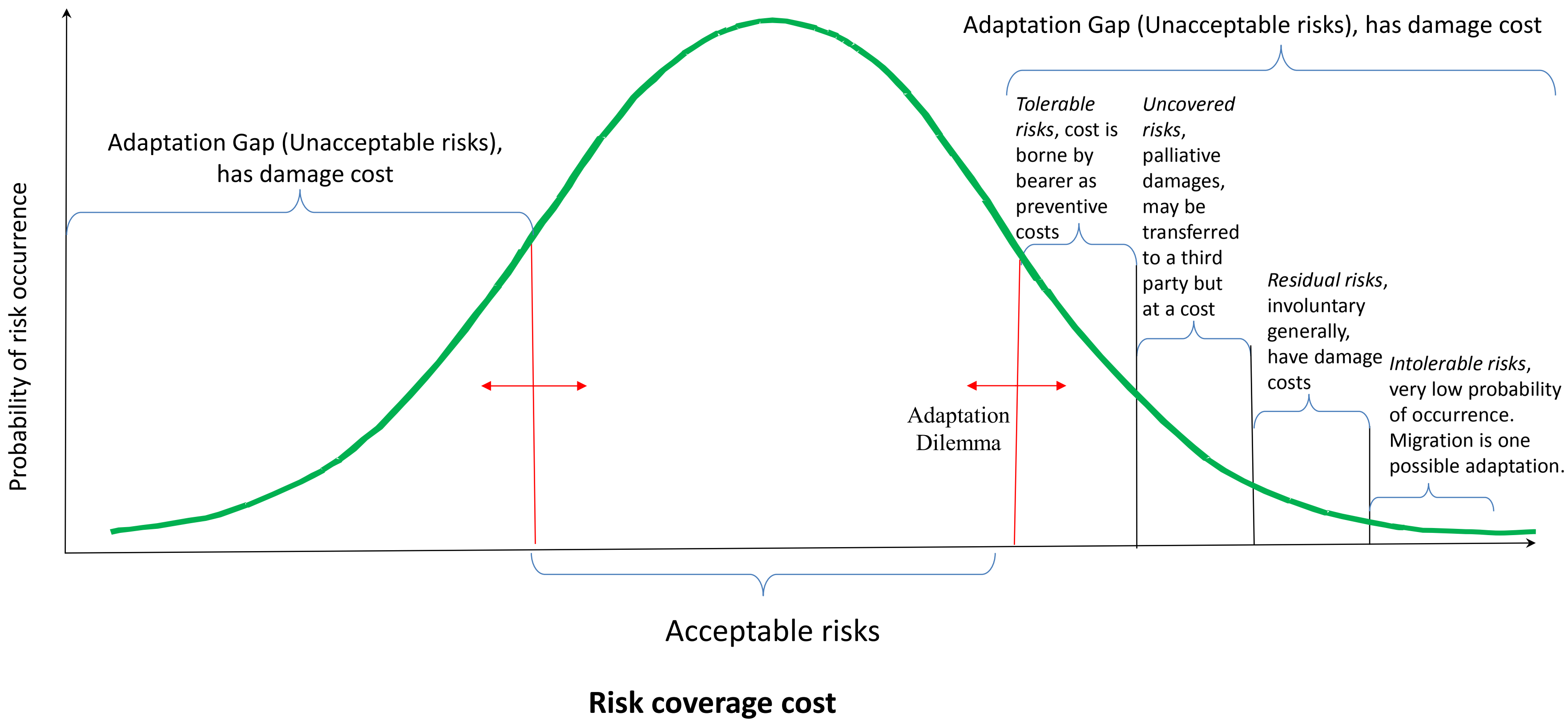


Figure 1.1: Risks and costs associated with adaptation gap

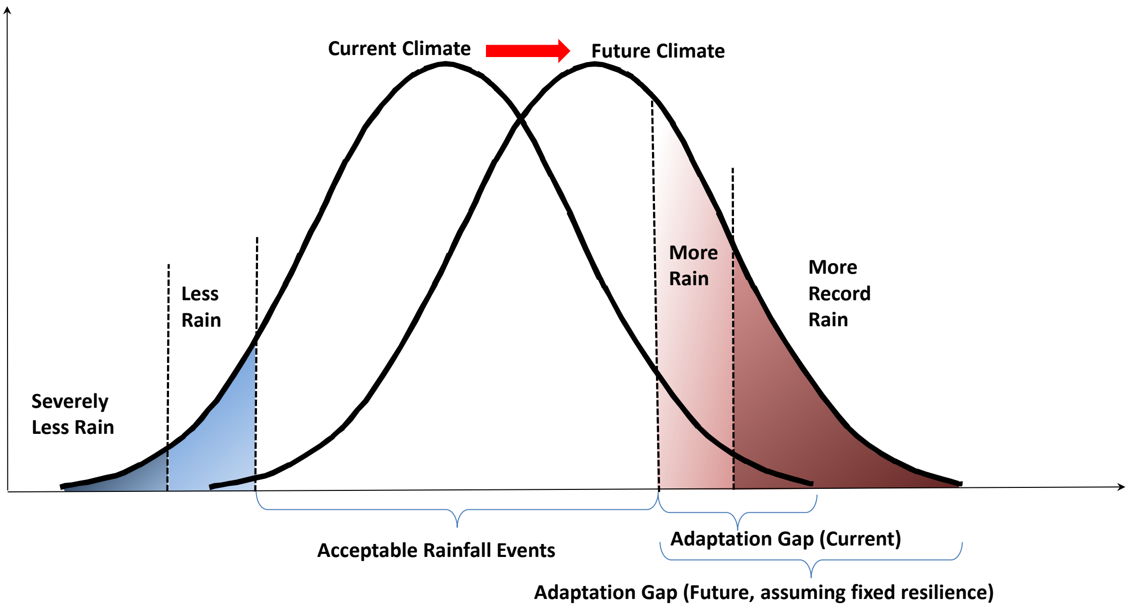


Figure 1.2: Adaptation Gap enhances in future

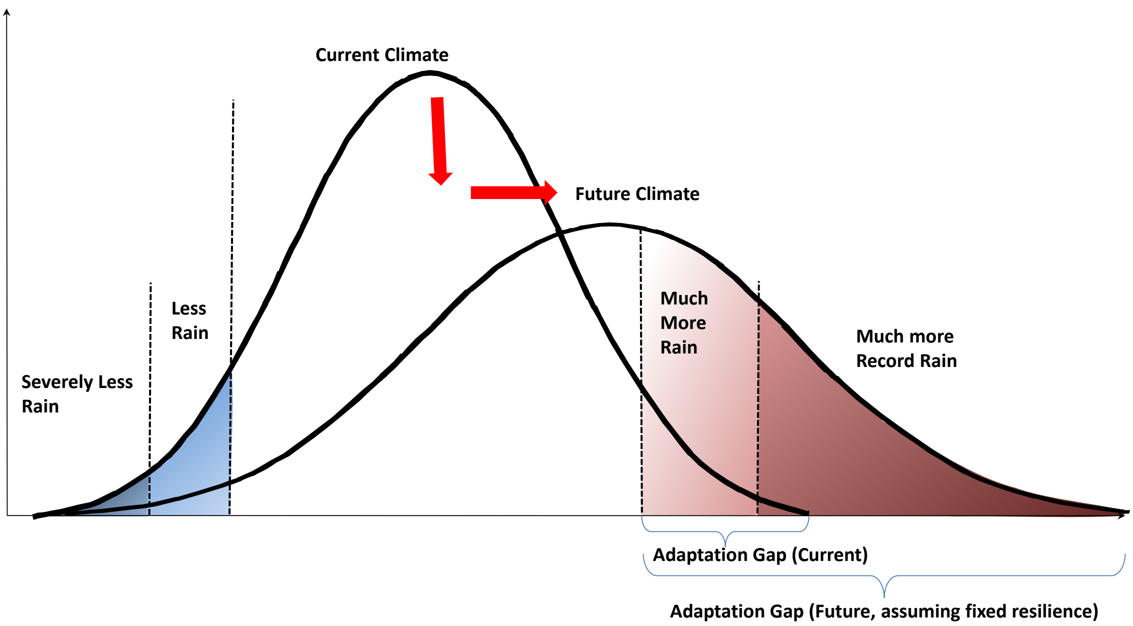


Figure 1.3: Adaptation Gap enhances much more in future

1.6 Ways of filling the Adaptation Gap

Conventionally, Adaptation Gaps may be filled in through managing the associated risks – either covering them through preventive investments or through paying the palliative costs of unacceptable risks. Involuntarily tolerated risks and also the residual risks form part of the uncovered risks in an adaptation gap. All the unacceptable risks, in turn, may be covered by the bearer or someone else through a prior arrangement where in the palliative damages are restored by a third party (the impacted party, the host country government, international bodies, reinsurer or someone else). Since CBDR is not currently implemented in adaptation effectively, these unacceptable risks (and associated palliative costs) mostly fall on the host country governments as a sovereign obligation, and to a very lesser extent on developed country parties and multilateral donor agencies who take these as a welfare measure and not as a liability measure. It may also be argued that US$ 100 billion/year by 2020 contribution commitment to the Global Climate Fund by developed country parties is based on a Welfare paradigm, and if this paradigm is changed to a Liability paradigm based on consistent and unequivocal IPCC findings on anthropogenic nature of climate change, the CBDR damage payments towards filling the Adaptation Gaps in all developing countries and emerging economies could be almost 10-times than this amount. Strong CBDR regimes in future would therefore change adaptation finance flows and technology transfers in favor of developing countries.

Risk management can be classified under four possible response options - avoid, mitigate, retain, and transfer the risk. The first two responses (avoidance and mitigation) may be categorized as risk control and the latter two (retention and transfer) as risk financing. The normal approach to risk management is to control all those risks that could be controlled within the physical resources available and finance the remainder. Effectively, risk financing funds those losses that remain after the application of risk control techniques, including both those risks accepted as not being able to be controlled and those where controls proved inadequate to contain the risk (AACI, 2003). All these response options are summarized below (Kapshe, 2012).

1.6.1 Risk Avoidance

An entity chooses to proceed with a particular investment on the basis of its perception of risk and whether the entity is willing to assume the risk; effectively the threshold is the tolerance for risk. This tolerance for risk will be a function of both the willingness to accept the risk and also the circumstances in which the entity is operating. If investors in a country, for instance, become too risk averse then investments in human and economic activities, and man-made ecosystems may dry down. However, it will not be possible for the government not to invest in their development even if the perceived risks of future climate change are high in any region. Therefore, risk avoidance for climate change related impacts may not be a suitable choice for governments in most of the human and economic activities, natural ecosystems, and man-made ecosystems if these are otherwise expected to contribute towards development.

1.6.2 Risk Mitigation

The measures such as loss prevention and loss control can be categorized as risk mitigation. In a traditional insurance context these measures may include security measures and safety standards. In many instances adherence to required risk mitigation measures is a prerequisite for any project to be sanctioned. There is a need to revise the safety standards in view of the likely climate change impacts in future, as the present day standards do not have any explicit consideration for these impacts.

1.6.3 Risk Transfer

A risk that one organization is unwilling to bear may be transferred to another. This is what is commonly understood as insurance! In exchange for the payment of an agreed amount (the premium), the insurer agrees to indemnify the client for losses that result from specified perils. Options and hedges also operate to transfer risk from one party to another. In some instances the counter-parties may be entities specifically established to engage in the hedging or option trading, but in many instances they will be entities whose risk arises from the opposite movement in a price or volume of supply. In case of infrastructure projects there are many mechanisms existing for transfer of risks arising from the perceived uncertainties. However, there are no well-developed mechanisms specially designed to transfer the climate change impact risks.

1.6.4 Risk Retention

Risk retention can result from both a voluntary and involuntary action. Voluntary retention of risk results from a conscious decision to accept that a certain level of risk from any source should be retained rather than transferred to another party at a cost. Voluntary risk retention also includes acceptance of a level of risk that may be imposed by insurers. Involuntary risk retention occurs when a firm fails to identify and deal with a risk from within or outside the business and thus bears the risk unknowingly. Failure to recognize or understand a risk results in retention of the risk, which the firm will have to face in eventuality of the occurrence of event.

The next chapter provides an analysis of present climate change observed in India, especially through historic sub-regional temperature profile data. Future climate change parameters under alternate Representative Concentration Pathways (RCPs) are then projected from existing global models. Chapter 3 details the present adaptation efforts by the Government of India across regions and sectors. The next three chapters provide financial, technological, knowledge gaps in adaptation. Chapter 7 discusses capacity building and institutional gap. The last chapter provides a framework for filling the Adaptation Gap of India on a continuous basis, requiring financial flows and technology transfers from the developed countries under a CBDR regime for adaptation.

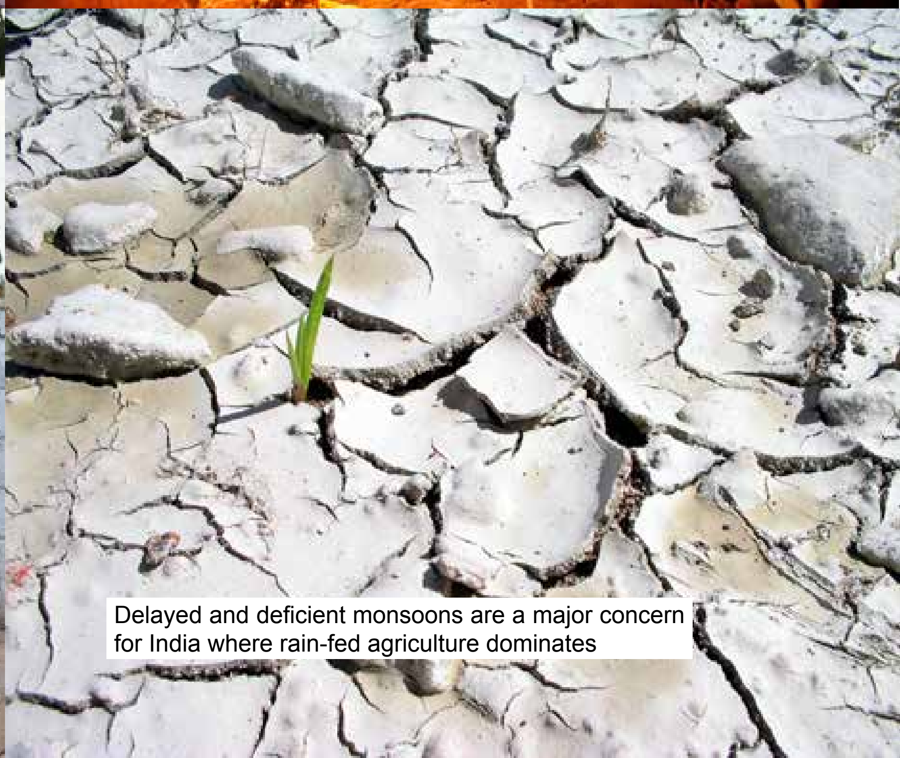
Chapter 2

Observed and Projected Climate Change in India

Vulnerability of Indian Livestock enhances during floods and drought events

Severe winters enhance temperature related mortality

Refrigerated lime water is an adaptation measure in most of the Indian cities during summers



Delayed and deficient monsoons are a major concern for India where rain-fed agriculture dominates

2. Observed and Projected Climate Change in India

2.1 Background and Introduction

The impacts of climate variability and change are already visible on observed temperature and rainfall. For instance, global and regional air temperatures increased in the 20th century with the largest warming occurred in the last 30 years [*WMO*, 2005]. Moreover, the year 2014 was recorded as the warmest year in the entire record for which measurements are available. The difference between maximum and minimum temperature is narrowing, which could be detrimental for agriculture [*Easterling et al.*, 1997]. Significant changes have also been noticed in climate variables (i.e. precipitation and air temperature) across India during the period of 1950-2008 [*Mishra et al.*, 2014a, 2014b]. Declining trends in the observed precipitation during the monsoon season were noticed in *Mishra et al.* [2012], which were partially associated with the warming in the Indian Ocean [*Alory et al.*, 2007; *Brown and Funk*, 2008]. An increase in mean air temperature was reported globally [*Karl et al.*, 1996]. At the regional scale, *Mishra et al.* [2014] reported that precipitation declined while temperature increased over the majority of India in the last few decades, which caused increased frequency of droughts and reduction in soil moisture for crop growth.

Some of these trends in climate variables (e.g. precipitation and air temperature) are projected to remain same under the future climate [*Easterling et al.*, 2000; *Sheffield and Wood*, 2008; *Mishra et al.*, 2014b]. *Kumar et al.* [2011] reported that annual air temperatures are expected to increase under the projected future climate change scenarios even more than India has witnessed so far. *Rupa Kumar et al.* [2006] reported that both rainfall and air temperature are projected to increase across India under the projected future climate. Moreover, *Chaturvedi et al.* [2012] using the CMIP5 climate projections showed that there is a large uncertainty in precipitation projections, however, temperature is projected to increase 3-4ºC under the representative concentration pathways (RCP) 8.5 by the end of 21st century. *Mishra* [2015] reported that there is a large uncertainty in projections of the monsoon season precipitation under the projected future climate. Moreover, *Mishra et al.* [2014] argued that the selection of model is important to understand the projected changes in the future climate. Since the global climate models use coarser grids (150-200km), it may be appropriate to use the regional climate models at higher spatial (50km) resolution for the climate impact studies.

Decreases in rainfall and increases in air temperature could lead to persistent moisture deficit conditions that can hamper the crop production in India. Frequent droughts during the monsoon season under the current and projected future climate will pose enormous challenges for crop production in India [*Mishra et al.*, 2014]. Future climate with significant increases in temperature and heat waves, number of hot days and hot nights as well as decreases in precipitation might further enhance the likelihood of drought occurrences. The impacts of drought and climate variability and changes on agricultural production are well documented [*Lobell and Asner*, 2003; *Lobell and Field*, 2007; *Mishra and Cherkauer*, 2010; *Mishra et al.*, 2014]. Modelling studies showed that grain yield might decline by 2.5% to 16% for every increase of 1°C in seasonal temperature in the sub-tropics and tropics [*Lobell et al.*, 2008; *Battisti and Naylor*, 2009]. Moreover, *Fischer et al.*, [2005] reported that in changing climate, the gap between crop production and consumption will increase especially in the developing countries. *Schmidhuber and Tubiello* [2007] argued that the impacts of climate change on food security could be even more than previously thought.

Food grain production in India increased significantly after the Green Revolution; however, still about 20-34% population in India is undernourished. Irrigation played a major role in food grain production especially after the Green Revolution. Our dependence on irrigation has substantially increased regardless of the monsoon rainfall variability mainly because of multi-cropping agricultural systems. Climate change can put severe pressure on water resources and agriculture in India due to the following reasons:

- Increased climate warming will lead to more losses through evaporation and evapotranspiration, which in turn will increase irrigation frequency for multiple crops and seasons[*Barnett et al.*, 2005; *Schlenker et al.*, 2007];
- During the recent years, climate has become somewhat more erratic leading to frequent droughts in India [*Ramanathan et al.*, 2005; *Mishra et al.*, 2010];
- Surface water storage in ponds and reservoirs may become short-lived under climate change and enhanced hydrologic cycle [*Barnett et al.*, 2005; *Tanaka et al.*, 2006] and;
- Indian population is growing while potential area that can be used for agriculture is shrinking [*Mishra et al.*, 2010].

This chapter tries to address the following questions and objectives:

1) *To what extent changes in mean and extreme climate occurred in India during the period of 1951-2013?*
2) *What do climate projections under the different Representative Concentration Pathways (RCPs) suggest changes in mean and extreme climate in India?*

Objectives:

1) To evaluate changes in the observed climate in India for the period of 1951-2013
2) To develop bias corrected and downscaled climate projections for India using the CMIP5 model output at 0.25 degree spatial and daily temporal resolution
3) To understand changes in mean and extreme climate variables using the high resolution climate change projections for the two periods: 2016-2045 and 2046- 2075

2.2 Data and Methods

2.2.1 Observed Data

Observed data for daily precipitation (rainfall) was obtained from the India Meteorological Department (IMD, *Pai et al.* [2014]) for the period of 1951-2013. The gridded daily precipitation data obtained from IMD were developed using 6995 stations [*Pai et al.*, 2014]. In the newly gridded precipitation product climatological features are well represented, which include orographic precipitation in the Western Ghats and Northeastern India. Further details on data can be obtained from *Pai et al.* [2014]. We obtained 0.5 degree gridded daily maximum and minimum temperatures data for the period of 1951-2013 from IMD. The dataset was developed by *Srivastava et al.* [2009]and are based on 395 observational stations across India. Daily maximum and minimum temperature were regridded to 0.25 degree (which is consistent to the resolution of precipitation) using lapse rate and Digital Elevation Model (DEM) as described by *Maurer et al.* [2002]. Using precipitation and temperature data, we developed daily meteorological dataset (precipitation, maximum and minimum temperatures) at 0.25 degree spatial and daily temporal resolutions for the period of 1951-2013.

2.2.2 Climate Change Projections

We developed high resolution climate change projections using the data from the CMIP5 models. The best performing models based on the representation of the Indian monsoon as well as air temperature were selected out of the 40 CMIP5 models that were evaluated. We used monthly data for the monsoon (June to September) season precipitation and air temperature from the 40 CMIP5 models (Table 2.1). Moreover, we obtained data from the CORDEX south Asia regional climate models (RCMs) for precipitation and air temperature. Data from all the models (CMIP5 and CORDEX) were evaluated for the monsoon season precipitation and air temperature against the observed data from the IMD for the period of 1951-2005. We evaluated the performance of the models for the monsoon season using the bias, temporal and spatial correlations, and coefficient of variation in the model output and the observed data. We selected the five best models (Table 2.2) based on the selected performance measures. We noticed that none of the CORDEX south Asia regional climate models fell in the selected five best models, which indicate that the CORDEX models need further improvements before these can be used for the regional climate change impact assessment. These findings are consistent with the results reported in *Mishra et al.* [2014a].

Table 2.1 List of the CMIP5 models that were evaluated for the monsoon season precipitation and air temperature

IPSL-CM5B-LR	IPSL-CM5A-LR	CanESM2	CESM1-CAM5
MRI-CGCM3	FGOALS-g2	MPI-ESM-LR	NorESM1-M
MRI-ESM1	IPSL-CM5A-MR	MPI-ESM-MR	NorESM1-ME
GISS-E2-R-CC	bcc-csm1-1-m	ACCESS1-0	CESM1-CAM5-1-FV2
GISS-E2-R	HadGEM2-CC	CNRM-CM5	GFDL-CM3
GISS-E2-H-CC	HadGEM2-ES	inmcm4	CESM1-BGC
CSIRO-Mk3-6-0	CMCC-CM	CMCC-CESM	CESM1-FASTCHEM
GISS-E2-H	CMCC-CMS	FIO-ESM	CCSM4
ACCESS1-3	HadGEM2-AO	GFDL-ESM2M	MIROC5
bcc-csm1-1	MPI-ESM-P	GFDL-ESM2G	CESM1-WACCM

Table 2.2 List of the five best CMIP5 models that were selected for the downscaling and bias correction

CCSM4
GFDL-ESM2M
MIROC5
NorESM1-M
NorESM1-ME

The bias correction and statistical downscaling was performed using the data from the best 5 CMIP5 models at 0.25 degree spatial and daily temporal resolutions. We selected 1950-2099 as the time period of bias correction and statistical downscaling. Bias corrected and spatially disaggregated (BCSD) data were used to evaluate changes under the projected future climate. The BCSD approach was originally developed by *Wood et al.* [2002, 2004]. The modified BCSD approach [*Thrasher et al.*, 2013] was used to develop daily meteorological forcings using the daily precipitation, maximum and minimum temperatures and diurnal temperature range (DTR) outputs from the five best General Circulation Models (GCMs) for the period of 1950-2099.

Daily outputs of precipitation and air temperature were obtained from the five best GCMs (Table 2.1) that participated in the *Coupled Model Intercomparison Project Phase 5* (CMIP5). Daily data from the GCMs were obtained from ensemble member r1i1p1 (see *Taylor et al.* [2012] for details) for representative concentration pathways 2.6,4.5, 6.0, and 8.5 (RCP 2.6, 4.5, 6.0, and 8.5), which assumes an increase of 2.5, 4.5, 6.0, and 8.5 Watt/m^2 in radiative forcing by the end of 21st century [*Taylor et al.*, 2012]. The RCP 8.5 is the most pessimistic scenario while the RCP 2.6 is the most optimistic scenario. The RCP scenarios were developed based on the assumptions on the development, economy, and the mitigation effort [*Taylor et al.*, 2012]. For the climate change impact assessment, it is recommended to evaluate all the RCPs so that uncertainty associated with the scenarios can be well understood for the policy making. Because of uncertainty in the climate model projections that could vary regionally, data from the five best GCMs were used for the downscaling and bias correction. The modified BCSD approach [*Thrasher et al.*, 2013] is different from the original BCSD method [*Wood et al.*, 2002, 2004] as this uses daily projections of precipitation and maximum and minimum temperatures rather than monthly precipitation and average temperature. As the modified BCSD approach uses daily dataset, it essentially avoids daily data disaggregation from bias corrected monthly data using daily time series from a monthly historic climatology as used in the original BCSD approach. The BCSD approach has been widely used for the hydrologic impact assessments [*Hayhoe et al.*, 2004; *Cayan et al.*, 2008; *Mishra et al.*, 2010]. Moreover, the BCSD approach has been successfully compared to various statistical and dynamical downscaling techniques for both mean and extremes [*Wood et al.*, 2004; *Maurer and Hidalgo*, 2008; *Bürger et al.*, 2012]. Bias-corrected and spatially disaggregated daily dataset were developed for the best five GCMs at 0.25 degree spatial resolution and daily temporal resolution. Consistent with the historic climatology, gridded future climate projections included daily precipitation and maximum and minimum temperatures were developed for the period of 1950 to 2099. The observed climatological data for the bias correction and statistical downscaling were obtained from the IMD. *Mishra et al.* [2014b] used bias corrected and statistical downscaled data for the climate change impact assessment on soil moisture drought in India.

2.2.3 Analysis Approach

A range of indicators were selected to evaluate changes in the observed and projected future climate in India. For instance, the analysis was conducted to understand changes in monsoon (June to September) and annual periods for the observed record (1951-2013). However, for the projected future climate the analysis was done only for the monsoon season for precipitation and annual period for temperature to minimize uncertainty that could arise due to magnitude of precipitation and changes in seasons under the projected future climate. Similarly, changes in the mean air temperature for the monsoon season and annual periods were estimated in the observed record (1951-2013). Apart from the changes in mean climate, changes in the extremes under the observed and projected future climate were estimated for the period of 1951-2013. Changes in the mean annual number of hot days and hot nights were estimated using the 95th percentile of maximum and minimum temperatures, respectively [*Mishra et al.*, 2015]. The number of heat waves was estimated using the daily maximum temperature and the 95th percentile threshold for the three warmest months in the year. More information about the extreme indices can be obtained from *Mishra et al.* [2015]. Moreover, changes in annual maximum precipitation and meteorological droughts for the monsoon season were estimated. For the drought assessment, standardized precipitation index (SPI, *McKee et al.* [1993]) was used and a 4-month SPI at the end of September was considered to estimate changes and variability in the droughts during the monsoon season. For drought assessment, frequency of severe, extreme and exceptional droughts was estimated. Changes in the observed climate were estimated using the non-parametric Mann-Kendall analysis. To estimate changes for the period 1951-2013, trend slope was multiplied with the period of record as described in *Mishra* [2015]. Statistical significance in the trend analysis was estimated at 5% significance level. Since hydroclimatic variables often show persistence, the effect of serial and spatial autocorrelations was removed using the method described in *Yue and Wang* [2002]. The Mann-Kendall method has been widely used for trend detection in hydroclimatic variables at regional and global scales [*Mishra and Lettenmaier*, 2011; *Mishra et al.*, 2015].

Changes in the mean and extreme climate indices under the projected future climate were estimated using the downscaled and bias corrected dataset, which was obtained for the five best GCMs from the CMIP5 models. Changes in the projected future climate in the selected indices were estimated for the two periods of 30 years each: 2016-2045 (Near), and 2046-2075 (Mid) term climate with respect to the reference period of 1971-2000. Changes were estimated for all the four RCPs (2.6, 4.5, 6.0, and 8.5) for the monsoon season and annual period. Moreover, changes in the selected variables were also estimated.

2.3 Results

2.3.1 Observed and Projected Changes in Temperature

Climate change projections for daily precipitation and air temperature were developed using the five best CMIP5 model output. The bias correction and spatial disaggregation (BCSD) method was used for statistical downscaling as described in the methods section. The downscaled and bias corrected data at 0.25 degree spatial resolution and daily temporal resolution were developed for the historic (1950-2005) and projected future (2016-2075) periods. The changes under the projected climate were estimated for each model for the Near (2016-2045) and Mid (2046-2075) century periods against the historic reference period of 1971-2000. The multimodel ensemble mean change was estimated using the change from the individual models and taking the average of that. To represent the uncertainty in the five CMIP5 models, inter model variation was estimated. Changes under the projected future climate were estimated for the four (2.6, 4.5, 6.0, and 8.5) representative concentration pathways (RCPs).

Since there is uncertainty based on the emission scenarios (RCPs 2.6, 4.5, 6.0, and 8.5), we estimated the potential RCPs that India is following using the observed temperature data for the period of 2006-2013 and mean air temperature from the downscaled and bias corrected data (Figure 2.1). It was observed that air temperature increased between 0.6 and 0.8ºC in India during the period of 2006-2013 (Figure 2.1a). In India, the western and northeastern regions experienced more prominent warming that other regions. The observed change in air temperature estimated using the IMD data was then compared with the multimodel ensemble mean change under all the selected RCPs for each 0.25 degree grid-cell. Based on the comparison between observed and ensemble mean change, the closed RCP was identified for each grid cell (Figure 2.1b). It was noticed that the country follows the RCP 4.5. However, a few regions (northeastern, Madhya Pradesh, Rajasthan, and Jammu and Kashmir) that experienced prominent warming during the period of 2006-2013 have been following the RCP 6.0 and 8.5 (Figure 2.1b). Here, it is worth mentioning that RCP 8.5 is the most pessimistic emission scenario. Results also indicated that part of the eastern India (Bihar, Jharkhand, Odisha, and West Bengal) has been following the most optimistic emission scenario.

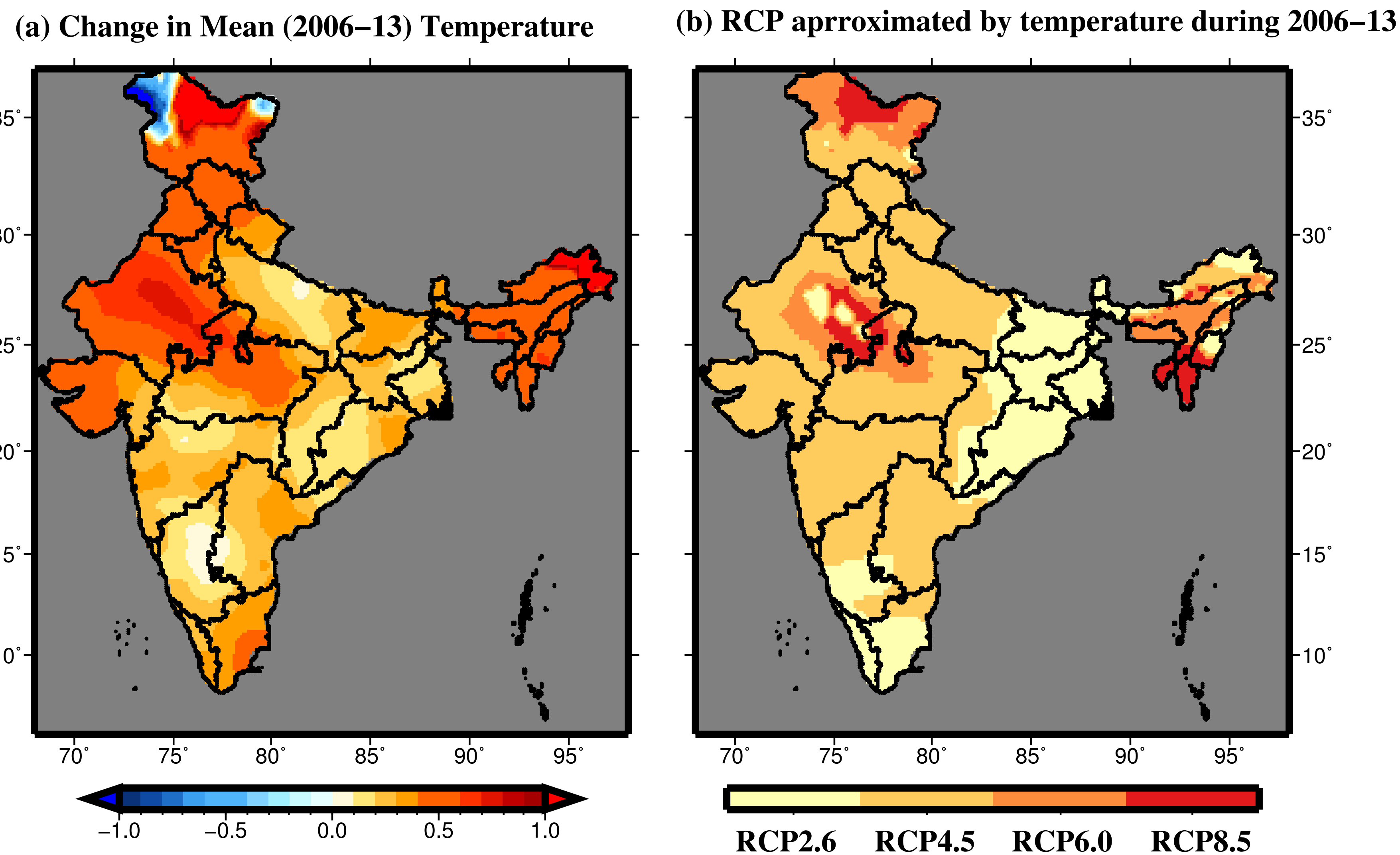


Figure 2.1: (a) Change in mean (2006-13) annual temperature as compared to historic (1951-2005) period and (b) Representative Concentration Pathway (RCP) approximated during 2006-2013 based on change in mean annual temperature for each grid cell.

Using the air temperature data for the projected future climate, the percentage area in India that is projected to experience above 2ºC change between 2016 and 2099 was estimated for all the RCPs (Figure 2.2a). There is a large intermodel variation in the estimates of the area of India that is projected to witness more than 2ºC rise in air temperature. However, results indicated that under the RCP 4.5 scenario, which is the most representative scenario for the state, about 10 % of the country is projected to witness more than 2ºC increase in air temperature by 2035 (Figure 2.2a). Moreover, under the RCP 8.5 scenario, the 35% of the country is projected to experience rise in more than 2 degree air temperature. More than 2ºC increases in air temperature may have profound implications on agriculture, water resources, and many other sectors. It is therefore desirable to evaluate the impacts of 2ºC increase in air temperature on the various sectors in India. Our results of the empirical probability distribution of air temperature for the Near and Mid periods of the 21st century showed a significant increases in both mean and extreme temperature in the state under the selected RCPs. All India mean temperature is projected to increase by 3.5 °C by the end of 21st century under the future climate. Significant increases in annual mean air temperature under the projected future climate will lead to rise in the frequency of temperature extremes (hot days, hot nights, and heat waves) which may have profound implications on sectors such as agriculture, water resources, and public health.

Observed and projected changes in hot days, hot nights, and growing degree days may have implications on adaptation in the sectors of agriculture and public health. We estimated mean and changes in the hot days, hot nights, and growing degree days for the observed climate for the period of 1951-2013 (Figure 2.3). Annual mean maximum and minimum temperature varied in the range of 32-35 °C and 18-22°C in the majority of India (Figure 2.3a, b). On the other hand, mean growing degree days varied between 2000 and 3000 in the majority of country during the period of 1951-2013 (Figure 2.3c). Analysis of the observed record showed that frequency of hot days has increased across India (except the Gangetic Plain) during the period of 1951-2013 (Figure 2.3d). However, increases in the number of hot nights were observed in the northeastern and western regions of India (Figure 2.3e). Growing degree days increased by 50-150 in majority of the country during the period of 1951-2013. These results indicate the disparities in the changes in day and night time temperature during the observed period in India, which may have substantial adaptation related implications in many parts of the country. Results also showed that the northeastern states are in particular experienced significant increase in the frequency of extreme temperature events during the last few decades.

Multimodel ensemble mean annual air temperature, growing degree days, number of hot days and hot nights were estimated using the downscaled and bias corrected data for the five best CMIP5 models for the reference period (1971-2000). Both spatial pattern and magnitudes of annual mean temperature, growing degree days, and the frequency of hot days and hot nights were well captured in the bias corrected and downscaled climate data (Figure 2.4), which highlights that the downscaled and bias corrected data can represent observations for the climatological period in a reasonable manner.

Multimodel ensemble mean projected changes in annual mean temperature were estimated using the downscaled and bias corrected climate projections for the Near (2016-2045) and Mid (2046-2075) periods (Figure 2.5). Here, it can be noted that the changes under the projected future climate in annual average temperature were estimated with respect to the historic reference period (1971-2000). Mean annual temperature is projected to increase by 1-1.5 ºC under all the RCPs in the Near (2016-2045) term climate. However, based on multimodel ensemble mean projections, mean annual temperature is projected to increase between 1.8 to 3.0 ºC in the Mid term climate (Figure 2.5). Moreover, the RCP 8.5 scenarios showed higher increases ranging between 2.5 to 3.5 ºC in the multimodel ensemble mean annual air temperature in India in the Mid (2046-2075) term projections. Significant increases that are projected in the mean annual air temperature across India will have serious implications and pose challenges for adaptations in the sectors of agriculture, water resources, and public health. An increase of air temperature of 2°C is likely in majority of India by the Mid 21st century under the projected future climate.

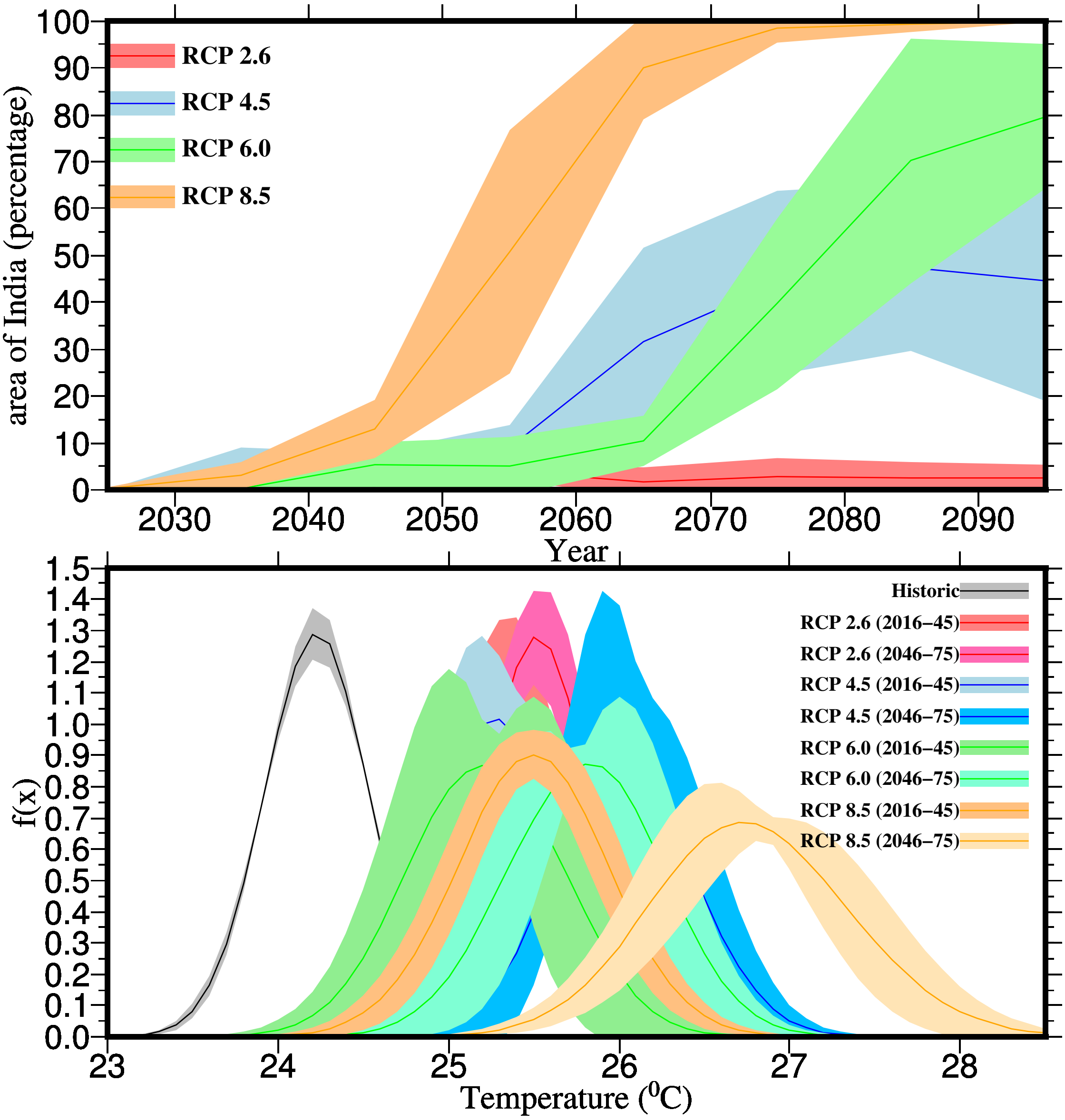


Figure 2.2: (a) Projections of percentage of grid cells that are projected to experience more than 2°C increase in air temperature during each decade (represented by central value in figure) under different scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) as compared to base period (1971-2000). (b) Ensemble mean empirical probability distribution function of mean annual temperature for historical period (1971-2000) and annual mean air temperature under the projected future climate different (for the periods 2016-45 and 2046-70).

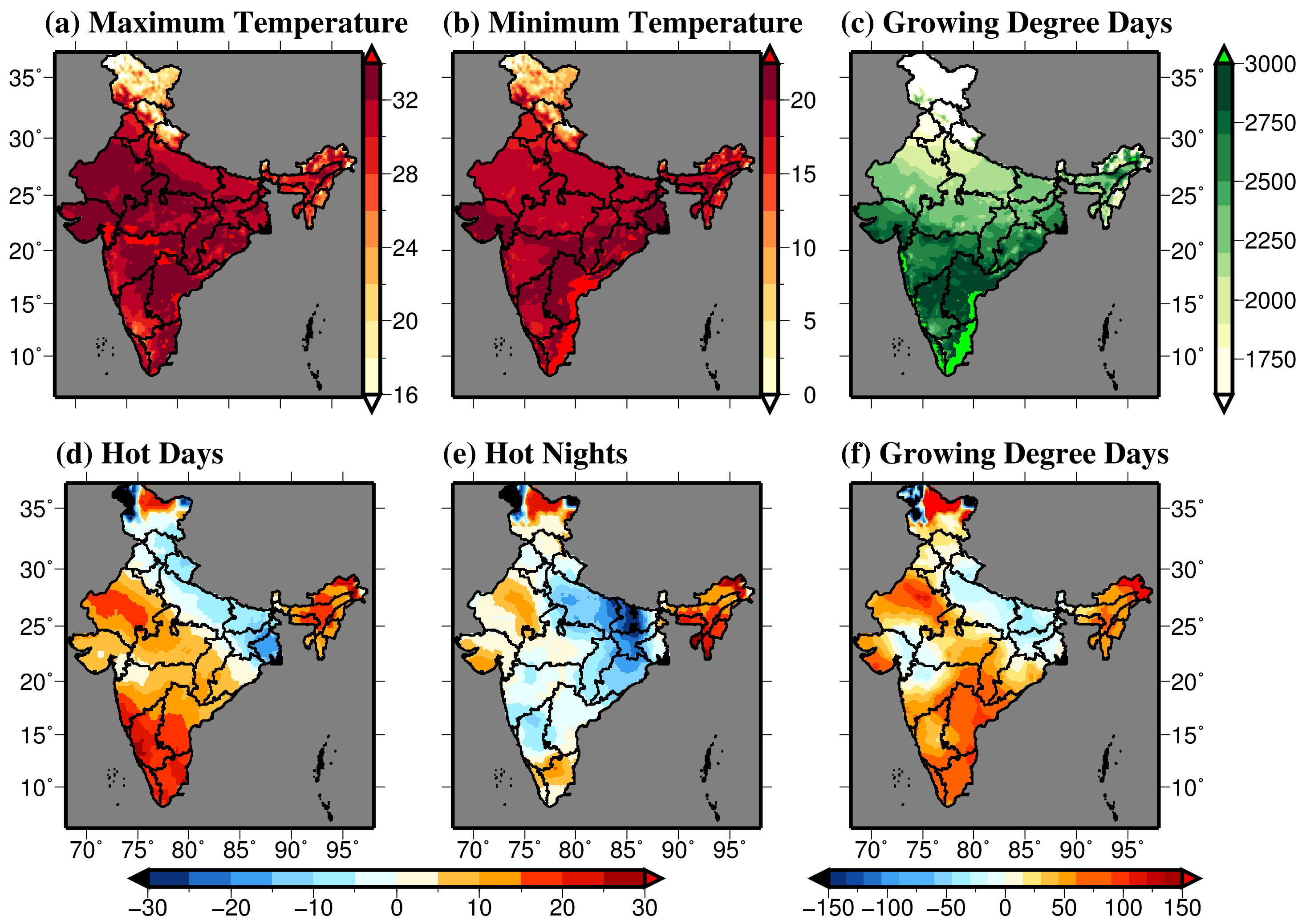


Figure 2.3: (a,b) Observed mean (1951-2013) annual daily maximum and minimum temperature (c) mean annual Growing Degree Days. (d.e) Change in number of hot days and hot nights (hot days and nights- when maximum and minimum temperature is above 95th percentile of temperature during base period). (f) Changes in Growing Degree Days. Changes were estimated using the reference period of 1971-2000.

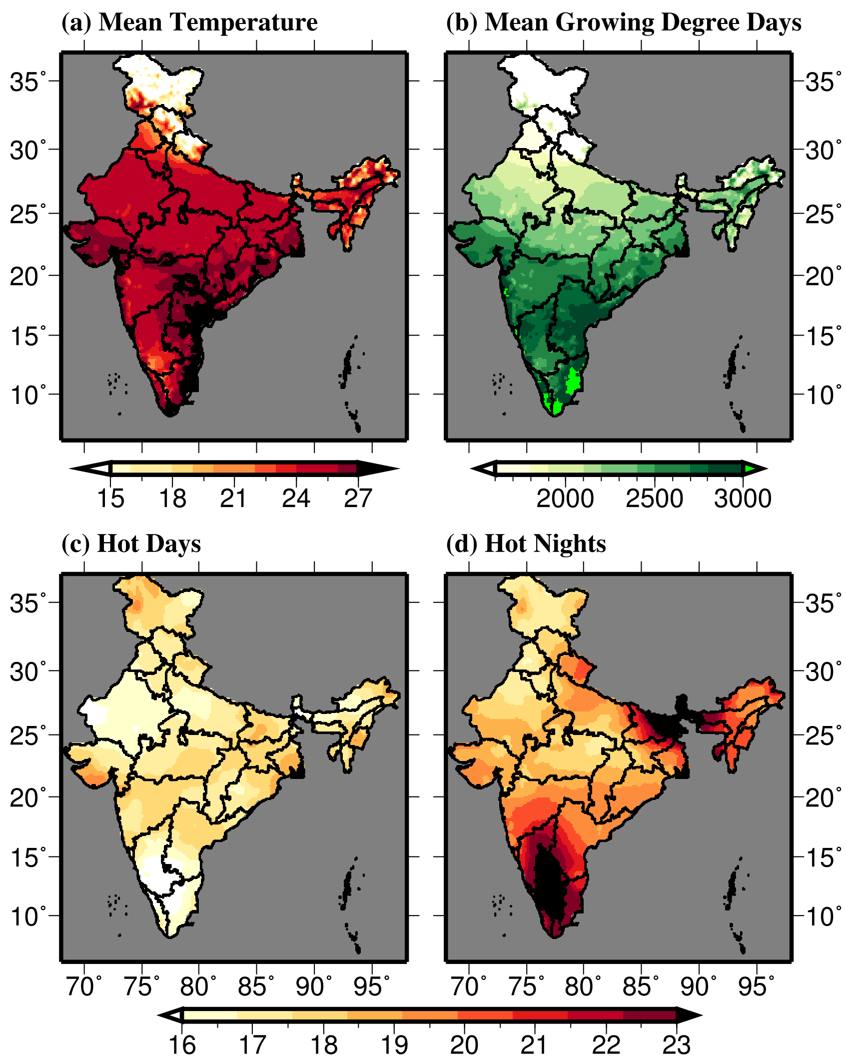


Figure 2.4: Historic mean (1951-2005) (a) annual temperature. (b) Growing Degree Days (c,d) hot days and nights of ensemble mean from GCMs

Multimodel ensemble mean projections based on the downscaled and bias corrected data showed a significant increase in the frequency of hot days under the future climate (Figure 2.6). In all the RCPs, the majority of country is projected to experience an increased frequency (10-15 days per year) of hot days in the Near (2016-2045) term climate. Increases in the frequency of hot days are more prominent (20-25 days per year) in the northeastern, northern, and southern regions in the Near term projected future climate (Figure 2.6). Under the RCP 8.5, the frequency of hot days is projected to increase by 30-40 days in some parts of the country. On the other hand, frequency of hot days may increase more than 45 days per year in the Mid (2046-2075) term climate (Figure 2.6). Climate change projections based on downscaled and bias corrected data showed even more prominent increases in the number of hot nights in India (Figure 2.7). An increase of 20-30 hot nights per year is projected under the Near (2016-2045) term climate in all the RCPs in India. On the other hand, an increase of more than 50 hot nights is projected in the Mid (2046-2075) term climate based on multimodel ensemble mean downscaled and bias corrected datasets.

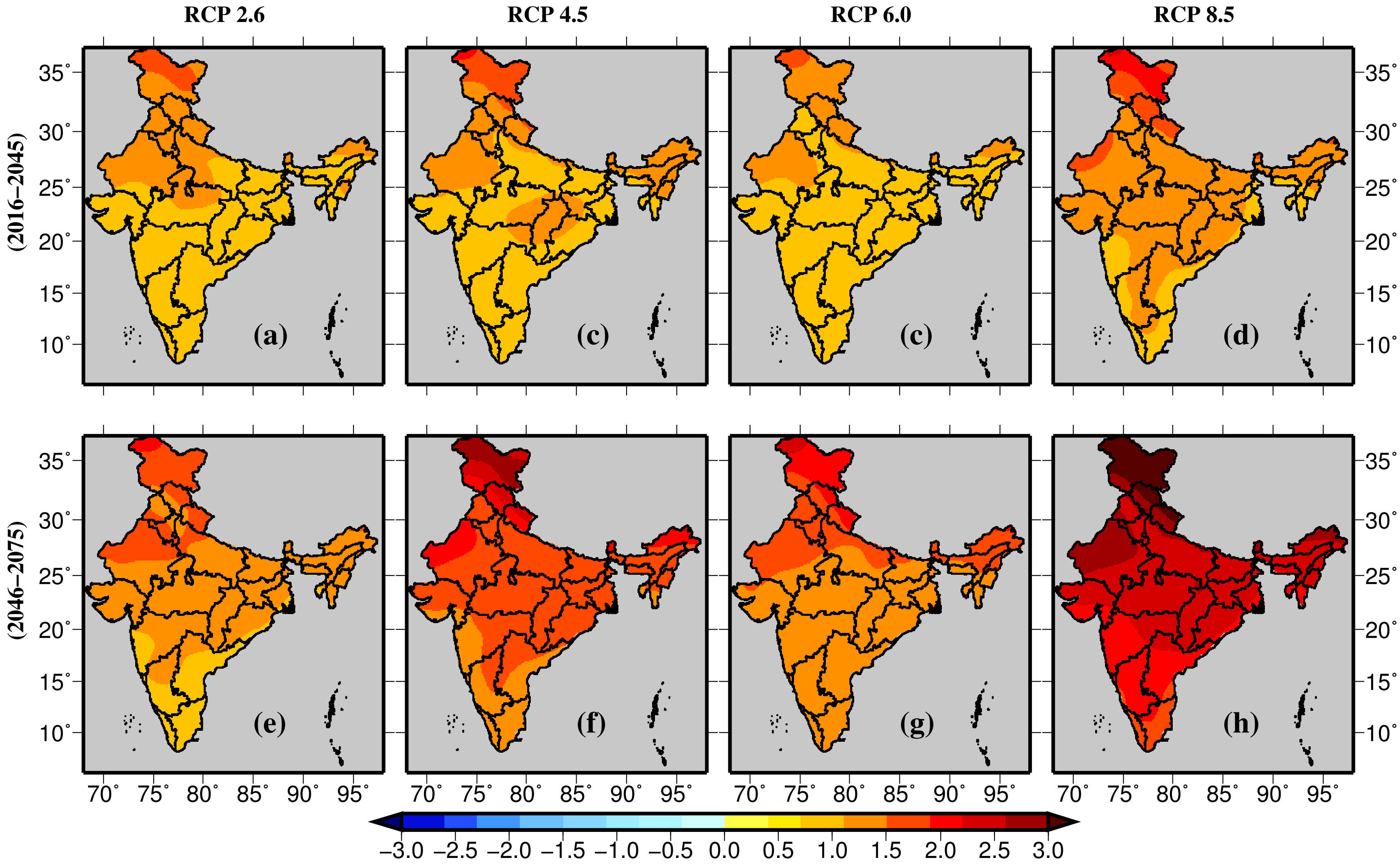


Figure 2.5: Multimodel ensemble projected change in mean annual daily mean temperature for the Near (2016-2045) and Mid (2046-2075) periods under the selected RCPs.

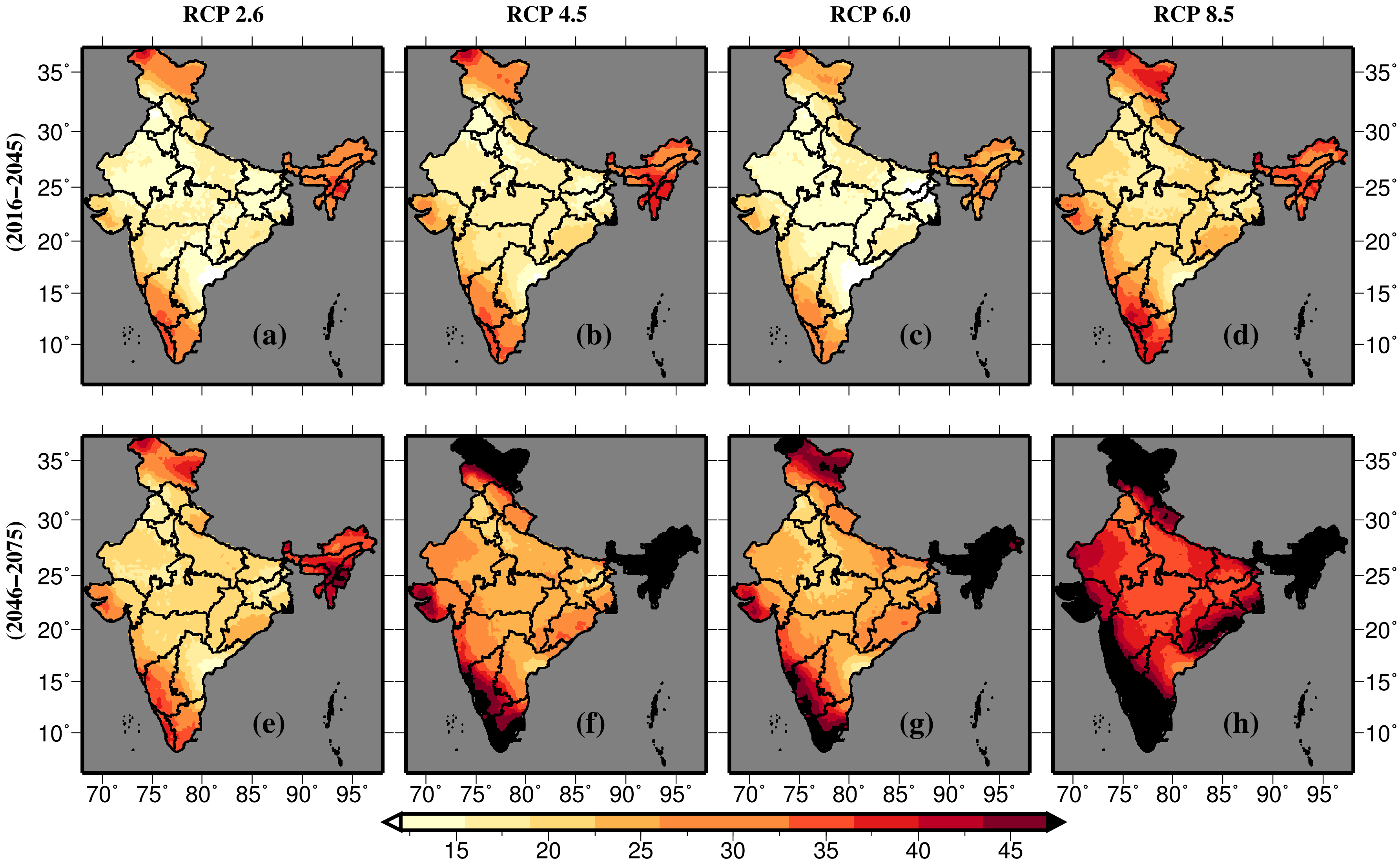


Figure 2.6: Multimodel ensemble mean projected changes in number of hot days (i.e. above 95th percentile of maximum temperature during 1971-2000).

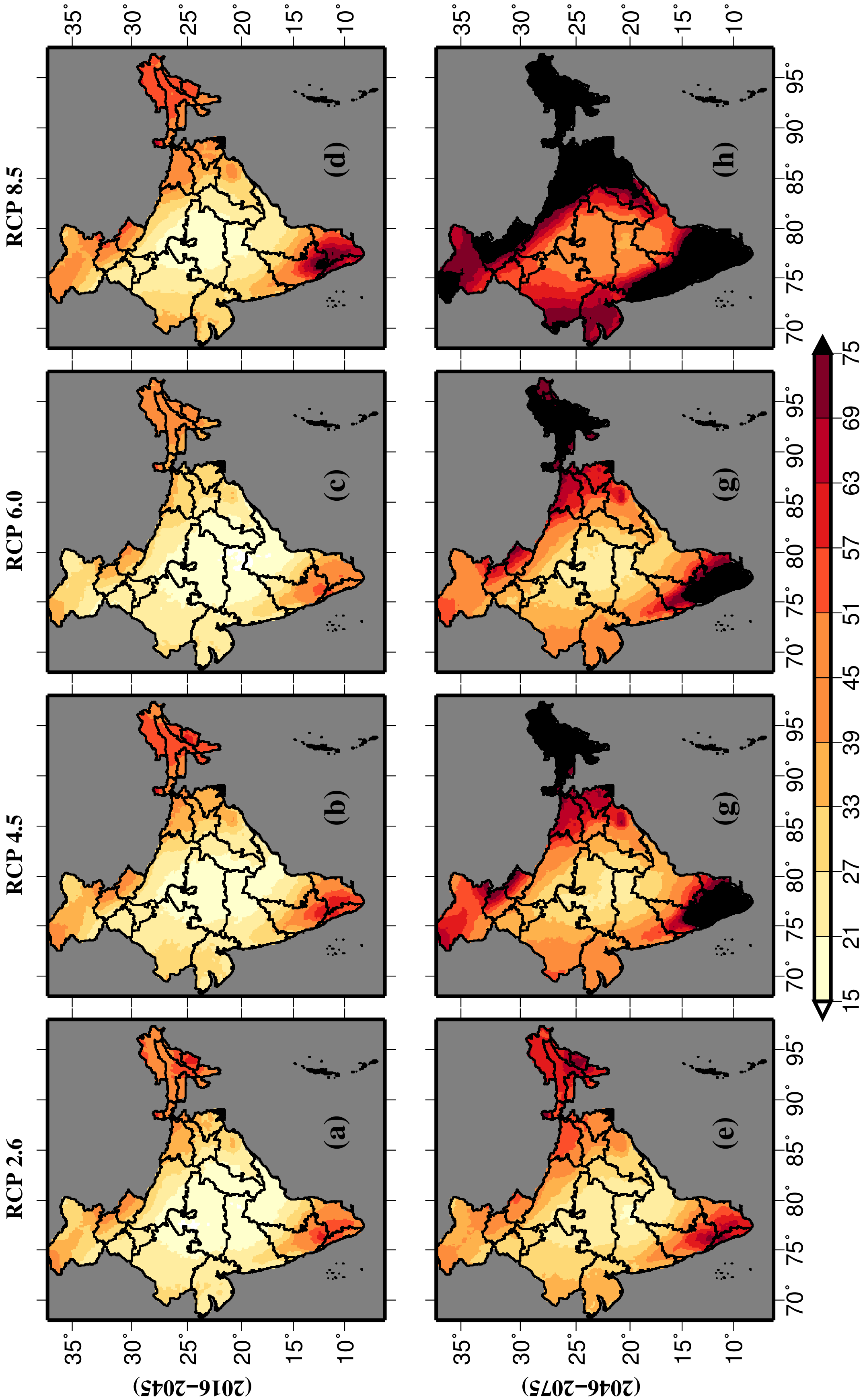


Figure 2.7: Multimodel ensemble mean projected changes in number of hot nights (i.e. above 95th percentile of minimum daily temperature during 1971-2000).

Considering the importance on agriculture, multimodel ensemble mean projected changes were estimated in mean annual night time (minimum) air temperature and growing degree days under the future climate (Figure 2.8 and 2.9). Significant increase in the night-time temperature is projected in India under the future climate. For instance, mean annual night-time temperature is projected to increase by 1-1.5 °C in the Near (2016-2045) term climate. Moreover, an increase of 2-3° in mean annual night-time temperature is projected in the Mid (2045-2075) term climate. Increases more than even 3°C are projected in some parts of the country under the RCP 8.5. Changes in the mean annual air temperature are reflected on the projections of growing degree days in India. Multimodel ensemble mean growing degree days are projected to increase by 100-350 in the Near and Mid term climate in India (Figure 2.9). Larger increases in growing degree days are projected in RCP 8.5 in the northern and northeastern regions. Increases in night-time temperature and growing degree days may lead to changes in cropping period and crop yields (Figure 2.9).

2.4 Observed and Projected Changes in Precipitation

About 80% of the total annual precipitation in India occur during the monsoon (June to September) season. Changes in the monsoon season precipitation were estimated using the observed data from IMD for the period of 1951-2013 (Figure 2.10). The monsoon season precipitation declined significantly in many parts of India during the period of 1951-2013 (Figure 2.10). Prominent declines in the monsoon season precipitation were observed in the Gangetic Plain and central India. It was observed that the monsoon season precipitation has become erratic during the last few decades [*Mishra et al.*, 2012]. Decline in the monsoon season rainfall resulted in an increased frequency of droughts in the Gangtic Plain region and profound water crisis in many other regions of India. [*Mishra et al.*, 2012] showed that the decline in the monsoon season rainfall is associated with the increased warming in the Indian Ocean sea surface temperature. However, *Bollasina et al.* [2011] reported that the decline in the monsoon season rainfall is associated with an increased aerosol over the Gangetic Plain region. Frequency of droughts has increased in the recent decades in India [*Mishra et al.*, 2014b], which had tremendous economic losses, societal implications, and challenges for the water management and agriculture.

Multimodel ensemble mean monsoon season precipitation, number of extreme precipitation events, and frequency of severe, extreme, and exceptional droughts were estimated for the reference (1971-2000) period using the downscaled and bias corrected data from the five CMIP5 models. It was noticed that the downscaled and bias corrected data represented spatial variability and magnitudes of the monsoon season precipitation considerably well (Figure 2.12). Moreover, frequency of extreme precipitation and droughts was also well represented in the downscaled and bias corrected datasets. Frequency of extreme precipitation was estimated using the 95th percentile of rainy (precipitation more than 1 mm) days during the reference period (1971-2000). Similarly, the frequency of severe, extreme, and exceptional droughts were estimated using the 4-month Standardized Precipitation Index (SPI) at the end of monsoon season for the reference period.

Multimodel model ensemble mean monsoon season precipitation is projected to increase by 10-15 % under Near and Mid term climate in most of the RCPs (Figure 2.14). However, under the RCP 4.5 scenario, which is the most representative scenario for India, the monsoon season precipitation is projected to decline in the Near (2016-2045) term climate especially in the central India (Figure 2.14). These results indicated that despite that majority of CMIP5 models [*Menon et al.*, 2013] project increases in the monsoon season precipitation under the projected future climate, large uncertainty remains in the monsoon season precipitation projections. For instance, *Kumar et al.* [2011] reported increases in the monsoon season precipitation in India under the projected future climate while *Ashfaq et al.* [2010] showed that the monsoon season precipitation is likely to be suppressed under the projected climate. Notwithstanding the wetter monsoon seasons that are projected, the risks of droughts cannot be ignored in the future climate.

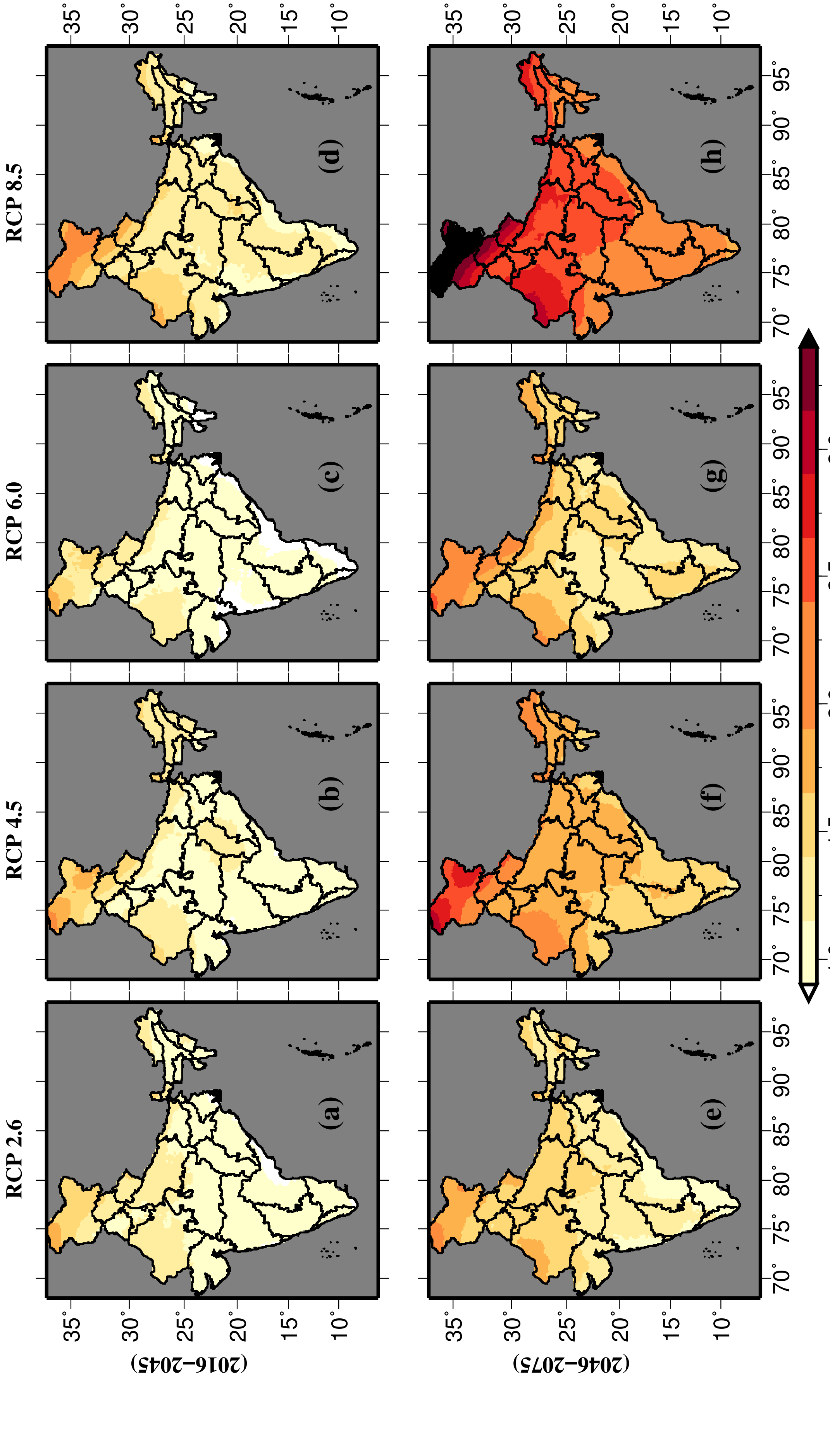


Figure 2.8: Multimodel ensemble mean projected changes (°C) in night time temperature.

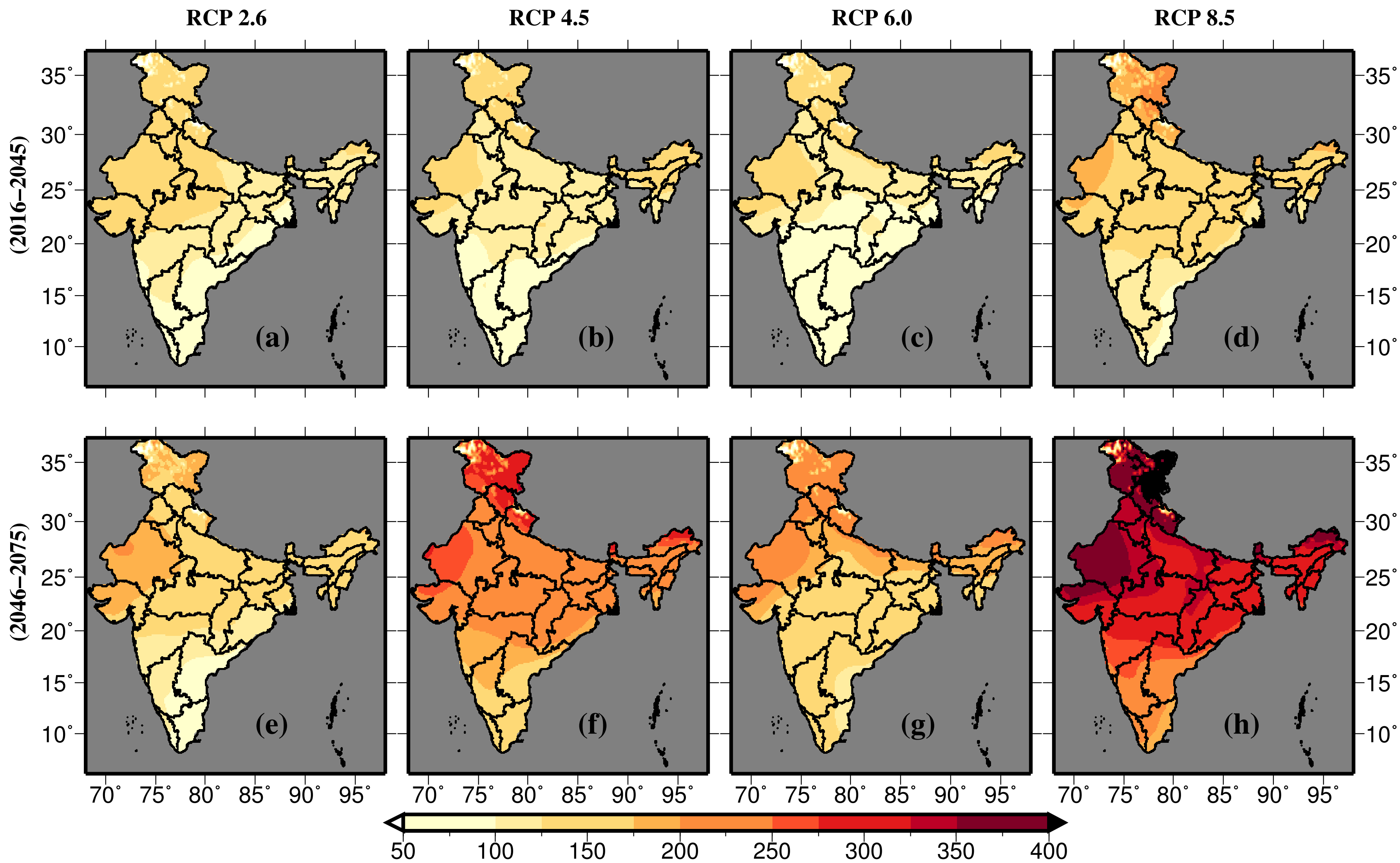


Figure 2.9. Multimodel ensemble mean projected changes in growing degree days. Changes were estimated with respect to the reference (1971-2000) period.

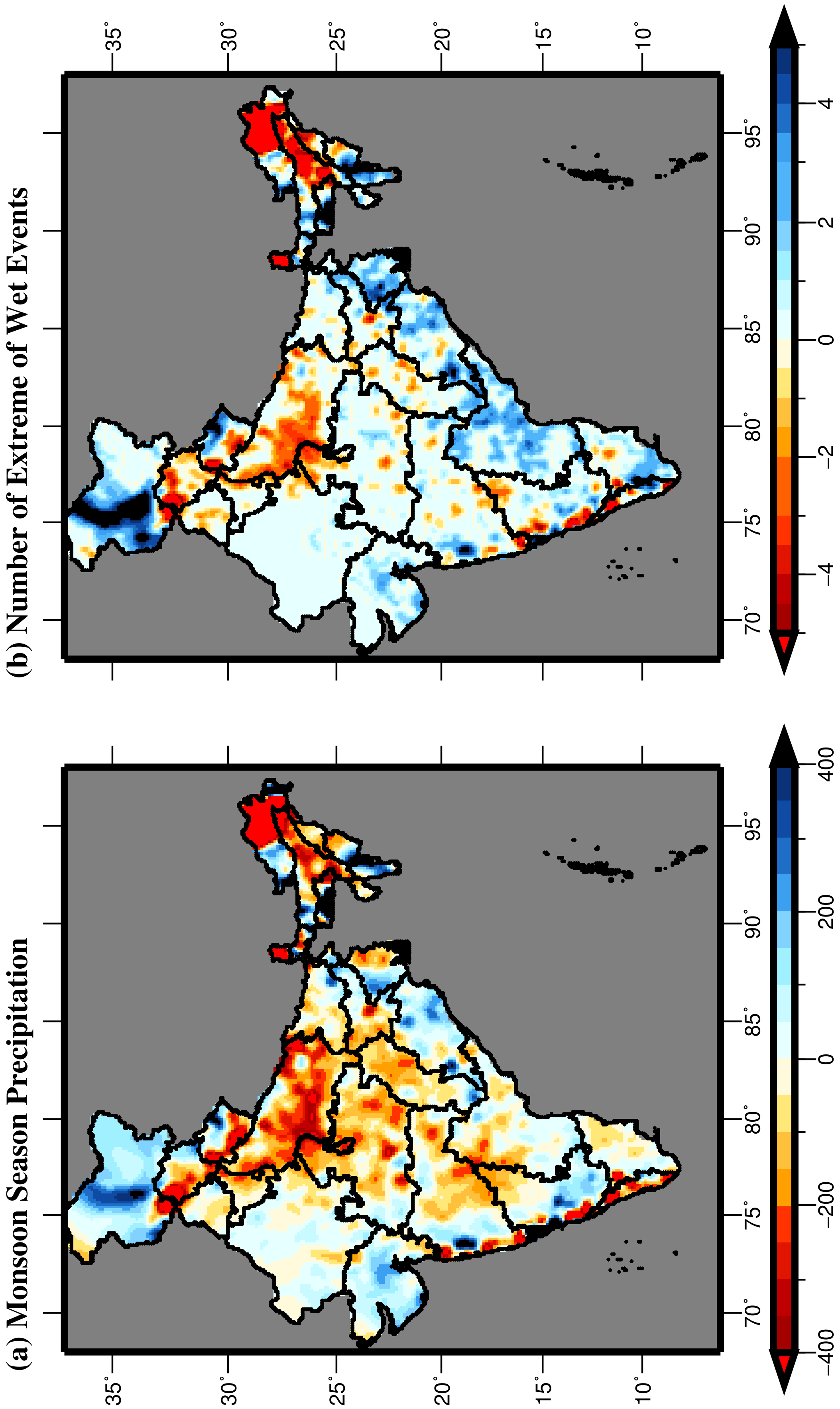


Figure 2.10: Observed change in the monsoon season precipitation (mm) during the period of 1951-2013

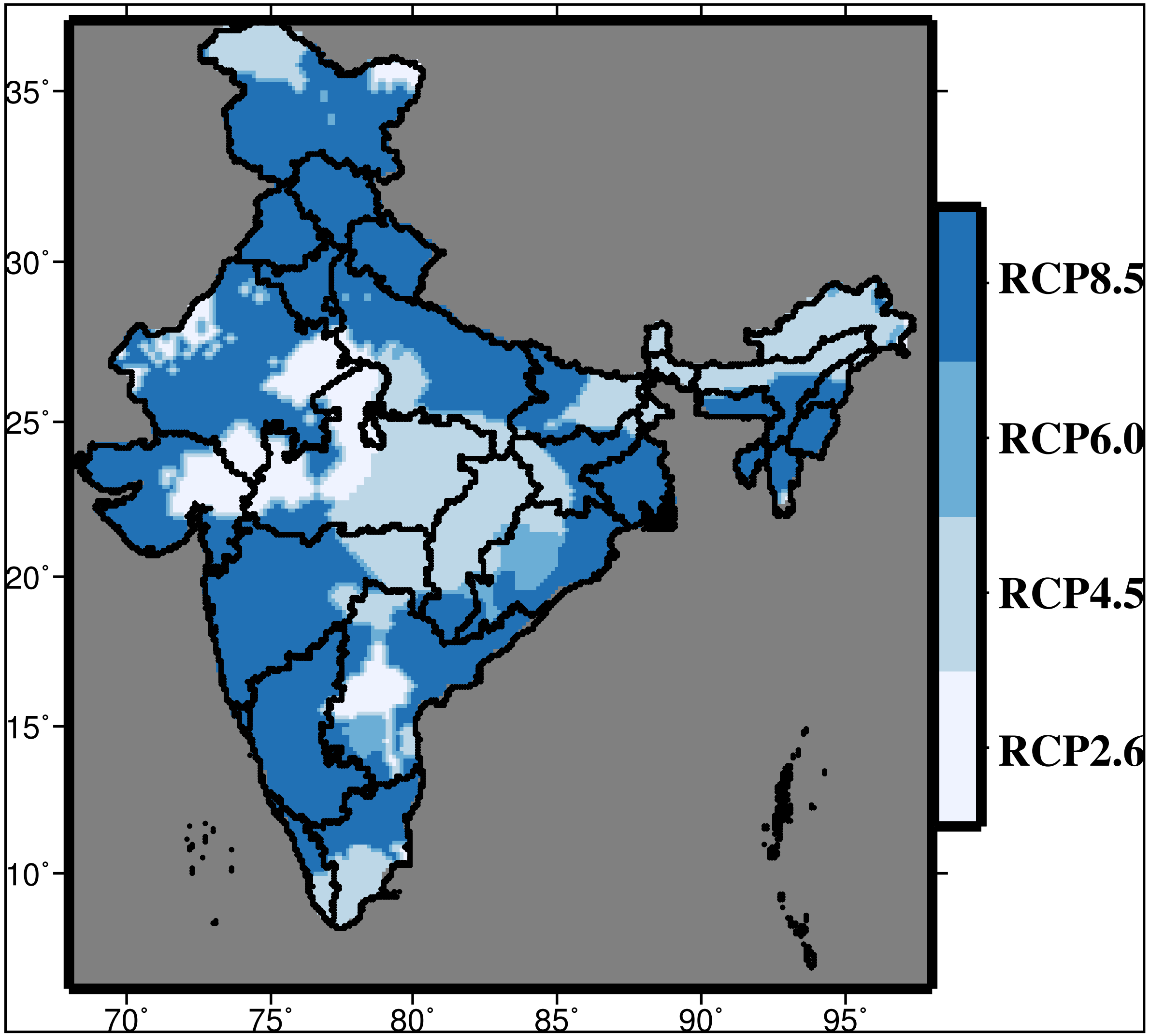


Figure 2.11: RCP path already followed in various districts for precipitation during 2006-2013

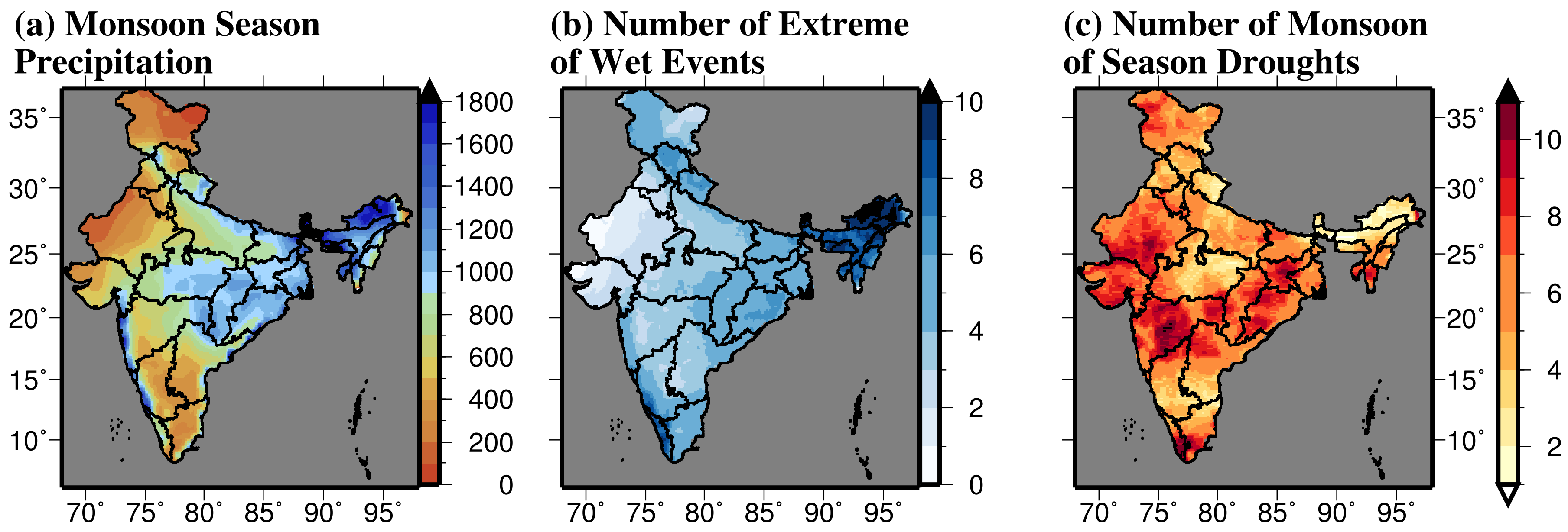


Figure 2.12: Historic mean (1971-2000) of (a) Monsoon season precipitation, (b) number of extreme precipitation events (above 95th percentile of rainy days for the base period), and (c) frequency of severe-exceptional monsoon season drought (base period: 1971-2000) from ensemble mean of GCMs.

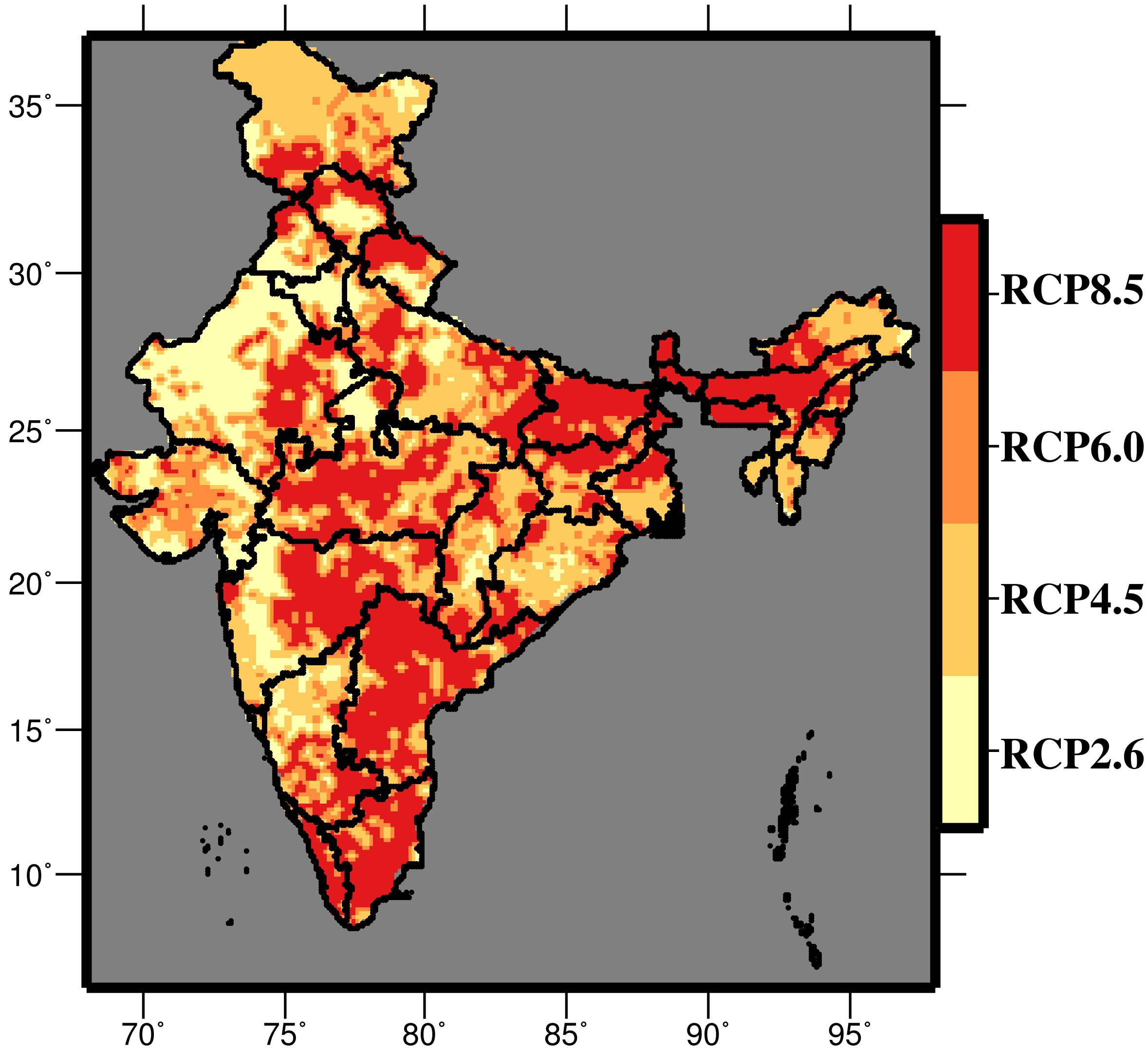


Figure 2.13: RCP followed based on precipitation deficit during monsoon season for the period 2006-2013.

Goswami et al. [2006] reported an increase in extreme precipitation in India under the observed climate. Moreover, *Ali et al.* [2014] showed that precipitation extremes increased in many urban areas during the last few decades. Changes in the frequency of extreme precipitation were estimated using the downscaled and bias corrected data from the best five CMIP5 models under the projected future climate. Changes were estimated for the Near (2016-2045) and Mid (2046-2075) term climate against the reference period. Despite the inter model variation (uncertainty), the ensemble mean frequency of extreme precipitation is projected to increase under all the RCPs (2.6, 4.5, 6.0, and 8.5). However, results showed decline in extreme precipitation frequency under the RCP 4.5 in the central India, which might be associated with the projected decline in the mean monsoon season precipitation (Figure 2.15). Increases in frequency of extreme precipitation may have far reaching implications for urban infrastructure, storm water management, and agriculture [*Mishra et al.*, 2015]. India has witnessed some of the most significant extreme precipitation events during the recent times. For instance, the extreme rainfall event that occurred in June 2013 causes loss of 6000 lives. On the other hand, extreme rainfall events in Jammu and Kashmir in 2014 led to substantial damage in property. Extreme precipitation events often cause flooding in the fast responding catchments such as urban areas and regions located in hilly terrain. Frequency of floods in India has increased during the recent decades, which caused migration of people and damage to agriculture and other infrastructure.

Droughts affect food and water security of a region directly or indirectly. For instance, meteorological droughts lead to soil moisture deficits [*Wang et al.*, 2009], affecting plant growths [*Chapin*, 1991] and affect overall quality and quantity of crops yields [*Mishra and Cherkauer*, 2010b]. Moreover, soil moisture depleting below permanent wilting point results in crop mortality putting food security of the region at risk. Drought during 1979 in India led to reduction of 20% in crop production. Other than food security, hydrologic droughts often lead to fresh water security in the affected region. Prolonged meteorological droughts lead to hydrologic droughts which in turn results in reduced streamflow [*Feyen and Dankers*, 2009], groundwater [*Dahm et al.*, 2003], and depleted lakes, ponds, and reservoirs. Major River basins and parts of India face regular occurrences of droughts, largely driven by erratic monsoon conditions [*Bollasina et al.*, 2011; *Mishra et al.*, 2012]. Multimodel ensemble mean projected changes were estimated using downscaled and bias corrected data for the future climate. Changes in the meteorological droughts were estimated using 4-month SPI at the end of the monsoon season (Figure 2.16). Here, it should be noted that the projected changes in agricultural droughts (based on soil moisture) and hydrologic drought (based on streamflow) may differ from those obtained for the meteorological droughts. This is mainly because meteorological droughts are based only on the monsoon season precipitation. However, soil moisture variability under the projected future climate can be affected by the increased warming. Similar to the projected changes in the monsoon season precipitation, frequency of severe, extreme, and exceptional droughts in the monsoon season is projected to decline in India. However, under the RCP 4.5, drought frequency is projected to increase in the Near (2016-2045) term climate (Figure 2.16). Additionally, drought frequency is also projected to increase under the RCP 8.5 scenario in the Mid term climate. These results indicate that despite the projected increase in the monsoon season precipitation, drought risks under the projected future climate in India can significantly affect food security and water management.

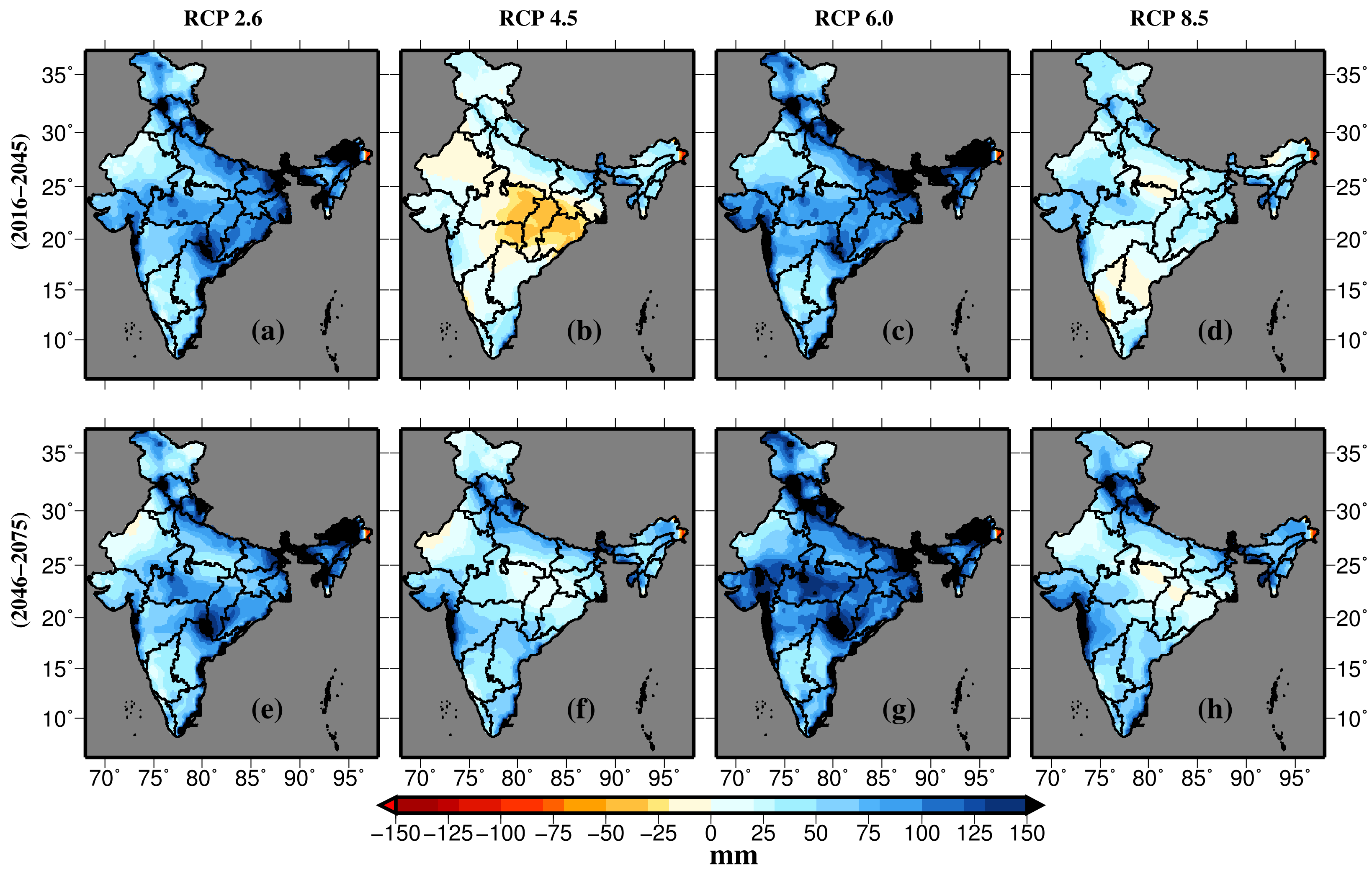


Figure 2.14: Multimodel ensemble mean projected changes (mm) in the monsoon season precipitation for the Near (2016-2045) and Mid (2046-2075) term period under the RCPs 2.6, 4.5, 6.0, and 6.5. Changes were estimated against the reference period of 1971-2000.

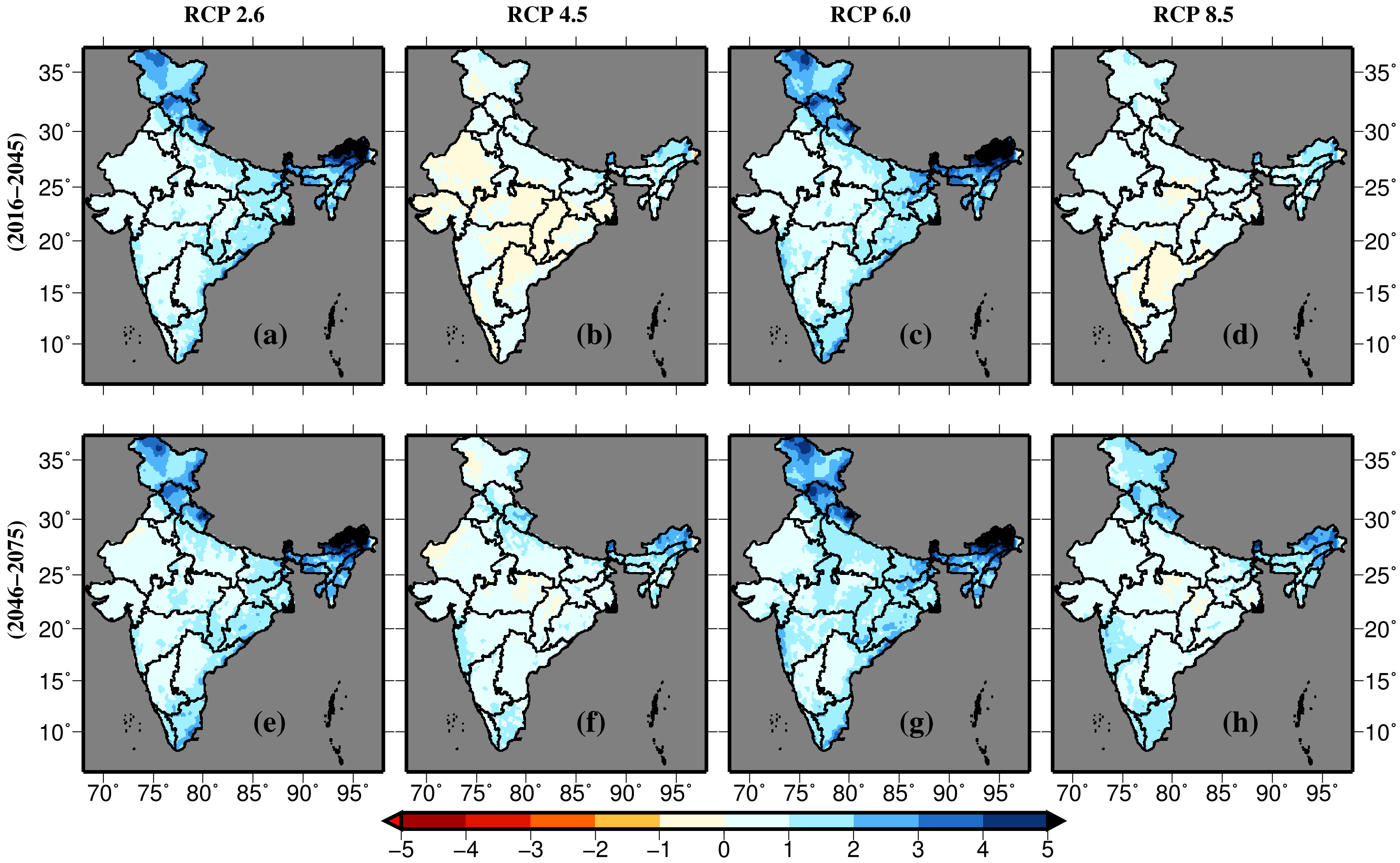


Figure 2.15: Multimodel ensemble projected change in number of extreme wet events (i.e. change in number of events above threshold estimated using 95th percentile from historic period of rainy days.

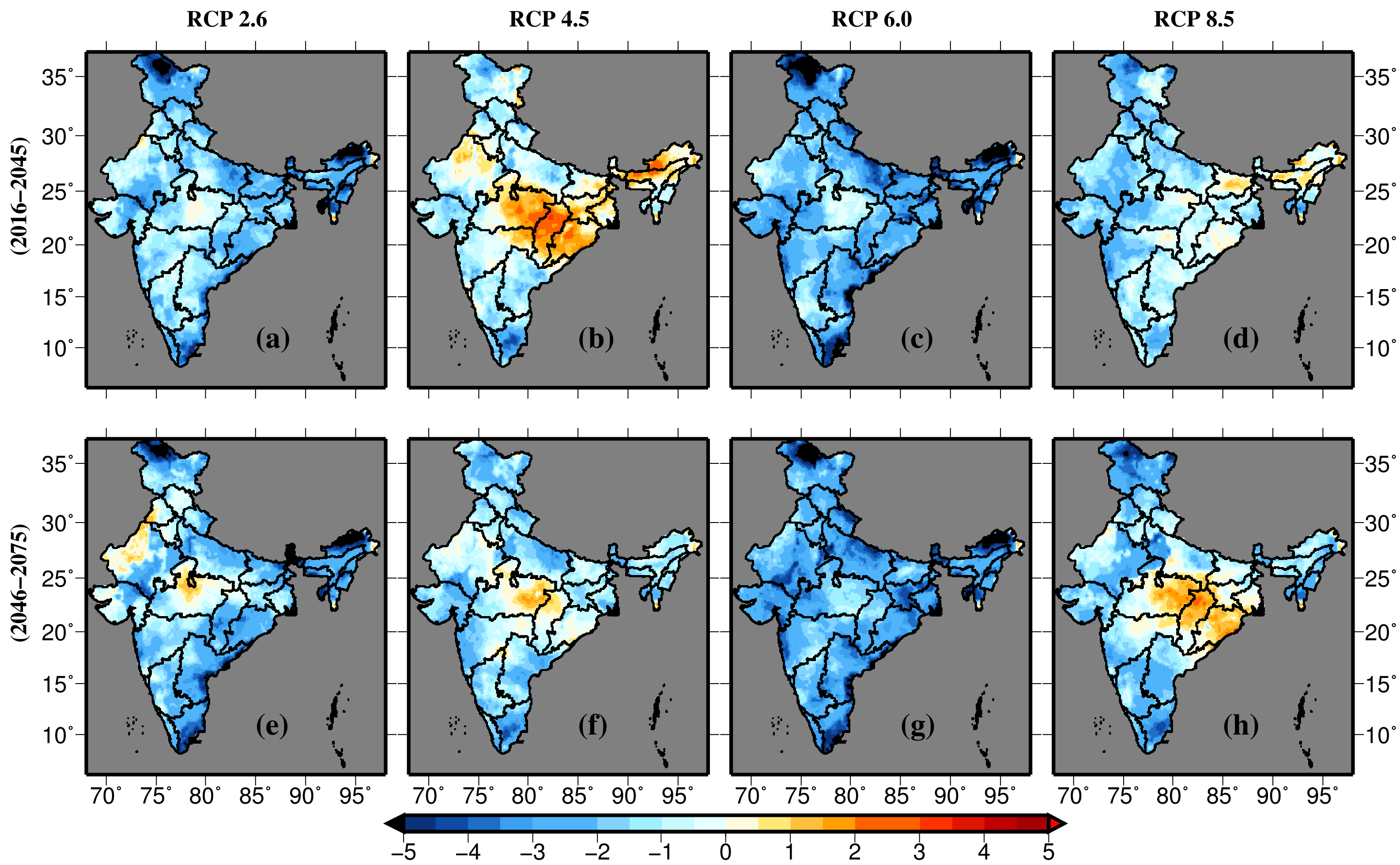


Figure 2.16: Ensemble projected change in number of severe-exceptional drought events (estimated based on Standardized Precipitation Index < -1.3) Reference period: 1971-2000.

2.5. Conclusions

Based on the findings, the following conclusions can be made:

1. India has experienced substantial changes in mean and extreme climate during the period of 1951-2013. For instance, mean annual air temperature has increased in many regions of the country. Other than the mean annual air temperature, prominent increase was observed in the number of hot days, night-time temperature, and growing degree days during the period of 1951-2013.
2. The monsoon season precipitation declined in many regions (western ghats, Gangetic Plain, and central India) during the period of 1951-2013. The monsoon season precipitation became more erratic leading to some of the most severe and widespread droughts during the recent decades (2002, 2009, and 2015). The increased frequency of droughts pose challenges to food security and water management in India. Drought during the monsoon season of 2015 led to water crisis in many regions of the country (Maharashtra, Karnataka, and Uttar Pradesh). Additionally, the monsoon season droughts that have increased during the recent decades posed tremendous socioeconomic challenges in many regions of the country.
3. Frequency of extreme precipitation events showed a mixed change under the observed climate. For instance, frequency of extreme precipitation increased in the eastern part of the country. On the other hand, declines in extreme precipitation events were noticed in some parts of the country.
4. High resolution (0.25 degree) downscaled and bias corrected climate change projections showed that India is projected to experience 1-1.5°C increase in mean annual air temperature in the Near (2016-2045) term climate. On the other hand, multimodel ensemble mean annual air temperature is projected to increase by 2-3 °C by the Mid-21st century.
5. Multimodel ensemble mean projections indicate that India is projected to witness substantial increases in night-time temperature and growing degree days, which may have profound implications for agriculture and crop production, Moreover, frequency of temperature extremes (hot days and hot nights) is projected to increase significantly under the projected future climate.
6. While projected increase in extreme precipitation events may cause enormous damage to infrastructure and result to flooding, which in turn may affect crop production and other socioeconomic aspects in India. Meteorological droughts are projected to decline under the future climate due to increase in the monsoon season precipitation. However, frequency of droughts is projected to increase in the Near (2016-2045) term under the RCP 4.5 scenario. Results indicated that despite projected increase in air temperature drought risks in India under the future climate cannot be ignored. Moreover, the soil moisture variability that affected agricultural production is likely to be affected by the projected warming in India in the non-monsoon season, which will pose challenges for irrigation water management under the projected future climate.
7. Climate change projections for India showed that the new and robust adaptation strategies will be required in the sectors of agriculture, water resources, and public health under the future climate. New approaches to assess projected losses in economy and infrastructure are needed that can be used to estimate adaptation gap at local scale.

Chapter 3

Present Adaptation Efforts by India

Cyclones cause wide spread damage across economic strata every year

3. Present Adaptation Efforts by India

India remains among the most vulnerable countries to climate change impacts [*IPCC*, 2014]. A heavy dependence on agriculture; the Himalayan ecosystem; potentially reduced precipitation under a changing climate; long coastline; investments in infrastructure and large population imply that nearly all major sectors are required to adapt to climate change. Therefore, Indian policymakers need to anticipate and respond to climate change induced challenges.

The impacts of climate change and related adaptation needs for India are contingent upon the extent of mitigation that is achieved globally. For instance, the level of adaptation measures required in a world with four degree temperature rise will be significantly more than that required with two degree temperature rise. A key factor that will help countries respond to adaptation needs is their level of development. This is because development is known to alter adaptive capacity of communities and regions [*Smit & Wandel*, 2006]. Investments in development are critical to reducing underlying vulnerabilities, thereby ensuring success of adaptation measures [*Schipper*, 2007]. Higher levels of development typically confer greater adaptive capacity to nations. As a consequence, any discussion on climate change impacts, adaptation needs & gaps, finance and policies must be situated within the broader discussion of development. This chapter provides an overview of institutions, development policies and budget commitments of the Government of India that are aligned with improving capacity to adapt to climate change.

The Government of India has clearly recognised the need to build adaptive capacity across sectors and communities by investing in sustainable development [*Shukla et al*, 2015]. Institutional arrangements at various levels of governance include departments in nodal ministries at the Central and State governments as well as development finance institutions. These government institutions act in coordination with the International organizations, private sector entities and civil society organizations to direct investment and public finance for climate change [*Nakhooda & Jha*, 2014].

The flagship programme of the Indian Government to catalyse policy and regulatory action on climate change is the National Action Plan on Climate Change (NAPCC). The NAPCC comprises eight missions – three of which are mitigation focussed (National Solar Mission; National Mission on Enhanced Energy Efficiency; National Mission for Green India), four emphasise adaptation and natural resource conservation (National Water Mission; National Mission for Sustaining the Himalayan Ecosystem; National Mission for Sustainable Agriculture; National Mission on Sustainable Habitat) and one (National Mission on Strategic Knowledge) connects both. Each mission identifies overarching national goals and sets quantitative targets (where applicable) for mitigation or adaptation (Box 2.1).

Box 3.1 Adaptation relevant missions under the NAPCC

Launched in 2008, the NAPCC is the cornerstone of climate policy in India. These missions are highly interconnected measures to facilitate action across sectors. This policy co-ordination is essential for addressing the multifaceted nature of climate change. It can also help to leverage policy co-benefits across different sectors.

Here we discuss the five missions relevant to adaptation. The *National Mission on Sustainable Habitat* is aimed at better urban planning through expansion of public transport services, updating building energy efficiency, urban waste management, energy audits as well as rainwater harvesting. It aims to build climate resilience buildings and early warnings for disasters.

The *Mission on Sustainable Agriculture* aims to enhance food security through water conservation in 35 million hectares of rain-fed areas by 2017; as well as promotion of nitrogen efficiency in farming practices; instilling better risk management practices among farmers. This closely related to the *National Water Mission* that aims to increase water use efficiency by 20% in rural and urban areas.

The *National Mission on Himalayan Ecosystem* aims to promote biodiversity, development of green roads and sustain the livelihoods of millions of people living in these areas. Also included is continuous monitoring of ecological systems in the Himalayas through field and satellite observations.

The *Mission on Strategic Knowledge* aims to build human and institutional capacity in the area of climate change through innovative data collection and sharing, private sector involvement and investment in technology for adaptation and mitigation.

These missions have provided direction to states in mainstreaming climate change actions into state level development plans. This decentralized approach to climate policy (adaptation and mitigation) led to states formulating State Action Plans on Climate Change (SAPCC). Agriculture, water, health, forests, coasts are the major sectors covered under the themes of state specific climate impacts and vulnerability assessments, capacity building and developing adaptation measures [*MoF*, 2013; *Jha*, 2014]. Thirty two States and Union territories in India have formulated SAPCC drafts of which nineteen have been endorsed and the rest are under review [*MoEFCC*, 2014; *Dubash & Jogesh*, 2014]. In addition to the Centre and states, there exist a network of 127 institutions that form the Indian Network on Climate Change (INCCA) to develop knowledge in the area; Climate Change Centres with the Ministry of Science and Technology; there are also entities such as National Bank for Agriculture and Rural Development (NABARD) is the nodal implementing agency by the Green Climate Fund. As a result, a series of institutions are in place to address climate change challenges in India.

3.1 Commitments through Union Budgets

The Government of India has been committing resources through its budgets towards building resilience against climate change. Previous studies have analysed Union Budgets to estimate the amount of public spending on adaptation in India. The approach adopted was that development spending in key sectors (e.g. water, agriculture, health etc.) has a direct impact in building adaptive capacity by enhancing development. Using this approach, budgets for relevant schemes and programmes were analysed. For instance, in their analysis, *Ganguly and Panda* (2009) found that adaptation spending was ~1.7% of GDP in 2006-07. These are fairly consistent with other analyses that find that adaptation spending in India has been increasing from 1.45% of GDP (2000-01) to about 2.82% of GDP in 2009-10 [*MoEFCC*, 2015].

We carried out an analysis of Union budgets to understand present level of public spending on adaptation in India. For this, we identified thirty key ministries and studied their individual annual budgets. These included union ministries of rural development, tribal affairs, development of north eastern region, urban development, housing and urban poverty alleviation, water resources, drinking water supply and sanitation, agriculture, food processing industries, consumer affairs food and public distribution, environment forests and climate change, health and family welfare, women and child development new and renewable energy, power, mines, labour and employment, finance, law and justice, MSME, science and technology, earth sciences, infrastructure, road transport, railways, textiles, tourism, etc. We identified budget heads for different schemes and programmes that had direct and indirect links to climate change adaptation.

We find that the Government of India is consistently committing resources through the annual Union Budgets towards public spending on climate change adaptation. We observe that over the last ten years, the overall budget outlay has increased by a factor of four (from 2003-04 to 2014-15). On the other hand, development and adaptation related outlays have increased by a factor of five (Figure 1). This implies that rate of growth of government allocation to development and building adaptive capacity has been increasing steadily over the years, much faster than that of overall annual budgets. The public spending on adaptation in 2014-15 was INR 2130 billion i.e. 12% of the budget for the year (~2% of GDP).

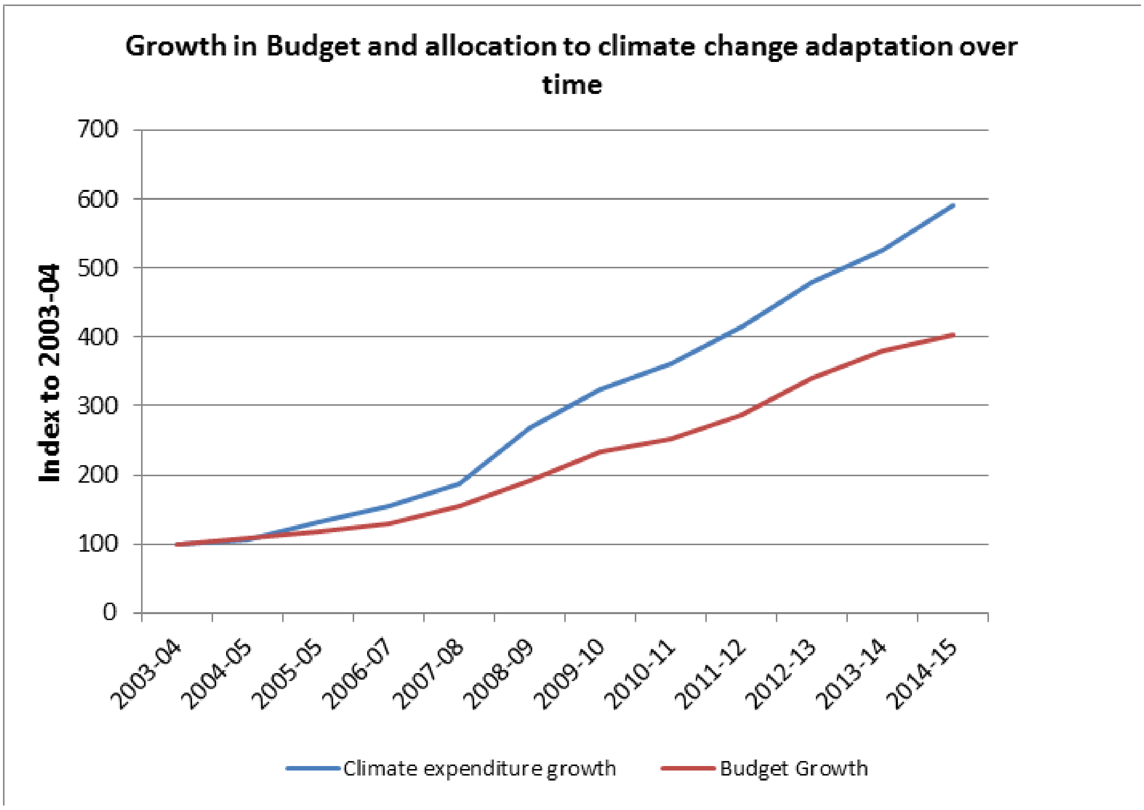


Figure 3.1 Allocation to development activities that enhance adaptive capacity has been increasing over time

The distribution of this development and adaptation-centric expenditure across different ministries has been provided in Figure 3.2. It is noted that development and adaptation-centric expenditure is a part of the total budget allocation for respective ministries. Three ministries – rural development, agriculture and consumer affairs, food and public distribution together constitute roughly one half of the development and adaptation expenditure. This is understandable given the direct and strong linkages of development with poverty alleviation. Ten per cent was allocated for health and family welfare and seven per cent for water and sanitation. Of the remaining, five and four per cent were allocated with women and child development and human resources respectively. Across the three key sectors of rural development, agriculture and food and public distribution, several policies such as Mahatma Gandhi National Rural Employment Guarantee Scheme, National Mission on Sustainable Agriculture, National Food Security Mission and National Initiative on Climate Resilient Agriculture have been put in place.

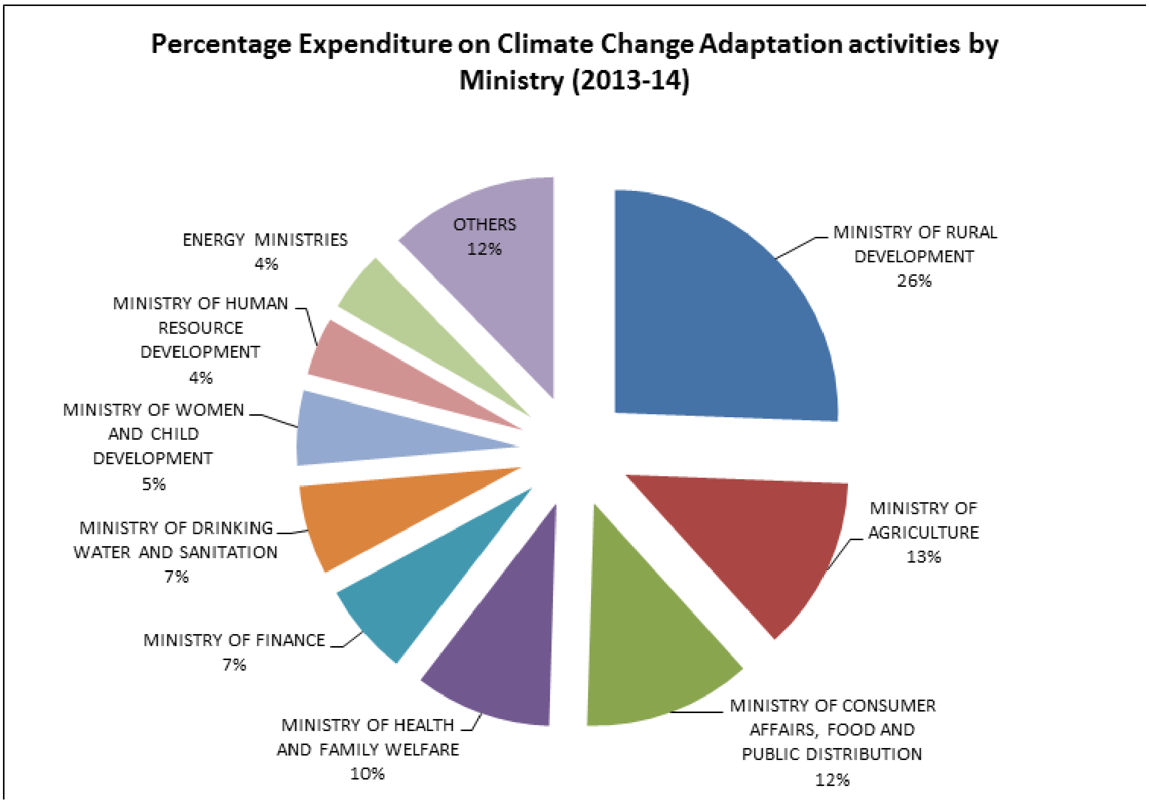


Figure 3.2: distribution of public expenditure on climate change activities by ministry

In addition to the overall development expenditure, we identified twenty-one from the sixty-six Central Government Schemes (Annexure 1) that are directly related to climate change adaptation. For each of these schemes, we carried out an analysis of the budgets over the last five years to study trends in expenditure. We mapped the revised budget estimates as well as the actual expenditure. This difference between the revised and actual expenditure has been identified as the '*financial implementation gap*'. In addition to the central budgets, we analysed budgets for two states – Kerala and Uttarakhand. Furthermore, we analysed international financial contributions to India (from multi-lateral agencies) for adaptation related projects.

Figure 3.3 shows the difference between the revised budget estimates and actual expenditure across 21 programmes. The total commitment (actual expenditure as per revised estimates for 2013-14) being INR 740 billion during 2013-14 or 0.7% of GDP. This level of commitment has remained roughly the same across the last five years.

It is observed that across the five year period (2009 – 2013), the actual cumulative expenditure was INR 3800 billion. This exceeded the budgeted estimates (cumulative budget over five years was INR 3746 billion) by INR 54 billion. However, on a year on year basis, there is a 13.5% decline in actual expenditure from 2010-11 to 2013-14. This may be related in part to the fiscal prudence measures instituted by the Indian government.

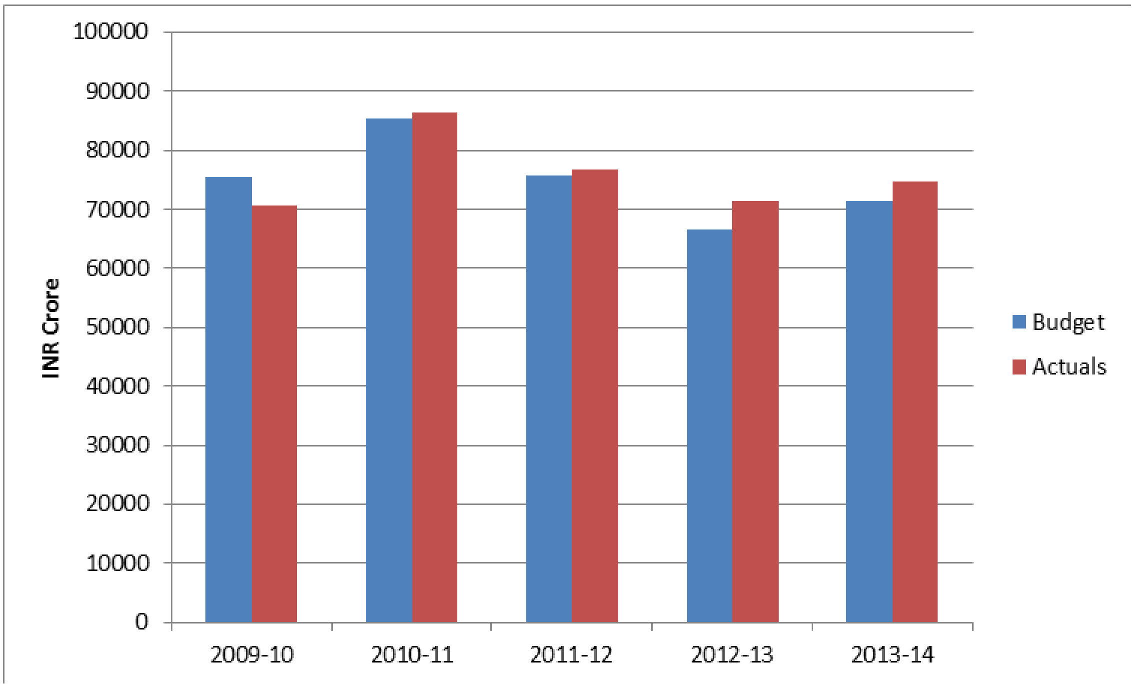


Figure 3.3 Actual versus Budget expenditure across 21 Central Government Programmes relevant to Climate Change Adaptation

Based on this analysis, no implementation gaps for budget expenses are observed. It must be noted that this analysis does not capture contributions made by the States towards adaptation actions. Therefore the total cumulative investments may be significantly higher. However as Union budgets account for over 50% of expenditure, this analysis provides a good indicator of broad policy trends. Nonetheless it highlights the requirement for higher commitments towards public spending on adaptation. To fill this very gap, the Government of India set up the National Adaptation Fund that has committed INR 3500 million (US $ 55.6 million) to combat adaptation needs in different sectors. This spending is over and above sectoral spending by the various ministries.

3.2 Commitments through state budgets

In addition to the Union Budget, we analysed state budgets to understand allocations for development activities that enhance adaptive capacities to withstand adverse impacts of climate change. In 2013-14, this allocation was estimated at INR 3100 billion (US $ 47.7 billion). In addition to the current spending, every state has been working to develop State Action Plans on Climate Change (SAPCC). These are an extension of the NAPCC at the sub-national level. The key objectives of the SAPCC include sustainable development for the state, protection of the most vulnerable populations in face of a changing climate and financial mechanisms for policy implementation [*Shukla et al*, 2015]. The framework of SAPCC allows states to align their development needs with national goals.

We analysed the budgets of states that have submitted their action plans. The total requirement for finance as indicated by the states (until 2030) is INR 10950 billion (US $ 168 billion). This is about three times the current expenditure and will require additional financial resources. It must be noted that different states have provided budgets for different time periods (2017, 2025, 2030) and thus the actual requirements may be significantly higher. As clear demarcations for adaptation and mitigation related activities are not always provided, in certain places, we have used our expert judgment in arriving at this estimate. A large proportion of the budget is for activities related to adaptation (~70 % to 75%) and the rest is for mitigation. Of the estimated budget for adaptation (Figure 3.4), the highest requirement is for agriculture (~83%), followed by forests (9.6%) and water sector (4.6%). The balance 2.8% is divided over other sectors such as infrastructure, livelihoods, health, coasts and weather extremes. Whereas the budget estimates have been provided by the states, there remains the need to understand mechanisms of how this will be financed.

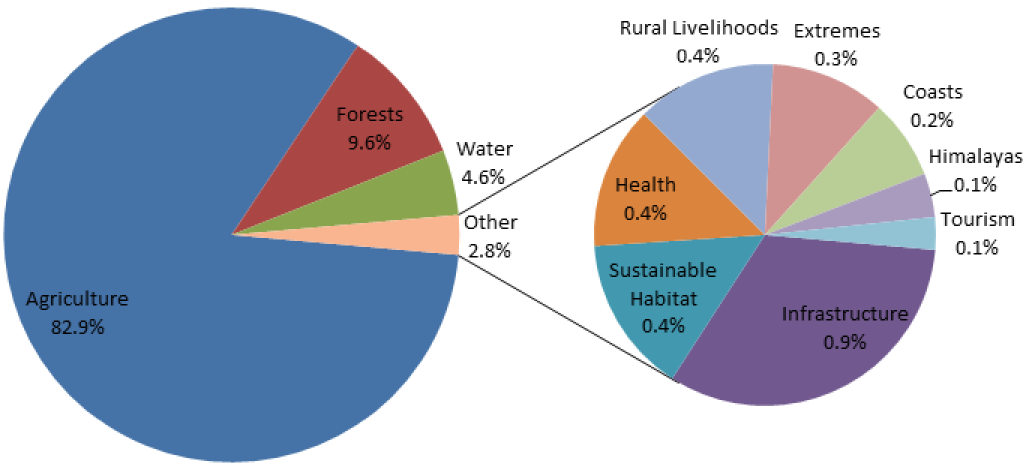


Figure 3.4: Sectoral break up of states budget requirement for adaptation

3.2.1 Uttarakhand

Uttarakhand, situated in northern India at the foothills of the Himalayas was formed as the 27th state of India. With a population of about 100 lakh people spread over 13 districts it is rich in natural resources such as water, forests and biodiversity and remains susceptible to climate change impacts. We undertook an analysis of budgets for the state of Uttarakhand to understand the public finance of adaptation at the state level. It is well understood that based on state priorities, these numbers may widely vary. Nonetheless, it remains important to study state budgets to get a sense of the direction and quantum of spending.

We find that year on year roughly 40% of the state budget across different sectors was allocated for development activities (Figure 3.5). However, there has been a lag between allocation and actual expenditure. The implementation gap therefore has varied across years between two to seven per cent.

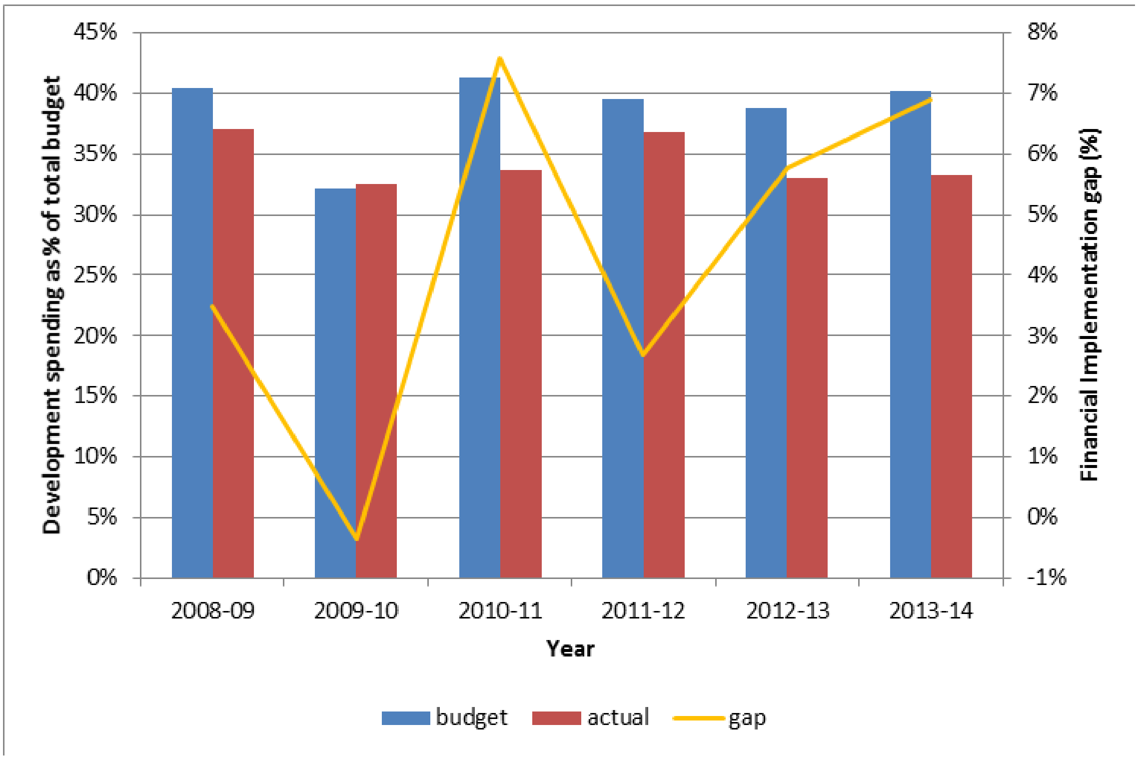


Figure 3.5: Development spending as a proportion of total budget for Uttarakhand across the years. The orange line shows the implementation gap (in %) across years studied

Of the total budget, we attempted to classify broadly spending into different groups such as capacity building, technology facilitation and knowledge development. To do this, the authors independently categorised each budget item into the three categories (where appropriate). In the event of any discrepancy, the final category was arrived at by mutual discussion. This approach is subject to bias, but was used to outline broadly the contours of state level spending. The analysis was carried out namely for three sectors – agriculture, rural development and water.

In the agriculture sector about 64% of the budget is focussed on technology development, 26% on capacity building and the remaining 11% around knowledge building. In the water supply and sanitation sector as well there is a dominant focus on technology (59%) followed by capacity building (40%) and knowledge and institution building (1%). On the other hand for rural development, the focus majority of the budgeted spending in focussed on building human capacity (56%) and the remaining 44% on developing technology.

3.2.2 Kerala

Kerala, a state situated in South-western India is known for its achievement on the human development index. With around 580 kilometres of coastline, majority of its livelihoods come from fisheries, agriculture and tourism. All these sectors are vulnerable to sea level rise and changes in coastal ecology as a result of climate change. We undertook an analysis of budgets for the state of Uttarakhand to understand the public finance of adaptation at the state level.

For the state of Kerala, we find that year on year roughly 30% of the state budget across different sectors was allocated for development activities (Figure 3.6). However, it is difficult to comment on any long term trends due to unavailability of budgets. The implementation gap across the two years studied varies between five to six per cent.

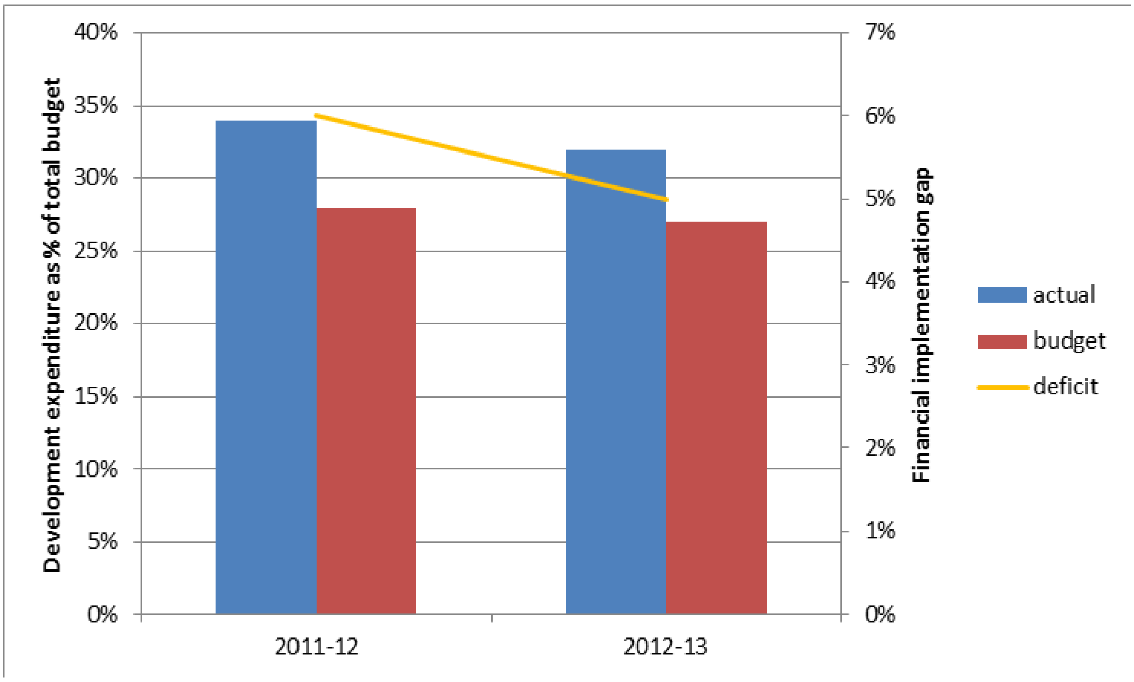


Figure 3.6 Development spending as a proportion of total budget for Kerala across the years. The orange line shows the implementation gap (in %) across years studied

3.3 International funding

From the year 1991 onwards, we identified 38 projects (relevant to climate change adaptation) supported by international organizations such as Global Environment Facility, United Nations Development Programme, World Bank and Asian Development Bank. These projects are spread across areas addressing urban areas, agriculture and natural resources, water, transport crises prevention and cross cutting multi-sectoral issues.

The total international support received across 38 projects is INR 306 billion (US $ 4.7 billion). Of the different agencies (Figure 3.7), highest number of projects is supported by the Asian Development Bank (66%), followed by World Bank (33%) and Global Environment Facility (1%). The two projects by the Global Environment Facility, received co-financing of INR 19 billion (US $ 288 million) by the Government of India.

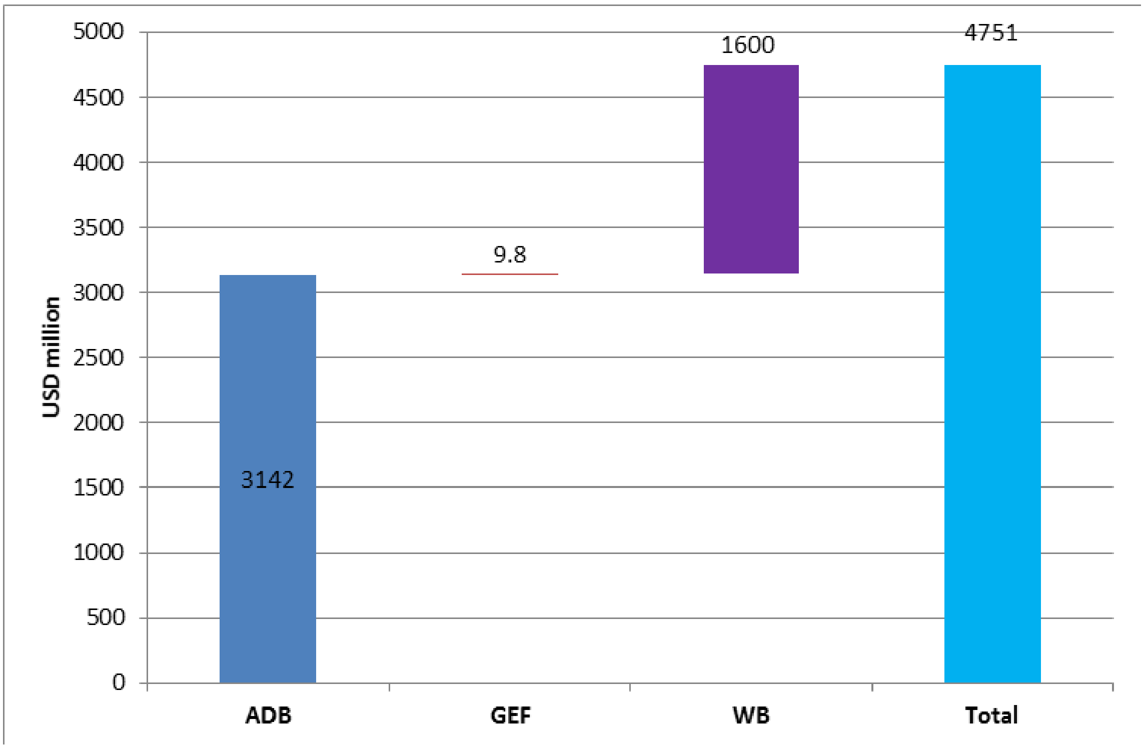


Figure 3.7: International contribution towards climate change adaptation projects in India since 1993

This suggests that international financing constitutes a small fraction (~3.4%) of national resource commitments towards climate change (Figure 3.8).

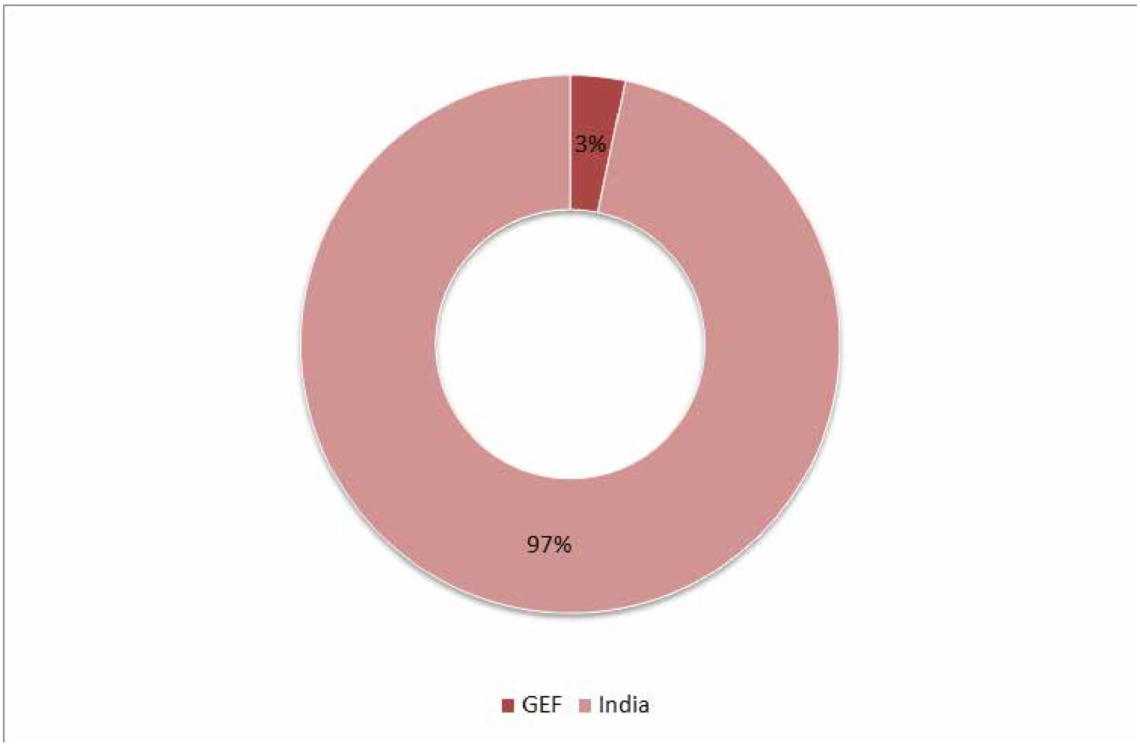


Figure 3.8: Co-financing (in percentage) by Government of India on Global Environment Facility Projects related to Adaptation

3.4 Cost of extreme events

In addition to preparing for adaptation, countries need to prepare for the loss and damage due to increased intensity and frequency of extreme events as a consequence of climate change. Over the last fourteen years, India experienced several extreme events. There were 131 instances of major flooding, 51 instances of cyclones and 26 instances of heat and cold waves as well as three instances of major drought [*EMDAT*, 2015].For heat and cold waves, we estimated Statistical Value of Life (VSL). For this we used VSL values for India from *Madheshwaran* (2007). For the remaining events (floods, drought and storms) we used values of economic losses as provided in the *EMDAT* (2015) database.

The total costs associated with extreme events were INR 3315 billion (US$ 51 billion). Of these, estimated losses (Figure 3.9) for floods were highest INR 2509 billion (US$ 38.6 billion), followed by cyclone related damage INR 559 billion (US $ 8.6 billion). It must be noted that these numbers are under-estimates as they capture only direct losses. Furthermore, an assessment of economic losses has not been carried out for every single event. Therefore, actual losses may be significantly higher. As the intensity and frequency of extreme events are expected to increase under a changing climate, costs associated with extreme events may rise significantly in future.

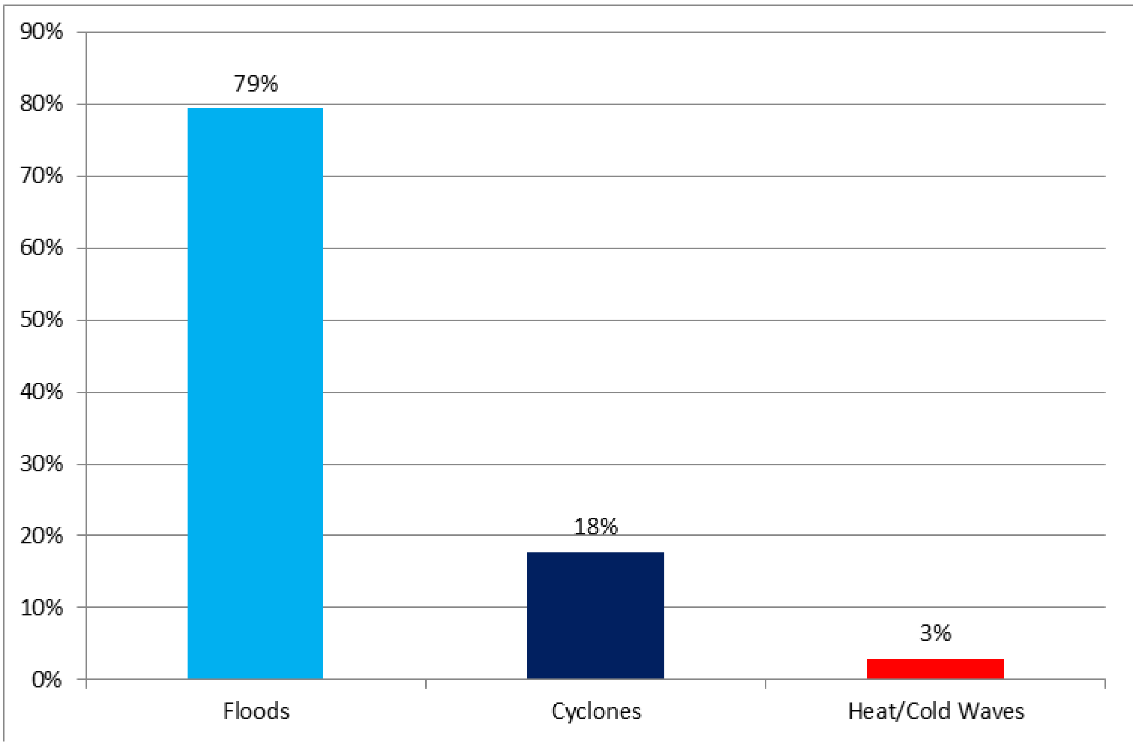


Figure 3.9: Direct costs associated with extreme events in India (2000 – 2014)

We observe (Table 3.1) that in a single year (2013-14) eleven major extreme events were recorded across India [*EMDAT*, 2015]. The economic losses were estimated only for four events and are estimated at INR 146 billion (US $ 2.25 billion). In addition, for a single year 2013-14 the National Agricultural Insurance Scheme disbursed monies worth INR 25 billion to agriculture farmers who have taken Loans. The losses borne by small and marginal farmers can be upto ten times this amount. The costs do not include small droughts, minor local weather related events such as traffic disruptions, supply chain disruptions, urban flooding, power disruptions etc. Therefore, the loss and damage related to climate extremes may be as high as US $ 5-6 billion each year.

Table 3.1 Major extreme events in 2013-14

Disaster type	Location	Total Deaths	Total Affected	Total Damage ('000 US$)
Storm	Uttar Pradesh state	9	0	NA
Storm	Andhra Pradesh	8	4	NA
Flood	Uttarakhand, Himachal Pradesh, Uttar Pradesh, Bihar, Karnataka, Kerala, Gujarat, West Bengal	6054	504473	1100000
Extreme temperature		557	0	NA
Flood	Uttar Pradesh state	174	500000	NA
Flood	Assam province	80	2000000	NA
Flood	Hopal, Hoshangabad, Seoni, Narsinghpur, Jabalpur (Mahya Pradesh); Uttar Prasdesh; Assam	73	40000	NA
Flood	Orissa, Andhra Pradesh	72	375000	260000
Storm	Orissa, Andhra Pradesh, Jharkhand, Bihar, West Bengal, Chhattisgarh states	47	13230000	633471
Storm	Bihar, Jharkhand states	32	0	NA
Storm	Andhra Pradesh	10	0	262000

Source: *EMDAT* Database (2015); NA – Not Available

3.4.1 Uttarakhand Floods of 2013

On the 16th and 17th of June, 2013 the state of Uttarakhand experienced extreme rainfall that resulted in severe devastation. The state had not witnessed this level of flooding in over 80 years (Swiss Re, 2014). The resulting losses in infrastructure, human life and livestock were immense. Over 6000 people lost their lives and more than 500000 people were affected because of the event [*EMDAT*, 2015]. Thousands of pilgrims were left stranded for several days and economic losses were estimated at US $ 1.1 billion [*EMDAT*, 2015]. Of these, US $ 0.5 billion were estimated to be insured losses for agriculture and hydropower stations [*Swiss Re*, 2014]. It is expected that frequency and intensity of extreme events will increase with a changing climate. Therefore, investing in measures to prevent loss and damage are crucial in future.

3.4.2. Droughts and floods affecting Indian agriculture is a regular impact

There is a national agriculture insurance scheme for all the loanee farmers. The Government of India subsidizes the insurance premium for these farmers. Incase of any loss, the insured amount is paid to the farmer and to the concerned financial institution that had provided agriculture loan. During 2013-14, NAIS disbursed INR 25 billion against insurance claims. However, these disbursements do not include the losses borne by farmers, including small and marginal farmers, that have not taken agriculture loans. These losses could be upto 10 times this amount.

3.5 Conclusion

The current chapter has provided a brief overview of current efforts related to climate change adaptation in India. There exist institutions at all levels of governance to coordinate climate change mitigation and adaptation activities in India. The Government of India has been committing resources through Union and State budgets towards public finance of adaptation. This contribution has been growing over time, with the aim of developing adaptive capacity.

Table 3.2 Public spending on activities to enhance adaptive capacity

Budget Commitment	INR (billions)	US $ (billions)
Union budget	2130	32.7
State budgets	3100	47.7
21 programmes related to climate adaptation	740	11.3
Total	5970	91.8

The total contribution through the Union and State budgets (Table 3.2) is INR 5970 billion (US $ 91.8 billion). The gaps between budget outlays and actual expenditure remain small. International funding has remained a small proportion of the overall finance for climate change. Disasters such has Uttarakhand have taken a huge toll and more needs to be done in terms of prevention through early warning systems etc. However it is equally important to understand the potential future impacts, their geographic and temporal distribution. Subsequent to understanding these impacts, it is important to know the amount of risk that we wish to cover and the finance that will be required for the same. Finally, this finance needs to be channelled through institutions to build action across sectors and stakeholders. Having addressed this gap in knowledge, India can be better prepared to adapt to climate change related challenges. The subsequent chapters discuss the knowledge, finance gaps that require to be addressed.

Chapter 4

Financial Gaps in Adaptation

Ripe crops getting severely damaged due to hailstorms is becoming more frequent

Extreme weather events cause flash floods, disrupting connectivity and endangering habitations

4. Financial Gaps in Adaptation

4.1 Introduction

It is well understood that the implementation of adaptation measures require financial resources. Any assessment of financial resources hinges on two pieces of information –estimating the quantum of finance required and the sources from where the finances will flow. The estimation of quantum of finance required is highly sensitive to the assumptions and methods with respect to the costs and benefits of adaptation. Typically, the approach involves connecting climate change risks with costs of implementing adaptation actions. The decrease in risks (as a consequence of implementing adaptation actions) is the benefits accrued. This estimation is critically linked to gaps in knowledge with respect to climate risks (and uncertainty), evidence of benefits of various adaptation actions. The sources of finance broadly may be public or private. Therefore, the financial gap for adaptation is the difference between the quantum required and the actual funds available.

Globally, several studies have attempted to assess the costs of adaptation. However, the results are not directly comparable given the differences in implicit adaptation targets and methodologies used [*UNEP*, 2014]. The first such study by the *UNFCCC* (2007) estimated adaptation requirements to be between US $30 billion to US $ 70 billion/year by 2030 for developing countries. The drawbacks of this study were partial sectoral coverage and little consideration of uncertainty. Subsequently, these estimates were revised to US $ 70 billion to US $ 100 billion by the *World Bank* (2010) using a sector impact assessment methodology. The World Bank study considered climate uncertainty in its assessment, but still had partial coverage and excluded policy costs. Since then, as the science and data have improved, there have been attempts to carry out more bottom-up national level estimations.

For India, there are few studies that have assessed the quantum of finance required for adaptation. One key study, by the Asian Development Bank estimates that implementation of adaptation actions will require India to invest 0.48% of GDP annually [*ADB*, 2014]. This translates to finance requirement of US $206 billion (excluding the energy sector) by 2030 [*MoEFCC*, 2015]. These findings were based on a top-down economic model for specific key sectors – agriculture, coastal and marine resources, energy, forests, health and water. However, this finance requirement may be underestimating finance requirements because sectors such as transport infrastructure (roads, bridges, ports) and buildings. Our assessment finds that adapting infrastructure to climate change may be as high as US $ 178 billion for current infrastructure alone. Further the *ADB* (2014) does not account for costs associated with policy implementation.

Currently, public spending is the mainstay of adaptation finance in India. The Government of India has been committing resources towards development to improve adaptive capacity. This has been discussed in detail in Chapter 2. In addition, the Government of India has set up the National Adaptation Fund. Through this, resources worth US $ 55.5 billion have been committed (that are over and above the spending under various development schemes). Compared to this, the international funding for adaptation (for India) is about a third of the domestic commitments. So far, about US $ 20 million have been approved for India (*Climate Funds Update*, 2015). Therefore, there remains the need to assess both the quantum of finance required as well as sources of the same to map the financial gap for India. Understanding India's financial gap requires – assessing the current and future climate risks under different scenarios (distribution), identification of adaptation actions and their associated costs (preventive costs) and finally understanding the quantum of uncovered risk (palliative costs).

4.2 Implications for alternate scenarios

Chapter 2 had projected the future climate under alternate scenarios for India. We use those results to articulate Adaptation gaps. The adaptation gap increases in future (Figure 4.1) as temperature distributions shift to right in the near term (2016-2045), and longer term (2046-2075) for RCP 2.6 scenario. These shifts are more pronounced under RCP 4.5, RCP 6 and RCP 8.5. This expansion of the adaptation gaps would require more financial resources to be committed for managing heat related mortality, morbidity, damage to eco-systems and space cooling. Many species may get extinct, including vegetative, land based, marine and aerial. The financial implication estimations are around 80% more in real terms than present.

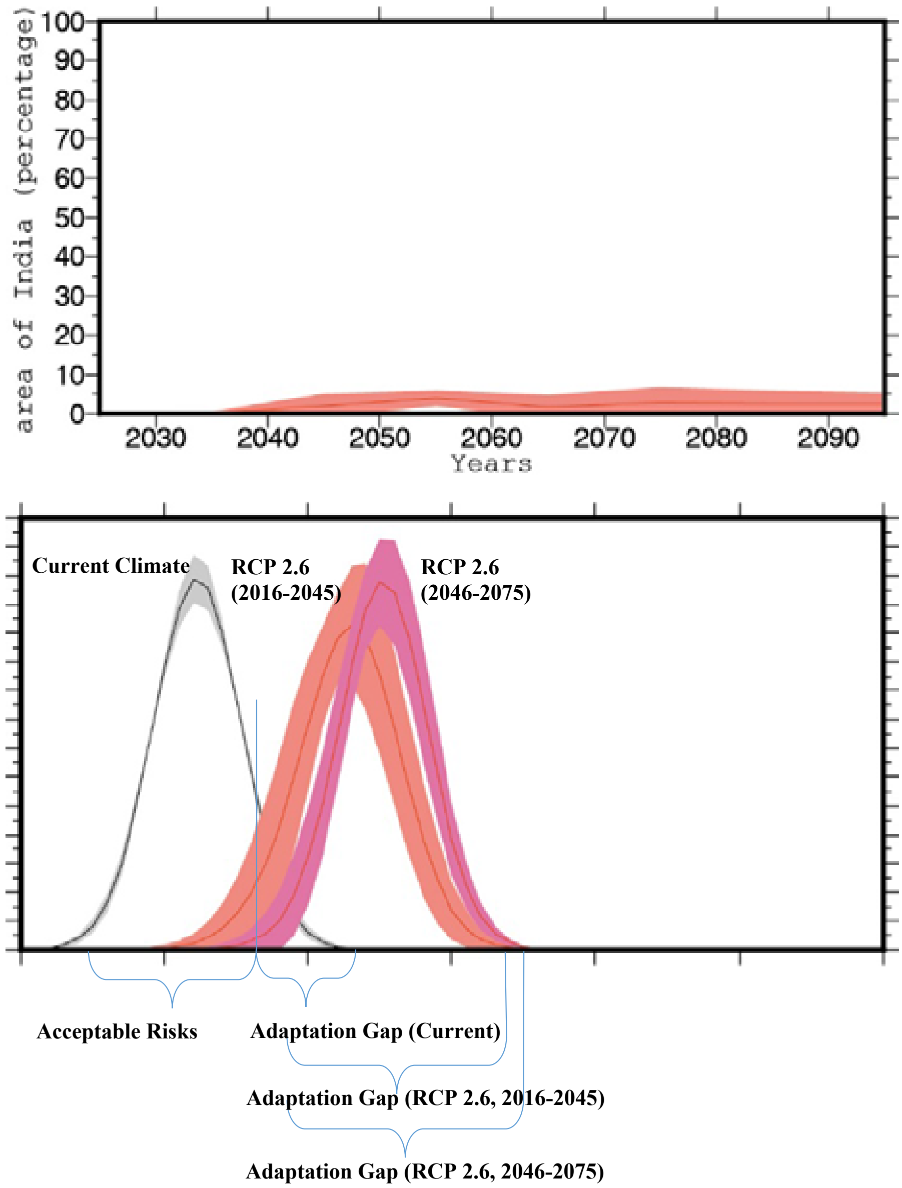
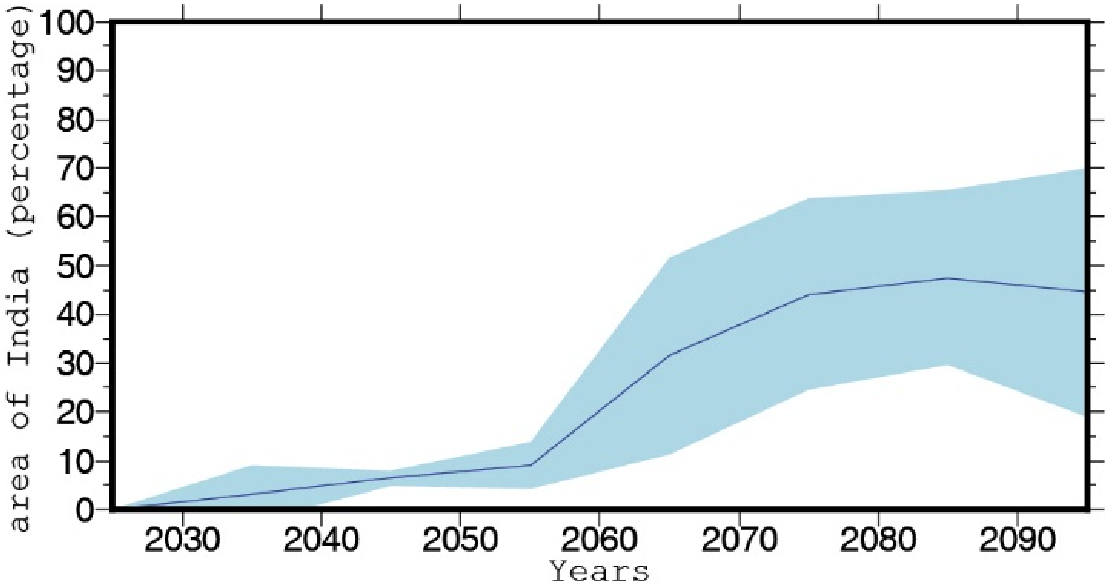


Figure 4.1: Articulating financial gap in adaptation under RCP 2.6 future projections



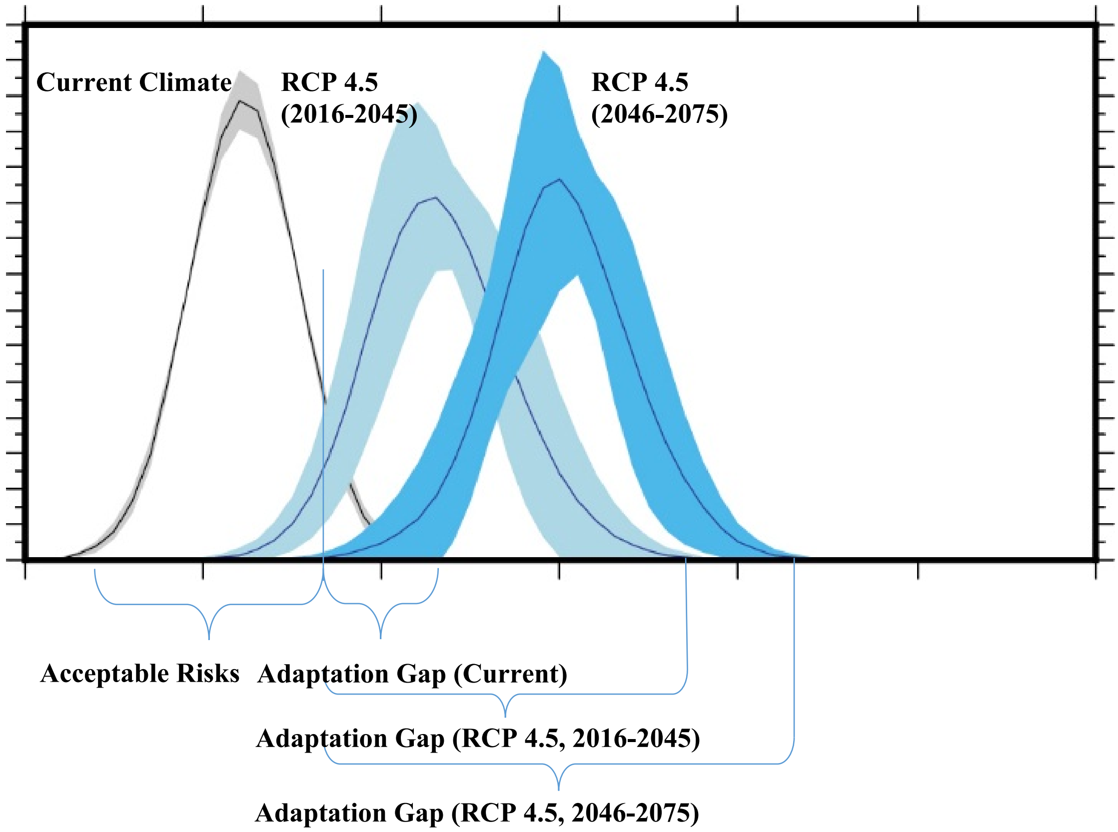


Figure 4.2: Articulating financial gap in adaptation under RCP 4.5 future projections

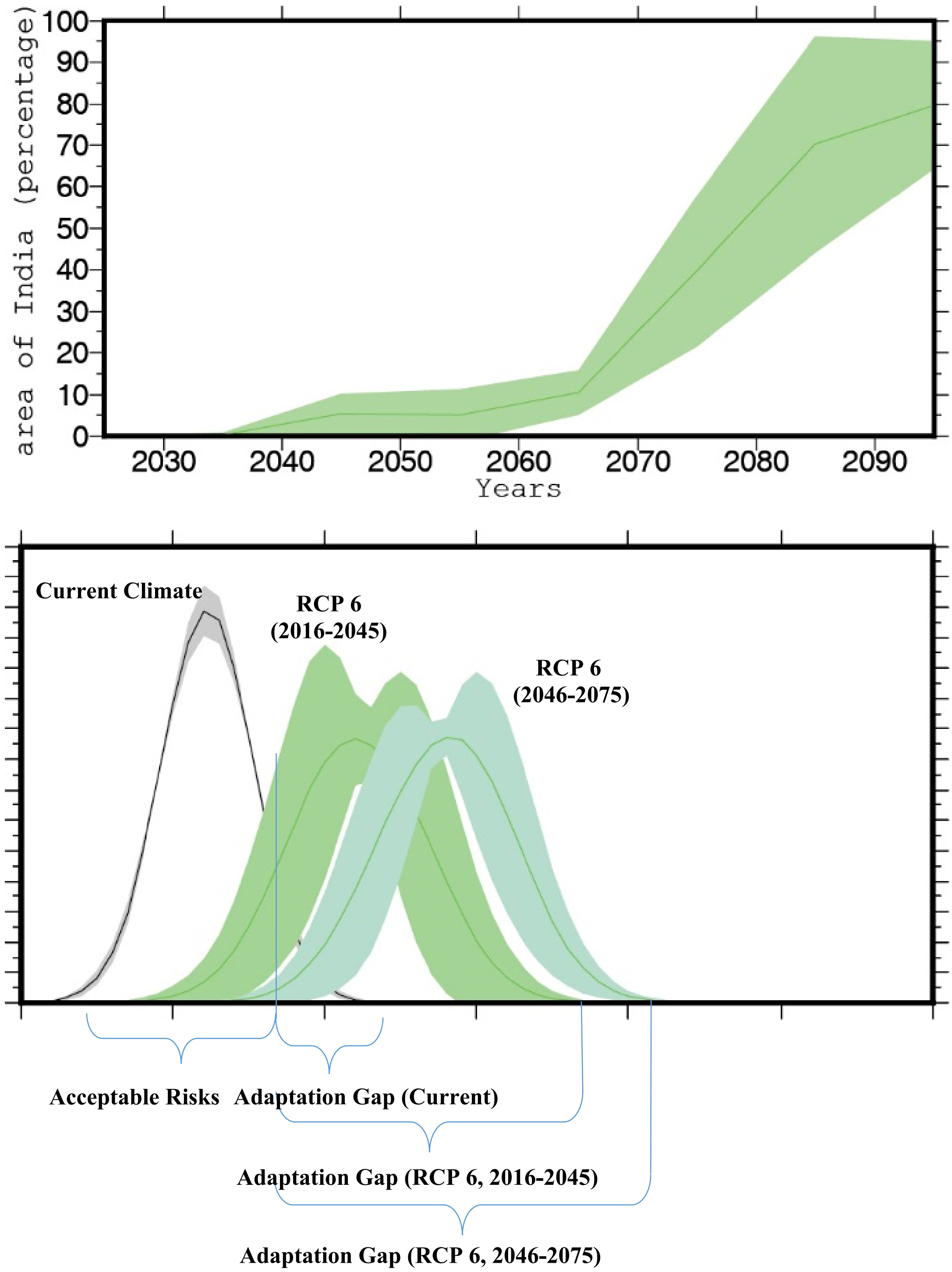


Figure 4.3: Articulating financial gap in adaptation under RCP 6 future projections

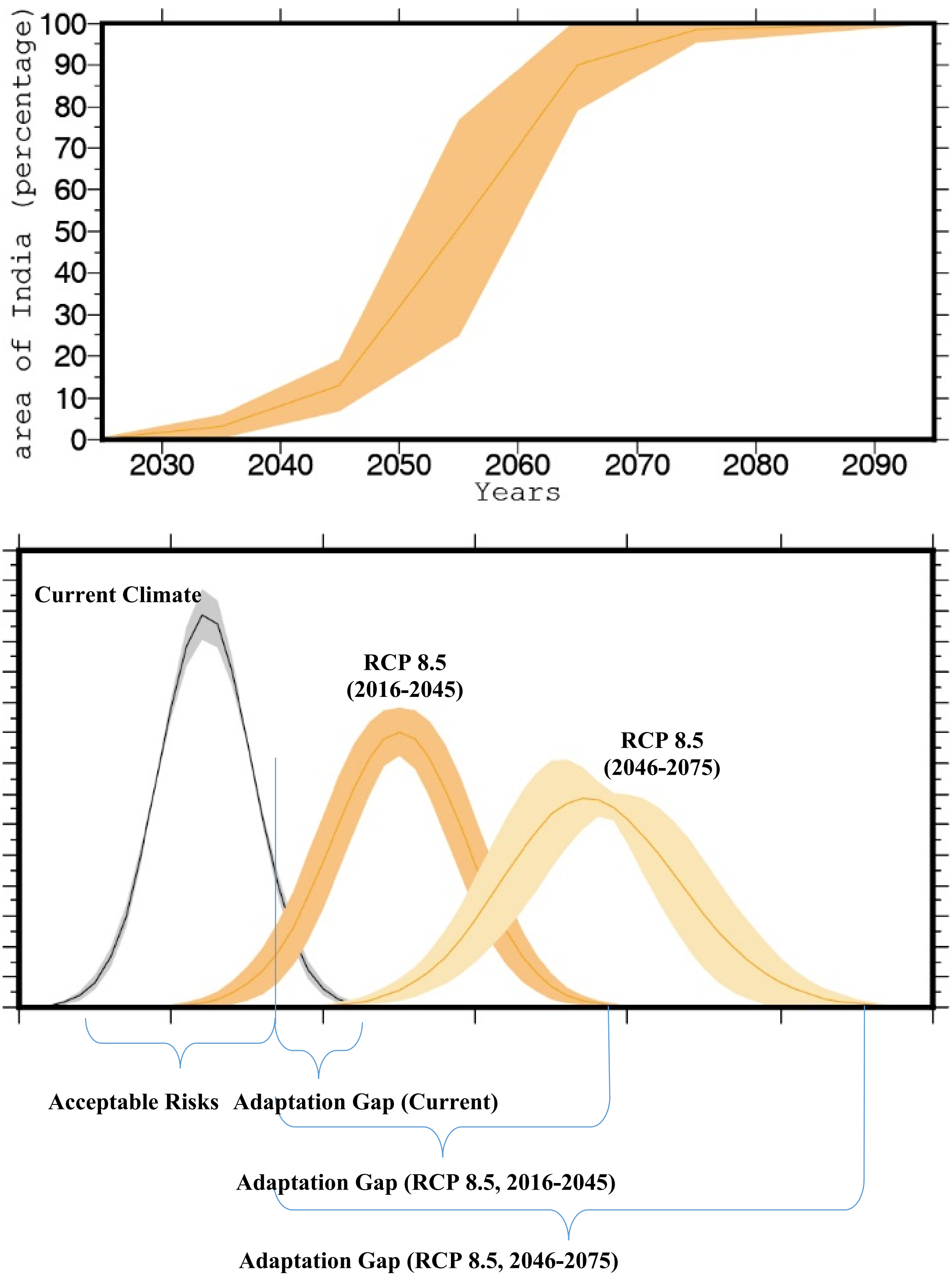


Figure 4.4: Articulating financial gap in adaptation under RCP 8.5 future projections

The current public spending on development activities (through Union and State budgets) was about INR 5970 billion (US $ 91.8 billion) which was about 4.9% of GDP in 2013-14. For India, the loss and damages from extreme events were estimated around an additional US $ 5-6 billion in 2013. Under future climate change, it is evident that there is a right-ward shift in the distribution of risk. The shifts imply that new and additional financial investments are required to cover risks. We estimate that in 2030 these investments may be about US $ 360 billion (at 2005 prices) as per the spread of the current distribution. It can be seen from Figures 4.1 to 4.4 that this spread may increase upto 2.5 times for RCP 2.6 and upto 4 times for RCP 8.5. This change in spread requires understanding the dynamic concept of acceptable risk and investing accordingly. Preventive adaptation to "expand" the range of acceptable risks would require much more investment as the risk profile is projected to shift to the right. This shift is crossing the right tails of present climate risk distributions under RCP 4.5, 6 and 8.5 during 2016-2045 itself. Almost no overlap remains during 2046-2075 risk profiles and the current risk profile. Most of the risks in future would therefore fall under unacceptable domains, thus increasing the palliative costs much faster. This also implies that future would become much more uncertain and risky, therefore increasing the chances of β errors much more. α errors may almost become negligible since whatever preventive measures would be taken, there would be hardly any chance of them going wasted.

Two approaches can be used while making these additional investments – wait and watch or take advance preventive actions. The wait and watch approach requires taking adaptation action (and investments) in future. This strategy implies lower preventive costs in the short term, but may lead to higher palliative costs in future. This is because a higher proportion of risk may be uncovered. The advance preventive actions require making investments now. This strategy implies higher expenditure in the short term, but may lead to lesser palliative costs in future. This is because a larger proportion of risk is covered. For instance, adaptation costs are estimated at US $ 178 billion for current infrastructure [*Planning Commission*, 2013]. These investments can be made in advance as the infrastructure is being built (advance strategy) or retrospectively (wait and watch approach). Therefore, there is an inherent trade-off between these two strategies. Governments are required to choose optimal investments based on the risk they want to cover.

Chapter 5

Technology Gaps in Adaptation

Enhance public transport may reduce road congestion

5. Technology Gaps in Adaptation

Technology plays a critical role in climate change adaptation. This is because it expands the horizon of possible options available for adaptation. Such an expansion has consequences for realisation of adaptation efforts (ADB, 2014). Technology transfer has been a crucial point even in climate change negotiations over the last two decades. Addressing the adaptation technology gap requires technology transfers, technology co-creation and clear structuring around intellectual property rights. The three main challenges that have hindered technology partnerships around climate change include lack of financing, intellectual property restrictions and capacity underutilization (Ghosh & Ray, 2015). Notwithstanding these challenges, there exist issues around scale of deployment, levels of risk that adaptation options can address, temporal dimensions for implementation (short, medium and long term) and associated costs and benefits. There are few studies that comprehensive list available technologies and their efficacy. A large proportion of adaptation may not require sophisticated technologies, but do require policy frameworks to maximise their diffusion or adoption at local scales (UNEP, 2014).

For India, there is a need for technological assessment across sectors that are critical to climate change adaptation. We have identified various technologies, across sectors that are relevant to climate change adaptation for India (Table 5.1). These technologies have been classified based on temporal scale of implementation into short, medium and long term. Several technologies are being implemented across development programmes in India for numerous sectors – agriculture, water, health, forests and livelihoods. However, different models of implementation have shown success in different states given the federal structure. For the successful models, India requires to scale the same up to different regions. For instance, the city of Ahmedabad incorporated India's Heat-Health warning system in 2013. Preliminary results show that there has been a reduction in heat-wave related deaths after implementing the system (Rajiva et al, forthcoming).

Those technologies that are in the development stage require maturation. There are some domestic initiatives on innovative technologies that would support sustainable development. National Innovations Foundation (NIF) set up by the Government of India is one such initiative. It has over 2500 grass-root innovation mapped in India that support sustainable development and enhance resilience of people. Technologies such as low cost wind mills, manual and power driven milking machine, and sanitary napkin making machine are part of these (figure 5.1). At the same time, there is the need to anticipate future risk and implement technologies using a 'no-regrets' approach. Technologies can be traditional, modern or future (Klein et al, 2006). A systematic evaluation of the potential of these technologies to address climate risks is required. Technology gaps remain among the lesser studied areas for India in the context of climate change adaptation. A very initial assessment of technology needs for filling the adaptation gap is provided in table 5.1.

Figure 5.1 : Examples of Domestic Technological Innovations

Table 5.1 : Initial assessment of technology needs for filling the adaptation gap

Sub-sectors	Technology needs for adaptation		
	Short Term	**Medium Term**	**Long Term**
Coastal Erosion and Flooding			
Extreme events	Cyclone warning systems	Climate models for India	
	Cyclone shelters	Industry related	Structure relocation technologies
Coastal flooding	Flood Warnings	Seawalls	Trapping river waters at river-sea-confluence
	Flood Proofing	Sea Dikes	
	Flood Hazard Mapping	Storm Surge Barriers	Managed Realignment
Sea level rise		Land Claim	
		Floating Agricultural Systems	
Others		Beach Nourishment	Wetland restoration
		Artificial Dunes & Dune Rehabilitation	Desalination
Water			
Potable water	Household Water Treatment and Safe Storage (HWTS)	Boreholes/Tubewells as a Drought Inter-vention for Domestic Water Supply	Water Reclamation and Reuse
	Increasing the Use of Water-efficient Fix-tures and Appliances	Desalination	Water Safety Plans (WSPs)
	Leakage Management, Detection and Repair in Piped Systems	Improving Resilience of Protected Wells to Flooding	Harvesting of surface runoff – unlined ponds and lined ponds
	Post-construction Support (PCS) for Community-managed Water Systems	Rainwater Collection from Ground Surfac-es—Small Reservoirs and Micro-catchments	
		Rainwater harvesting from Roofs	
Floods and draughts	Warning systems	Tidal barriers (Sluice gates)	Appropriate GM crops
	Crops to withstand erratic monsoons	Saltwater Intrusion barrier	Deep aquifer recharge
	Crop insurance	Desalinization for drinking water in coastal areas	
Agriculture			
Planning for Climate Change and Variability	Warning systems	National Climate Change Monitoring System	

Sub-sectors	Technology needs for adaptation		
	Short Term	**Medium Term**	**Long Term**
	Soil testing technologies	Seasonal to Inter-annual Prediction	
	Crop models	Decentralised Community-run Early Warning Systems	
		Climate Insurance	
Increase crop resiliency	Organic pest control	Genetic Modified Crops (Rice, Wheat)	Non-invasive technologies
		Crop breeding	
		Fungal symbionts	
Sustainable Water Use and Management	Water use efficiency enhancing technologies	Sprinkler and Drip Irrigation	
	Rainwater Harvesting	Fog Harvesting	
Soil Management	Cheap soil testing technologies	Slow-forming Terraces	Farm level lab creation
		Conservation Tillage	
		Integrated Soil Nutrient Management	
Sustainable Crop Management		Crop Diversification and New varieties	
		New Varieties through Biotechnology	
	Ecological Pest Management		
	Seed and Grain Storage	Seed and Grain Storage	
Sustainable Livestock Management	Selective Breeding		
	Livestock Disease Management	Sustainable Pasture Management	Livestock Disease Management
	Milking Martine	Improved livestock feed (High Milk Yielding)	
Sustainable Farming Systems		Mixed Farming	
		Agro-forestry	
Capacity Building and Stakeholder Organisation	Farmer Field Schools	Low-cost agriculture laboratory in every village	
	Using ICT	Remote sensing	Community Extension Agents
		Forest User Groups	
		Water User Associations	
Health			
Lessen the impact of changes in vector-borne diseases	Use of ICT	Long-lasting insecticidal bed nets	

Sub-sectors	Technology needs for adaptation		
	Short Term	Medium Term	Long Term
		Rapid diagnostic tests	
Incorporate advanced information technology into the health sector	Air quality Monitoring	Disease surveillance systems	Capacity Building (Emergency Services)
	Early Warning System	Flood-proof sanitary latrines	
	Capacity Building (Emergency Services)	Flood-proof drinking water wells	
	Low Cost Sanitary Napkins		
Transport			
	Improve durability of road surface material	Warm-mix asphalt	
		Water absorbent/resistant roads	Engineered cementitious composite
	Improve resiliency of ports	Active motion dampening systems	
	Intelligent transportation systems	Low Carbon Vehicles	High Occupancy Vehicle Lanes
	Parking Management, Car Free city areas, Low Emission Zones	Fuel Efficiency Standards	High speed trains
		Mass Public Transportation, BRTS and Metro Facility, Bicycle Zones	
		High axle-load wagons	Convert diesel or Coal railcars to Electric (Railway)
		Electric Vehicles, Plug-In-Hybrids	Electronic Road Pricing
Buildings			
	Efficient Lightning System (Solar & LED)	Energy Efficient Buildings	
	Use of Solar Energy	Building Management System, Automation and Control	
	Building codes and Standards	Grid responsive buildings	Sensor Technology to track the Conditions
		Efficient Central HVAC System (Efficient Motors)	
Industry			
		Energy Efficient machines	
		Pollution Control System (Air, Water)	

Sub-sectors	Technology needs for adaptation		
	Short Term	Medium Term	Long Term
		Use of Renewable Sources	
Waste			
	Expand compost land-fill techniques	Waste to wealth technologies in various sectors	Designing interventions to reduce waste generation
	Recycling technologies	Arrow operation	Dematerialization technologies
	Waste segregation	Mechanical Biological treatment (MBT)	
	Waste water recycling at low cost		
	Low Cost Sanitary Napkins		
Energy and Power			
	Biomass as fuel and co-fired with coal (renewable)	Grid Modernization	Smart Grid (Substation, Power Plant)
	Use of Renewable resources	Dry cooling Technologies	Clean Coal technologies such as super critical, IGCC
	Fly ash usage technologies	HVDC Transmission Lines	CCS Technology
	Low water Coal Washing technologies	Underground long-distance Cabling for utilities	Low water cleaner coal technologies
	Low Cost Winds Mills	Clean Coal Technologies	
		Underground Mining Technologies	
		Oil and Gas Exploration Technologies	
Forests, land-use and wildlife			
	Land-use mapping using remote sensing	Systematic monitoring of changes in Forest Ecosystems	Technologies to monitor migration of forest eco-systems
	Enhanced Afforestation	Gene Management	Technologies for protecting endangered species
	Weeding, pruning technologies	Forest Regeneration Technology	
		Park and wilderness area management	
		Agroforestry	

Chapter 6

Knowledge, Capacity Building and Institutional Gaps in Adaptation

Solid biomass is a major source of cooking in poor Indian households and is also a reason for high indoor air pollution related health impacts. Climate change is going to exacerbate energy security concerns for the poor.

Women and girls have to walk long distances to fetch potable water. Enhanced water stresses due to climate change are projected to lengthen their daily drudgery.

6. Knowledge, Capacity Building and Institutional Gaps in Adaptation

The first challenge in thinking about adaptation in a strategic manner is understanding the knowledge gaps that exist. These knowledge gaps can be broadly classified into three groups – lack of knowledge resources (e.g. lack of quality data, published studies etc.); lack of integration across different knowledge streams and lack of uptake by policy makers (UNEP, 2014). Of these, we try to understand the first type of knowledge gap in the Indian context.

A lack of knowledge resources typically hinders evidence-based policy formulation and consequently stakeholder action.

The distribution of impacts across temporal and spatial dimensions under alternative scenarios forms the basis of determining (and prioritizing) required adaptation actions. In particular, this requires answering questions such as – Which sectors have been studied to understand impacts under a changing climate? Which geographical areas have been covered? Which sectors have been studied to a lesser extent?

We carried out a review of the potential projected impacts across different sectors under future climate. We were interested in studies that have attempted to quantify impacts linked to a 'future climate signal' based on modeling assessments. Only those assessments that were pertinent to India were included. In cases where assessments were carried out for South Asia or globally, only India specific results were included. Studies that assessed the benefits of a particular intervention on adaptation (e.g. an early heat – health warning system, watershed management etc.) were excluded.

Table 6.1 shows the sectoral impacts for India under alternate climate scenarios. Of the different sectors, water, sea-level rise and agriculture have studied to a greater extent. On the other hand, livelihoods including fisheries have received lesser attention. There are few studies that look at impacts across sectors such as health, infrastructure damage and forests. Impacts have not necessarily been studied for all time periods across alternate climate scenarios. Although more studies are needed to address these knowledge gaps, the broad direction of climate change impacts can understood based on current knowledge.

In the water sector, the frequency and intensity of both drought and floods are expected to increase in the near and long term. In the near term, risks of drought are high South and Central India. In the long term, this risk is expected to spread across all major river systems in India. Increased risk of flooding is expected in the North and Central plains of India, associated with increases in mean flow and run-offs for the Ganga and Mahanadi basins. Future glacial melting will likely contribute to the increased run-offs.

Table 6.1 Sectoral impacts for India under different climate change scenarios

		A1 B Scenario - Second National Communication		**Related Studies (Local + National)**	**2°C Scenario (World Bank Study for South Asia)**	**3°C Scenario (World Bank Study for South Asia)**	**4°C Scenario (World Bank Study for South Asia)**
Sector	sub-sector	2021 - 2050	2071 - 2098				
Water systems	Droughts & Floods	Increase in moderate droughts for Krishna, Narmada, Pennar, Cauvery, Brahmini; Increase in moderate to devere drought in Baitarum, Sabarmati, Ganga & Mahi systems	Moderate drought in all river systems except Tapi	Increases in peak run-offs in Mahanadi basin (~38%) in 2050 - 2075, increasing flood risk (Asokan & Dutta, 2008)	Mean flow increase of 65% by 2080s in Indus with possible reductions accounting for glacial melt in summer; 20% increase in Ganges run-off; Substantial reductions in late spring and sumer flow of Bramhaputra	Mean flow increase of 65% by 2080s in Indus with possible reductions accounting for glacial melt in summer; 20% increase in Ganges run-off;	50% increase in Ganges run-off; Significant increase in peak flow of Brahmaputra
	Water availability	Aggregate level availability exceeds demand. Poor practices leading to current and future stress on water resources in certain areas	Not assessed		Food water requirements in India projected to exceed green water requirement by >150% for India	10% decline in per capita water availability	Not Assessed
	Himalayan glacier	Further research required - contrasting findings regarding behavior of glaciers			Not Assessed	Not Assessed	Not Assessed

		A1 B Scenario - Second National Communication		Related Studies (Local + National)	2°C Scenario (World Bank Study for South Asia)	3°C Scenario (World Bank Study for South Asia)	4°C Scenario (World Bank Study for South Asia)
Forests & Biodiversity	Distribution of forests	Slight expansion of forests into western part of India; expansion of tropical evergreen forests in eastern India & western ghats					
	Net primary productivity	Net primary productivity increase of 30%	Net primary productivity increase of 56%				
	Biodiversity	High vulnerability of forests leading to increased species loss	Shift towards wetter forest type across most grids in north-east and drier forest types for grids in central and north-western india				
	Vulnerability to Climate change	30% of forest grids show high amounts of vulnerability	45% of forest grids show high amounts of vulnerability				

		A1 B Scenario - Second National Communication		Related Studies (Local + National)	2°C Scenario (World Bank Study for South Asia)	3°C Scenario (World Bank Study for South Asia)	4°C Scenario (World Bank Study for South Asia)
Agriculture	Rice	Linear decline per degree centrigrade temperature increase is 14%			Decline in crop yields regardless of potential beneficial CO2 fertilization	Decline in crop yields regardless of potential beneficial CO2 fertilization	Decline in crop yields regardless of potential beneficial CO2 fertilization
	Wheat	Linear decline per degree centrigrade temperature increase is 7%					
	Potato	Linear decline per degree centrigrade temperature increase is 9.5%					
	Soybean	Linear decline per degree centrigrade temperature increase is 8.8%					
	Green gram	Linear decline per degree centrigrade temperature increase is 7.2%					
	Chickpea	Yield increase of 23%	Yield increase of 52%				
	Cotton	Likely to decline					
	Coconut	Yield increase of 4%	Yield increase of 2% / Stagnation				
Fisheries		Not assessed					
Coasts		Average increases of 4mm/year - scenario sensitive		Increased risk for Mumbai & Kolkata to flooding in 2070s (Hanson et al, 2011)	30cm in 2040s; 50 cm in 2070s; 70cm in 2080s	30cm in 2040s; 50 cm in 2060s; 85cm in 2080s	30cm in 2040s; 50 cm in 2060s; 105cm in 2080s

		A1 B Scenario - Second National Communication		Related Studies (Local + National)	2°C Scenario (World Bank Study for South Asia)	3°C Scenario (World Bank Study for South Asia)	4°C Scenario (World Bank Study for South Asia)
Human health	Malaria/Dengue	Increase in transmission windows for northern states, that were closed in baseline	Not assessed		Relative risk of malaria projected to increase by 5% in 2050s	Not assessed	Not assessed
	Heat related mortality			Excess heat related deaths in 2080s across 52 million plus cities in India (Dholakia et al, unpublished)	Not assessed	Substantial increase in heat stress mortality by 2090s	Not assessed
	Malnutrition	Not assessed	Not assessed				
Human settlements		Not assessed	Not assessed		Not assessed	Not assessed	Not assessed
Infrastructure assets		Not assessed	Not assessed	Large infrastructure assests-ports, railways vulnerable under RCP 4.5 & 8.5; Risk management through adaptation likely to be expensive (Garg et al., 2014)	Not assessed	Not assessed	Not assessed
Climate Extremes	Tropical cyclones				More intense tropical cyclones	Not assessed	Not assessed

Whereas absolute declines in water availability are not expected in the near term, poor water management practices and unsustainable consumption may aggravate availability in water scarce areas. In the long term, under a 3°C scenario, ~10% declines in water availability are expected.

These impacts in the water sector are likely to further stress the agricultural sector. With every degree of temperature increase, declines in agricultural productivity are expected (even after accounting for beneficial effects of CO_2 fertilization). Productivity declines in agriculture have implications for poverty alleviation as this sector employs roughly 65% of the Indian population. It may also exacerbate poor nutritional status of many Indians especially children.

Sea-level rise in future puts a large population at risk given India's coastline of 7500 km. Though the extent of sea level rise remains uncertain, a large population that lives in cities and villages across 70 coast districts is at risk. The associated infrastructure damage, loss of crops, loss of livelihoods may trigger widespread migration. Other direct impacts such as deaths due to extremes of heat, impacts on fisheries, livelihood losses and extreme events have been studied to a lesser degree.

It is recognized that impacts in one sector will have repercussions across other sectors. All these will ultimately impact the development of Indian society. However, it is observed that the knowledge base on climate change impacts is sparse. This is because, in part, the attention has been on mitigation actions. There, however, remain crucial knowledge gaps in terms of understanding the geographical heterogeneity of impacts for India. These gaps make it difficult to prioritize adaptation actions. Whereas interventions across all sectors are required, prioritizing action will help in efficient resource utilization. Impacts that transcend geographic boundaries (e.g. flooding) may require development of new institutional mechanisms for an adaptation response. Therefore, addressing the knowledge gaps remains a key first step to reduce India's adaptation gap.

Chapter 7

Filling the Adaptation Gaps


Poor and rich live together in cities highlighting the vulnerability gaps and synergies

7. Filling the Adaptation Gaps

Adaptation responses are embedded in complex socio-economic environments and influenced by a variety of stakeholders such as host country government and civil society, international communities including governments and multilateral agencies, and other private actors. Further, the extent and type of responses to fill various Adaptation Gaps are contingent upon several drivers. Therefore, to understand the different gap fillings related to adaptation, a comprehensive approach is suggested (Figure 7.1).

At the core of this approach are the sustainable development goals for India. The sustainable development of the Indian population (and associated climate resilience) is contingent on several factors that include climate change variables, sustainable development goals, resources, products and services available and policies and measures that are in place.

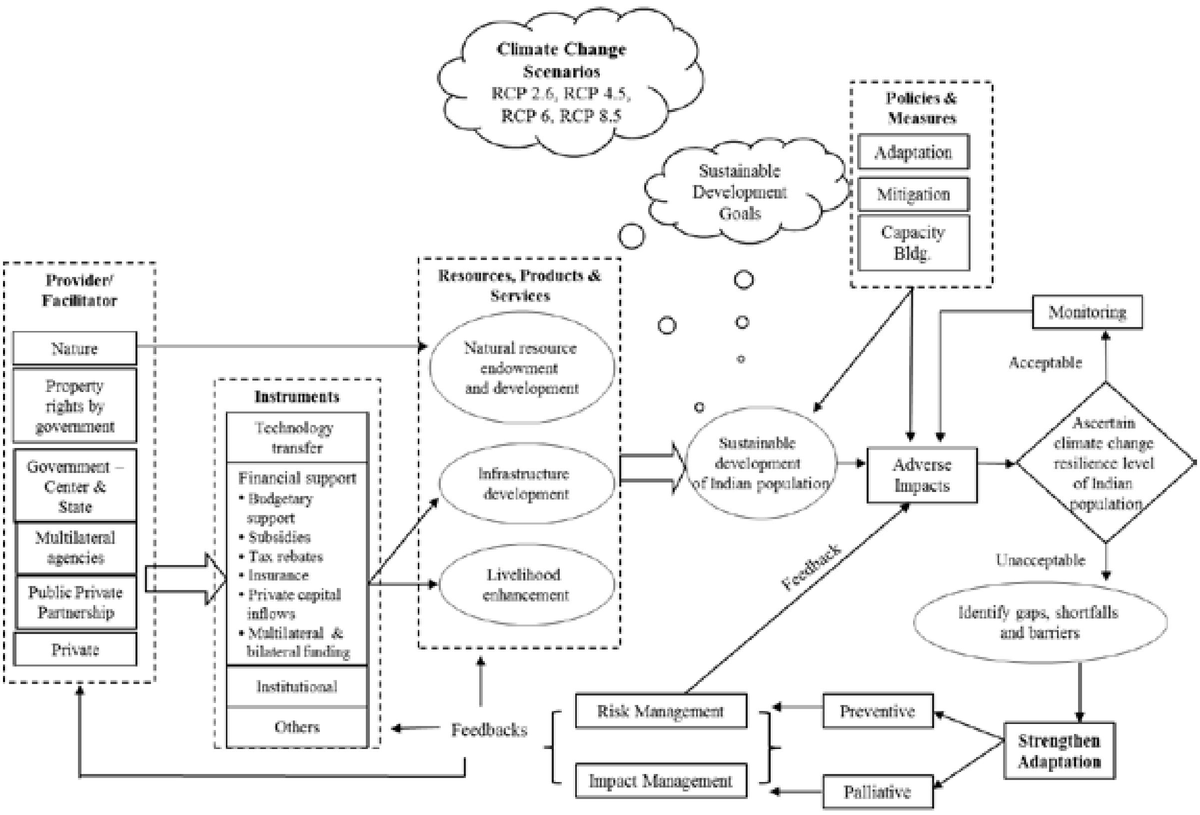


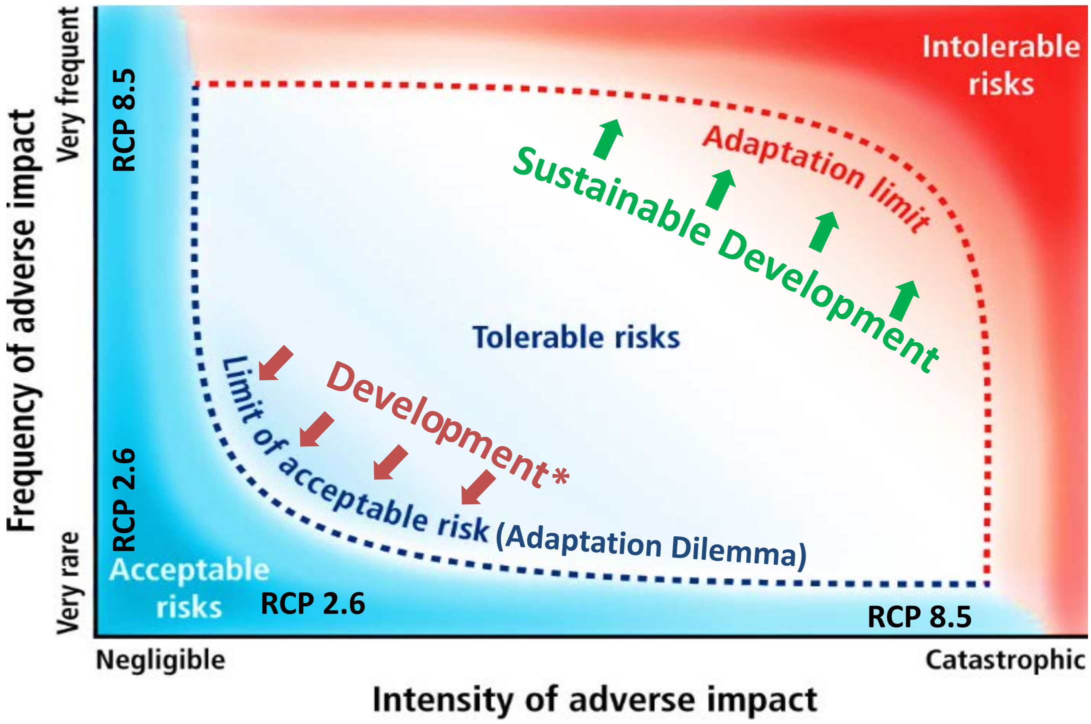
Figure 7.1: Filling the Adaptation Gap

The impact of climate change variables (radiative forcing) in future will be an outcome of current and future mitigation efforts. Strong mitigation efforts will result in lower radiative forcing trajectories (e.g. RCP 2.6 scenario). Lower radiative forcing trajectories are associated with lower impacts from climate change and consequently lower adaptation responses. Scenarios in which radiative forcing levels are higher (e.g. RCP 6.0 or RCP8.5) would typically result in greater impacts thereby requiring greater adaptation measures. However, impacts and adaptation needs are likely to increase in a non-linear fashion as we transition from lower to higher radiative forcing trajectories.

The climate change variables will interact with current system conditions and sustainable development variables. The system condition variables may naturally pre-dispose certain sectors or populations to be more vulnerable to climate change variables as compared to others. For instance, poverty may be pre-disposed to loss of livelihoods due to lack of social, educational and health related capital. Impacts are likely to be less if development is spread evenly across different sectors and is equitable. These sustainable development variables will be driven partly by the policies and measures that are put in place. A complex combination of these variables will simultaneously determine the level of resilience and impacts.

If the resilience to these impacts is within acceptable limits, then continuous monitoring will be required. However, if the impacts are within unreasonable limits, then identifying gaps, shortfalls and barriers are important to strengthen adaptation. Adaptation measures could either be preventive (i.e. minimizing risk of impacts) or palliative (i.e. minimizing loss and damage after impacts have occurred).

Both require different approaches, but are complementary in nature and need to be carried out simultaneously. The preventive approach requires projecting impacts (and uncertainties) under future climate. This analysis can inform development of adaptation responses often using a 'no regrets' approach. The palliative approach requires responding to often unanticipated climate impacts in a swift manner. It also involves developing adaptation responses to minimize future impacts. Feedbacks from these will serve as inputs to fine-tune policy instruments and resource use by various stakeholders thereby influencing sustainable development of the Indian society. Based on this framework, the knowledge, financial, capacity building and institutional gaps were studied.



Note: * Sometimes mal-development enhances the risks individuals and communities have to accept willy-nilly. This is different than enhancing the limits of acceptable risks through positive developmental actions (preventive costs for adaptation) to enhance resilience of individuals and communities.

Source: Adapted from Figure 16.1, WG2, AR5

Figure 7.2: Adaptation, Mitigation and development are linked

Figure 7.2 highlights that adaptation, mitigation and development are linked, especially for a developing country like India. There is a limit of acceptable risk and there is a limit to adaptation. The line defining the limit of acceptable risk is the adaptation dilemma. Sometimes, however, more risks appear to be acceptable to a very vulnerable population. This may be due to mal-development enhancing the risks to unwilling individuals and communities, who have to willy-nilly accept these. This is different than enhancing the limits of acceptable risks through positive developmental actions (preventive costs of adaptation) to enhance resilience of individuals and communities. Similarly the adaptation limit frontier could be enhanced through sustainable development.

Our analysis highlighted the deep financial, technological, institutional and capacity building needs to fill the Adaptation gap for India. The financial needs could be upto US $ 360 billion in 2030 and beyond in case we ride RCP 8.5 pathway. In real terms, the Adaptation gap for India could be over a trillion US$ from now until 2030. It could increase substantially beyond 2030. Technologies needed for adaptation could be both simple and advance. We provide a preliminary listing of the same.

The adaptation dividend would not be visible until 2040 by our assessment. That is whatever global action on GHG mitigation, India would have to rely more of enhanced adaptation efforts to keep the adverse impacts of climate change within acceptable limits for the vast vulnerable populations and eco-systems. Of course India is standing with the global community on GHG mitigation and has promised a strong action on mitigation through her INDCs, including one of the most ambitious renewable energy programmes in the world. However supporting and enhancing sustainable development of 1.25 billion people is at the heart of Indian adaptation gap filling strategy. The fruits of development should not be lost due to increasing Adaptation Gap in future. Developed countries have to come forward, under CBDR, to provide additional financial resources and technology transfers for filling India's Adaptation Gap. As decided in the last COP at Lima (2014), adaptation has to be elevated onto the same level as the curbing and cutting of curbing greenhouse gas emissions.

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Annexure I: Centrally Sponsored Programmes relevant to Climate Change Adaptation

No.	Programme	Year of Start	Ministry / Department
1	National Food Security Mission	2007	Ministry of Agriculture
2	National Horticulture Mission	2005-2006	Ministry of Agriculture
3	National Mission on Sustainable Agriculture	2011	Ministry of Agriculture
4	National Rural Drinking Water Programme		Drinking water & Sanitation
5	National Programme for Conservation of Aquatic Ecosystems	1972-73	Environment and Forest
6	National River Conservation Plan	1995	Environment and Forest
7	Conservation of Natural Resources and Eco-systems	1995	Environment and Forest
8	Integrated Development of Wild Life Habitats		Ministry of Environment and Forests
9	National Rural Health Mission (NRHM)	2005	Health & Family Welfare
10	National Urban Livelihood Mission (Earlier SJSRY)		Ministry of Housing and Urban Poverty Alleviation
11	Raijiv Aawas Yojna	2013	Ministry of Housing and Urban Poverty Alleviation
12	Mahatma Gandhi National Rural Employment Guarantee Act	2006	Ministry of Rural Development
13	Pradhan Mantri Gram Sadak Yojana	2000	Ministry of Rural Development
14	National Rural Livelihood Mission	June 2011.	Ministry of Rural Development
15	Integrated Watershed Management Programme	2008	Ministry of Rural Development (Department of Land Resources)
16	Pradhan Mantri Adarsh Gram Yojana	2009-2010	Ministry of Social Justice and Empowerment & Disability Affairs
17	Accelerated Irrigation Benefits & Flood Management Programme	1996-1997	Ministry of Water Resources
18	Jawaharlal Nehru National Urban Renewal Mission	2005	Ministry of Urban Development
19	National Mission on Sustainable Habitat	2008	Urban Development
20	National Water Mission	2008	Water Resources
21	National Mission for Sustaining the Himalayan Ecosystem	2008	Science & Technology