Vulnerability and Adaptation to Climate Change in the Semi-Arid Regions of India

CARIAA
Collaborative Adaptation Research Initiative in Africa and Asia

ASSAR
Adaptation at Scale in Semi-Arid Regions

About ASSAR Working Papers

This series is based on work funded by Canada's International Development Research Centre (IDRC) and the UK's Department for International Development (DFID) through the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA). CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The program supports collaborative research to inform adaptation policy and practice.

Titles in this series are intended to share initial findings and lessons from research and background studies commissioned by the program. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the CARIAA program, they have not undergone an external review process. Opinions stated are those of the author(s) and do not necessarily reflect the policies or opinions of IDRC, DFID, or partners. Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

Contact

Collaborative Adaptation Research Initiative in Africa and Asia
c/o International Development Research Centre
PO Box 8500, Ottawa, ON
Canada K1G 3H9
Tel: (+1) 613-236-6163; Email: cariaa@idrc.ca

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Canada

Vulnerability and Adaptation to Climate Change in Semi-Arid Areas in India

Indian Institute for Human Settlements (IIHS)

IIHS Bangalore City Campus
No. 197/36, 2nd Main Road
Sadashivanagar
Bangalore 560 080 Karnataka, India
http://iihs.co.in/

Ashoka Trust for Research in Ecology and Environment (ATREE)

Bangalore Main
Royal Enclave, Sriramapura
Jakkur Post
Bangalore 560 064 Karnataka, India
http://atree.org/

Watershed Organization Trust (WOTR)

The Forum 2nd Floor
Padmavati corner
Pune Satara Road,
Pune 411 009 Maharashtra, India
http://www.wotr.org/

Indian Institute of Tropical Meteorology (IITM)

Indian Institute of Tropical Meteorology (IITM)
Dr. Homi Bhabha Road, Pashan
Pune 411 008 Maharashtra, India
http://www.tropmet.res.in/

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List of Acronyms

ACCCRN	Asian Cities Climate Change Resilience network
ADB	Asian Development Bank
AGCMs	Atmosphere global climate model
AgMIP	Agricultural Model Inter-comparison and Improvement Project
AOGCMs	Atmosphere-ocean global climate models
APHRODITE	Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation
AR	Assessment Report
ASSAR	Adaptation at Scale in Semi-Arid Regions
ATREE	Ashoka Trust for Research in Ecology and the Environment
BDA	Bangalore Development Authority
BSUP	Basic Services to the Urban Poor
BWSSB	Bangalore Water Supply and Sewerage Board
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CARIAA	Collaborative Adaptation Research Initiative in Africa and Asia
CbA	Community-based Adaptation
CBD	Convention on Biological diversity
CBI	Climate and Biophysical Impacts
CCA	Climate change adaptation
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CGIAR	Consultative Group for International Agricultural Research
CCCR	Center for Climate Change Research, IITM
CDKN	Climate and Development Knowledge Network
CGIAR	Consultative Group for International Agricultural Research
CMIP3	Coupled Model Inter-Comparison Project Phase 3
CMIP5	Coupled Model Inter-Comparison Project Phase 5
CoP	Conference of Parties
CORDEX	Coordinated Regional Downscaling Experiment
COWDEP	Comprehensive Watershed Development Program
CPR	Common Property Resources
CRU	Climate Research Unit
CSE	Centre for Science and Environment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSR	Corporate Social Responsibility
CSTEP	Centre for Study of Science, Technology and Policy
DFID	Department for International Development
DGVM	Dynamic Global Vegetation Modeling
DJF	December, January, February
DPAP	Drought Prone Areas Programme
DRM	Disaster Risk Management
DSSAT	Decision Support System for Agrotechnology Transfer
EbA	Ecosystem-based adaptation
ECMWF	European Centre for Medium-Range Weather Forecasts
EGS	Employment Guarantee Scheme
ENSO	El Nino-Southern Oscillation
EREs	Extreme Rain Events
ESM	Earth System Model
ET	Evapo-transpiration
FACE	Free Atmospheric CO_2 Enrichment
FAO	Food and Agriculture Organization
GCM	Global Circulation Models
GDP	Gross Domestic Product

GEF	Global Environment Facility
GII	Gender Inequality Index
GIM	Green India Mission
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoI	Government of India
HadCM3	Hadley Centre Coupled Model version 3
HadRM2	Hadley Centre Regional Model, version 2
HAG	High-Level Advisory Group
HDI	Human Development Index
HUL	Hindustan Unilever
ICAR	Indian Council of Agricultural Research
ICDS	Integrated Child Development Scheme
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and Communication Technology
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development
IIHS	Indian Institute for Human Settlements
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Metrological Department
INCCA	Indian Network on Climate Change Assessment
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISMR	Indian Summer Monsoonal Rainfall
ITC	Indian Tobacco Company
IWDP	Integrated Wasteland Development Programme
IWMI	International Water Management Institute
IWMP	Integrated Watershed Management Programme
JICA	Japan International Cooperation Agency
JJAS	June, July, August, Spetember
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KIIs	Key Informant Interviews
LBP	Lower Bhavani Project
MDGs	Millennium Development Goals
mha	million hectares
MIROC3	Model for Interdisciplinary Research on Climate version 3.0
MNREGA	Mahatma Gandhi National Rural Employment Guarantee Scheme
MoEF	Ministry of Environment and Forest
MoF	Ministry of Finance
msl	mean sea level
MWRRA	Maharashtra Water Resources Regulatory Authority Act
NABARD	National Bank for Agriculture and Rural Development
NADP	National Agricultural Development Programme
NAIS	National Agricultural Insurance Scheme
NAP	National Afforestation Programme
NAPA	National Adaptation Programmes of Action
NAPCC	National Action Plan on Climate Change
NATCOM	National Communication
NCSD	National Council on Skill Development
NEP	National Environmental Policy
NFSM	National Food Security Mission
NGO	Non-governmental Organization
NHM	National Horticulture Mission
NICRA	National Initiative on Climate Resilient Agriculture

NLM	National Livestock Mission
NMSA	National Mission for Sustainable Agriculture
NPBBD	National Programme for Bovine Breeding and Dairy
NPP	Net Primary Productivity
NPV	Net Present Value
NREGS	National Rural Employment Guarantee Scheme
NSSO	National Sample Survey Organisation
NTFP	Non-timber Forest Products
NUTP	National Urban Transport Policy
NWDPRA	National Watershed Development Project for Rainfed Areas
OECD	Organization for Economic Co-operation and Development
PPP	Public-Private Partnerships
PRECIS	Providing Regional Climates for Impacts Studies
QUMP	Quantifying Uncertainty in Model Prediction
RCM	Regional Climate Models
RCPs	Representative Concentration Pathways
RDS	Regional Diagnostic Studies
RKVY	Rashtriya Krishi Vikas Yojana
RRP	Regional Research Programme
SAPCC	State Action Plans on Climate Change
SARs	Semi-Arid Regions
SCI	System of Crop Intensification
SCs	Scheduled Castes
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SDP	State Domestic Product
SES	Socio-Ecological System
SHG	Self-Help Group
SLD	Shared Learning Dialogue
SPI	System of Pulses Intensification
SRES	Special Report on Emission Scenarios
SRI	System of Rice Intensification
SSI	Sustainable Sugarcane Initiatives
ST	Scheduled Tribes
SUDS	Sustainable Drainage Systems
SWAT	Soil and Water Assessment Tool
TGTs	Temperature Gradient Tunnels
TINP	Tamil Nadu Integrated Nutrition Project
TN IAMWARM	Tamil Nadu Irrigated Agriculture Modernization and Water Bodies Restoration and Management Project
TNAU	Tamil Nadu Agricultural University
TSP	Transformative Scenario Planning
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
USAID	United States Agency for International Development
WCED	World Commission on Environment and Development
WOTR	Watershed Organisation Trust

Executive Summary

The emerging development dynamics in India

India's economic growth has been notably impressive in the last two decades but this has not resulted in substantial reduction in poverty, and the progress on other human development indicators has been slow. During this period of high economic growth which has also seen major degradation of natural resources, there has been a shift towards a rights-based and people-centred policy framework, notable interventions being the recognition of rights to information, education, forest rights and focused food and employment programmes. However, the country still faces numerous challenges, such as stagnant agricultural growth, rising regional and sub-regional inequality, unemployment, and inadequate access to public services for the poor. There has been a perceptible recent prioritisation aimed at reducing economic and social vulnerability of the poor and building the adaptive capacity of the poor (such as a re-invigorated shift towards improving investment in all kinds of infrastructure, focusing on creating employment-generating industries, imparting employable skills and training to a young labour force and enhancing productivity from agriculture and allied systems).

Development dynamics in the sub-regions

Bangalore sub-region

Along with economic growth, multiple city-centric imaginations (metro, mega and a world- class city) have shaped the spatial, economic and social development of the Bangalore sub-region, with international financial institutions playing a role in determining the city's spatial configurations and governance regimes. Connected as it is now is to the global economy, Bangalore is becoming less dependent on its regional economy with negative impacts on its natural and built environment. A growing economy offers numerous livelihood options and attracts seasonal and permanent workers across economic sectors. The city however faces significant risks to its future growth and prosperity, including risks arising from water scarcity and droughts, and climatic hazards such as flooding. Observed rising temperature trends are projected to compound the impact of the urban heat island effect and increase the risk of health impacts. These risks are multiple and interlinked, and the current development trajectory seems to be intensifying them.

Moyar-Bhavani sub-region

The combined catchment area of the Bhavani and Moyar rivers is a high altitude area at the confluence of the Eastern and Western Ghats, bounded to the north by the state of Karnataka, to the west by Kerala, to the east by the Bhavani Sagar reservoir and to the south by the Coimbatore plateau. The Bhavani region lies in the central and south central regions of Tamil Nadu, which are predominantly semi-arid plains and receive relatively lower rainfall than the eastern and northern parts of the state. The topography is undulating in the lower plateau and uplands and rugged in the western parts. The vegetation cover is a mosaic of grassland, scrub, deciduous and evergreen forests, plantations of exotic tree-species, and cropping.

Along with diverse wildlife and physiographic features, the landscape has very high human density and a long history of human use. Major livelihood activities include agriculture, fisheries, pastoralism and collection of non-timber forest products (NTFPs). This area is inhabited by diverse indigenous tribal communities such as the Kurumbas, Badagas, Sholigas and Irulas as well as a large population of scheduled castes (socially marginalised groups). These communities continue to depend on NTFPs and agricultural enclaves, which are located in and close to forested areas. Thus, the Agriculture Forestry Socio-Ecological System (SES) is a key aspect of the sub-region. The forested landscapes have seen major conservation initiatives, even as there has been proliferation of invasive species and enhancement of human-wildlife conflicts. There are existing stressors within the agricultural system including ground water dependency, decreasing labour, low productivity and low levels of mechanisation. Climate change is projected to further intensify the existing dimensions of vulnerabilities and impact. Risks due to the occurrence of droughts, increasing temperature profile, declining crop yields and livestock mortality are some of the key challenges in the sub-region. With ongoing deforestation, degradation, fragmentation, and local extinction impacts, the forest-based ecosystems suffer from rapid land use changes, and considering the essential role of the forest ecosystem in ensuring tribal livelihoods, climate change is considered an added dimension to the existing risks.

Sangamner sub-region

The Sangamner sub-region lies within the state of Maharashtra and falls within the Ahmednagar District, with a predominantly agrarian economy. Due to large-scale livelihoods dependency, agriculture and allied sectors are critical sectors for the sub-region. Water availability constraints and poor agricultural productivity are major challenges in the sub-region. There is an evident transition from agricultural employment towards rural non-farm employment, as alternative livelihood avenues such as livestock rearing and a local agriculture-based service economy have grown. Agriculture in the region is largely rain-fed irrigated and crop productivity has been under severe stress, which puts to risk the dominant form of livelihood. Typically, the sub-region fares worst in terms of crop productivity, remuneration from agriculture, water use and soil fertility.

Assessing the multidimensional aspects of risk, impact and vulnerability

India and the sub-regions face a dynamic climatic and non-climatic risk profile. These climatic and non-climatic risks, separately and in interaction, make people and systems highly vulnerable. Key vulnerabilities and risks are found to be deeply embedded within the existing social and biophysical conditions of people and socio-ecological systems, which emerge as a critical barrier to effective, widespread and sustained adaptation.

The welfare cost of climate change impacts in India varies across geography and sectors. Given the natural resource-based livelihoods, high incidence of poverty and inherent socio-economic inequities, a significant section of the rural population is resource-constrained to adapt to the current and projected future climate variability. While households dependent on agriculture are affected directly, those living in urban areas are also affected by declining agricultural productivity and ongoing agrarian crisis in semi-arid areas. The situation is compounded by rapid and unplanned urbanisation, resulting in an intense competition for resources and land. The quality of life for the urban poor is characterised by the lack of access to social capital, poor quality of employment and exclusion from public services; in turn making the inhabitants highly vulnerable to social and environmental risk.

Climate trends in India and the sub-region

Critical sectors in the sub-region (agriculture, forests, water) are affected significantly by the changing climatic regime. Available evidence on the changing climatic regime in India and the sub-regions underscores the emergent climatic dimensions of risks that the sub-regions are exposed to.

Accelerated warming has been observed in India (1971-2007), primarily caused by an intense warming trend observed in the recent decade (1998-2007). A noticeable increase in heat waves and hot days recorded have also been reported. The Indian Monsoon has weakened in recent decades with an increase in the frequency of intense precipitation events in some areas. The increase in frequency of these intense precipitation events is attributed to the increasing influence of the Indian Ocean Dipole (IOD), warming and land-use change. Increasing trends in temperature and a significant decline in precipitation have been observed in the Bangalore and Moyar-Bhavani sub-regions, but temperature trends were more uncertain in the Sangamner sub-region. Precipitation in the Sangamner sub-region was also observed to be highly variable and has increased modestly since the 1990s.

Recent simulations using a three-member climate ensemble and its constituent models have indicated an increase of more than 2˚C over central and northern parts of India for the period 2066-2095. Changes in the precipitation by the end of the 21st century, however, were not observed to be significant, potentially reflecting the disagreement between the constituent models. Despite the availability of these projections, we are currently unable to assess its validity over the ASSAR sub-regions. Our sub-regional analysis has therefore focused on understanding historical trends in the climate system and its variability. La Niña was linked to increased rainfall in the Moyar-Bhavani and Bangalore sub-regions, but its impact on the Sangamner sub-region was minimal.

Currently, available climate information is too coarse to be relevant to local decision-making processes. Statistical downscaling of climate projections, together with a robust validation process with station-level observations, is envisaged during the upcoming Regional Research Program (RRP) phase – to provide useful climate information for medium and long-term decision making, including the possibility of tailored climate information. The impacts of, and feedbacks from, ecosystem and land use and land cover (LULC) changes need to be additionally understood in the sub-regional context to efficiently understand the local climate.

The adaptation-development spectrum

In recent times, mainstreaming climate change adaptation (CCA) into development efforts (by the state, civil society, and international development organisations) has gained prominence due to enhanced awareness of possible climate change impacts across regions and sectors. In India, this mainstreaming has taken place in a) national-level policy planning and narratives, b) multi-scale (but predominantly local) risk management practices and c) individual and collective risk management strategies. It remains to be seen whether CCA mainstreaming is better operationalised as a bottom-up process, through which successful community-based strategies are scaled up, or as a top-down process, through national-level planning.

Individuals, communities, governments and organisations use various strategies at different scales to manage climatic and non-climatic risks through proactive, reactive, or transformative adaptation, mitigation, and sustainable development measures or/initiatives. Recognising that the priorities for development and adaptation are closely related, India's response is primarily shaped by the need to link the development of human, institutional and infrastructural capabilities in building adaptive capacities in people and systems, manifested in the form of missions and national and state action plans on climate change.

Most current development-adaptation interventions in India and the sub-regions focus on water and agricultural sectors, which are most directly affected by climate variability and are critical in alleviating poverty. Evidence from various adaptation projects suggests that risk management strategies at various scales and initiated by various actors, are enabling building of local adaptive capacities. However, such changes are not uniform across regions, sectors or scales. For example, a study looking at urban vulnerability to flooding found that risk management in Indian cities is still an individual or community-level activity in the absence or a deficit of planned adaptation. India's rural systems have seen relatively higher and longer investment in direct climate change adaptation projects, as well as those that have adaptation co-benefits such as interventions for livelihood diversification, biodiversity conservation, sustainable agriculture and natural resource management. Given large development deficits and the vulnerabilities of the rural poor, coping strategies to manage risk are more common than adaptive action.

Governance and institutional barriers emerge as a key constraint to ongoing and future adaptation. Governance in much of South Asia and India is fragmented, making coordination across different agencies and scales challenging. Cities in particular accumulate and generate new risks through unplanned development and deepening inequality. Urban settlements are vulnerable to food, energy and water fragility and consequent social and political unrest. Planning, including for risk management, often takes place at higher levels of government, while the role of local bodies, civil society and communities tends to be that of implementation with little room for innovation. The ways in which governance acts as a key barrier to adaptation are a) multiplicity and redundancy of actors and institutions, b) fragmentation of planning and execution, c) prevalence of top-down planning, d) institutional rigidity and path dependency and e) absence of certain actors and sectors in the planning process such as private sector participation and health.

CHAPTER 1

Introducing the Regional Diagnostic Studies Report

Indian Institute for Human Settlements (IIHS), Bangalore, India

Ashoka Trust for Research in Ecology and Environment (ATREE), Bangalore, India

Watershed Organisation Trust (WOTR), Pune, India

Indian Institute of Tropical Meteorology (IITM)

Semi-arid landscape in Maharashtra

Photo: Prathigna Poonacha

Introducing the Regional Diagnostic Study

The Adaptation at Scale in Semi-Arid Regions (ASSAR) project aims to develop a nuanced understanding of climate vulnerability and adaptation in semi-arid regions (SARs), as well as implementable plans to transform current adaptation processes in a way that makes them proactive, and widespread. This research project is being implemented in regions of Africa and India.

Currently, ASSAR is nearing the end of the first phase of a multi-year research program – the Regional Diagnostic Studies (RDS) phase. The RDS takes stock of the current state of knowledge on the extant and emergent climatic and non-climatic risks in semi-arid regions of India (Annexe 1.1) and Africa. It also explores why different people (people rather than communities/institutions as a unit of enquiry) are differentially vulnerable to these risks and how people, governments and other stakeholders at various scales are responding to current and future (projected) climatic and non-climatic challenges.

The broad objectives of this research are captured in the seven key research questions (RQs) the first six of which independently/or together lead up to RQ7 (What are the barriers and enablers for effective medium-term adaptation and what responses enable more widespread, sustained adaptation?). Responding to the above frame, this report provides a nuanced understanding on multi-dimensional aspects of social and biophysical aspects of risks, vulnerabilities and impacts in the national and sub-regional contexts. It also captures the dominant trends in adaptation response at multiple scales – within the broad objectives of achieving meaningful vulnerability reduction. In doing so, this report identifies critical social and intrinsic barriers to 'effective medium-term adaptation' and identifies key research gaps around 'responses that enable more widespread and sustained adaptation'. Two major research dimensions emerge from this report: (a) medium to long-term climate change trends and their biophysical impacts need more detailed sub-regional scale analysis and (b) dimensions of social and related vulnerabilities need more thorough analysis at the sub-regional level, using a coupled human-natural system and livelihoods focus.

To summarise, three major developmental transformation ('transformative adaptation') options exist in India: 1) increase productivity of existing biophysical and socio-economic systems, 2) create new sustainable livelihood forms and/or, 3) shift population from fragile ecosystems. It is pertinent to highlight that whichover option is embraced, it should be able to sustain existing ecosystems to some extent, respect embedded socio-cultural dynamics, innovate around redundant and archaic governance and institutional structures, and respond to emergent climate-induced risks (such as changing precipitation and temperature patterns).

This report thus summarises key findings from the RDS for South Asia. It discusses the socio-economic and biophysical context in India and the sub-regions (Chapter 2) and identifies major gaps in the existing literature in areas of climate science, vulnerability and adaptation in (Chapters 3, 4 and 5 respectively). It also draws on key informant interviews (KIIs) with multiple stakeholders to enrich our understanding of research gaps and key dialogues in the climate adaptation discourse (Annexe 1.2). By doing so, it will inform forthcoming research in the Regional Research Programme (RRP) phase.

This report is conceptually aligned with the ASSAR framework (Tschakert et al., 2013)[1], with Chapter 2, 3 and 4 corresponding with the 'assess sphere' wherein the key 'structural factors' and 'intrinsic properties' defining vulnerability are assessed, through the lens of understanding the dimensions in a 'coupled human-natural' perspective. Chapter 5 additionally identifies the key elements of contextual adaptation barriers and enablers. This report reflects on the 'support sphere' as well, where information and data gathering processes were imbued with an 'iterative, reflective dialogue' through scoping visits and stakeholder consultation. The other spheres, particularly the 'identity and initiate sphere' along with additional dimensions of the support sphere will be implemented during the RRP phase.

1.1 Audience for the report

The primary audience for this report is researchers involved in the ASSAR project across all four regions. One of the principal uses of this report will be to generate key policy briefs, to be used for stakeholder engagement – primarily the local, regional and national governments. As initial evidence to support enhancing adaptation activities, this report will be a useful starting point to mobilise a cohort of key policy influencers. This will in turn help build a loose-network that influences policy and research. A further aim is also to direct research and respond to critical emerging themes such as the dynamic interactions between rural and urban areas.

1.2 Approach for the RDS Phase

India is composed of a diverse set of ecosystems, a range of risk, climatic and non-climatic exposures, vulnerability profiles and institutional regimes. The changing geography of the global population, economic output, employment potential and investment in India indicates that a large volume of (livelihoods) transitions will take place around the rural-urban continuum, coupled with future (selective) incremental urbanisation. Such dynamics will create pockets that would be representative of a massive concentration of historical and emergent risk, compounded with climatic variability. It is equally complex, with multi-hazard environments and climate change hotspots and has significant populations living in extreme poverty, highly vulnerable to both everyday risk as well as risks from extreme events. These groups are also disproportionately impacted by environmental and health risks. Simultaneously, all regions face serious institutional and governance challenges, compounded by contested growth dynamics and migration (including the rural-urban dynamics and contested historical binaries of informality and formality). At times, regions have a circumscribed role, which is in variance with reality on the ground. The RDS phase has focused on deepening our understanding of how the regions under study are coping with socio-ecological risks and correspondingly responding to these risks (spontaneous or program-based). Focus is paid to understand what forms of planned intervention and spontaneous innovation have been effective, which of these can be deepened and/or scaled and in what potential sequence. Further, care has been given to understand what strategic institutional, technological and planning gaps could pragmatically be filled and at what scale. It was equally important to delineate the role

[1] Tschakert, P., van Oort, B., St. Clair, A. L., and La Madrid, A. (2013). Inequality and transformation analyses: a complementary lens for addressing vulnerability to climate change. *Climate and Development*, *5*(4), 340-350.

and kind of principal agencies and processes that could take forward the (transformation) development agenda.

In the Indian context, and within the sub-regions:

- Multiple challenges consistent with national and state development goals need to be addressed simultaneously. These include the provision of basic services, safe housing, sustainable livelihoods, addressing natural resource constraints, deteriorating ecosystems, and unplanned growth. In addition, marginalised and vulnerable populations are more exposed to risks arising from climate change-related variability such as drought-induced water scarcity and food insecurity, localised floods, and extreme temperature situation, as well as environmental and health risks.
- Governance is fragmented, making coordination across different agencies and scales challenging. Further, urban regions are vulnerable to food, energy and water fragility and consequent social and political unrest; they also accumulate and generate new risks through unplanned development. Planning often takes place at higher levels of government, with the role of local bodies, civil society and communities circumscribed to implementation with little room for innovation. These risks and challenges undermine their potential to foster inclusive and sustainable development.

The process of engagement and knowledge exchange is thus designed and implemented in a manner that provides comprehensive answers to ASSAR's research questions. This process has been translated into effective and formal partnerships with scientific seats of knowledge (like IITM, and ATREE) and a robust process of multi-stakeholder engagement (during the RDS phase, it translated into a national stakeholder consultation and intense key informant interviews (KIIs)).

1.2.1 Research evolution

The activities and discussions during the RDS phase helped understand the macro-level context, from changes at a global scale to identification of climate hotspots and the finer realities and experiences through field visits (ATREE in the TN sub-region, WOTR through their on-going research activity in Maharashtra and IIHS through their consultative and exploratory engagements within Bangalore). Thus, micro-level changes have been contextualised within larger spatial and temporal dynamics.

Some steps during the RDS phase included outlining the biophysical framework that could be implemented across urban and rural SARs in India. A decision was also made to expand the definition of semi-arid areas from one derived primarily from the meteorological criterion, to one that incorporates information from local land-use and hydrology, and actual water scarcity stress on communities. The discussion further identified the need to focus on the development of a historical climatological dataset for the three Indian SARs using both gridded and non-gridded (i.e. station) data. It has also been concluded that all assessments of climate and biophysical parameters will be undertaken at the river basin scale (respecting hydrological boundaries and not political/administrative boundaries). For detailed maps of the sub-regions and their contextual situation in the country, refer to Annexes 1.3, 1.4 and 1.5.

1.3 Regional diagnostic study for India – Methodology

An intense literature review process on climate change research for SARs in India was initiated during the RDS phase. The IPCC AR5 and extant local literature (peer reviewed literature such as journal articles and book chapters; grey literature such as project reports; policy documents such as government plans) were reviewed to extract salient messages for SARs in India. The bibliography from relevant IPCC AR5 chapters was used as a starting point. Thirteen chapters from IPCC WGII and one chapter from IPCC WGIII were reviewed thoroughly and synthesised (and relevant references in the Indian context identified). One of the modes of inquiry on relevant literature was informed by national and regional missions/programmes and assessments conducted by the Government of India as part of India's national communication to UNFCCC. This helped identify i) literature and networks working on climate sensitive sectors (e.g. water, agriculture), development and practice-oriented work, semi-arid regions in comparative sites outside our sub-regions (e.g. Rajasthan) and, ii) experts and organisations working on similar topics in India. Relevant work and networks were tracked to obtain pertinent literature. Additionally, specific search engines such as Google Scholar, JSTOR, and Web of Science were exhaustively searched for literature on the above mentioned subjects. The literature reviewed comprised diverse topics such as climate science, climate change impacts, vulnerabilities in agriculture, water, health, ecological systems, key policy frameworks to address climatic and non-climatic risks (focusing on development deficits) and response strategies. In addition, adaptation and development projects were reviewed and themes such as agriculture, infrastructure (mainly water), biodiversity, water and land management and livelihood strategies were covered. Extensive information was derived from the development practice domain through local NGOs working in the sub-regions (e.g. ATREE's connections with local NGOs; WOTR's 30-year engagement in the region).

The objective of the literatrure review process was to delineate emerging themes/issues that exacerbate the impacts of climate change on natural, physical and social systems. Based on an understanding that emerged from the literature and from the research experience of the India Internal Regional Partners (IIRP), economic development and livelihoods and urban-rural linkages emerged as the principal themes of national and sub-national inquiry.

In the Bangalore sub-region, in the RDS phase,– literature review and elicitation of expert knowledge through KIIs and stakeholder consultation provided useful insights, along with two scoping (exploratory) visits within Bangalore city. The literature review helped develop an understanding of the socio-economic, environmental and livelihood changes within the city as well as the institutional architecture that responds to climatic and non-climatic risks in and around Bangalore. Internal IIHS analytical databases, government reports, and project reports from past research studies provided a contextual narrative for the region. The KIIs provided insights into gaps in knowledge as well as possible ways of engaging with these gaps during the RRP.

The RDS phase for the Moyar-Bhavani sub-region consolidates available literature including government reports and focused research in the sub-region. This exercise helps in establishing a primary understanding of the current situation and development trends. It has therefore enabled the identification of key research gaps. The literature review also helped in understanding the regional socio-economic characteristics and agricultural and other livelihood practices. Available secondary sources of information have been triangulated with ground truthing from primary scoping studies to arrive at a broad narrative for the Moyar-Bhavani basin, describing existing socio-ecological systems, livelihood systems and examining the influence of present and (projected) future risks and vulnerabilities.

At the sub-region level, research activities in the RDS phase for the Sangamner sub-region included the assessment of local dimensions of vulnerability in select villages using a validated vulnerability assessment tool developed by WOTR – the CoDRIVE. It further comprised intense local literature review, consultations with regional experts and strategic informational sources at WOTR (owing to their long-history of engagement in the region). The review gives an overview of changes in demographic patterns, land use, agriculture, livestock, water resources and other major livelihoods. It also provides information on policy changes in certain key sectors. Seen from a climate change and adaptation context, these could help in identifying issues that need more in-depth research. Census data, statistical abstracts and reports have been used to compile adequate data for the state, district and block level. However, accessing consistent micro-level data has been a challenge which makes it difficult to assess changes (e.g. between 2001 and 2011).

Certain key dimensions in the RDS phase were approached separately, as follows:

- **Climate and Biophysical Impacts (CBI):** IIHS, working closely with IITM and ATREE, has produced regional climate messages for past, current and projected future climatic conditions in India based on recent assessments such as CMIP5 for future climate messages. It was premature to analyse the climatic future for the region, as outputs from the regional CORDEX experiment are still being generated and very few model outputs (out of an ensemble of models) are available. We emphasised understanding the nature of sub-region specific climatic trends and their drivers using a mix of historical model data (from the CORDEX ensemble) and station-level global data sources. It was essential to understand the extent of climatic variability and the associated biophysical response to ascertain appropriate entry points for the RRP phase.

- **Adaptation Options and Strategies:** To answer the various questions around the adaptation-development spectrum (Chapter 5), we began by defining different response strategies and pathways using existing literature. Further, we divided the work into three streams of enquiry: a) What is the current governance and institutional framework helping manage risk and address development challenges?, b) What are the current risk management practices, strategies, and projects at national, state and transect levels in urban and rural areas?, c) What are the barriers and enablers of such risk management adaptation strategies? This aspect is in addition to the existing state of social and biophysical barriers and specifically addresses scale and effectiveness in adaptation response. For each question, we reviewed peer-reviewed literature but also drew on policy documents (e.g., the National Action Plan on Climate Change), development plans at state and national levels, project documents from local NGOs, international development agencies and think tanks as well as case studies from practice-based institutions. These were analysed to construct a narrative around key risk management strategies at different scales and identify key contextual barriers and enablers of adaptation. To answer question (b) specifically, we conducted a rapid survey of adaptation projects funded by 10 prominent funding organisations, and analysed 76 of those that functioned within the Indian SARs. Finally, we also reviewed existing frameworks used to assess vulnerability in India and with equal focus on urban and rural vulnerabilities, supplemented by existing risk and vulnerability frameworks from IPCC Assessment Reports and available practitioner frameworks.

CHAPTER 2

The Regional to Sub-national Context

Lead authors:

Andaleeb Rahman[1], Ramkumar Bendapudi[3], Prathigna Poonacha[1], Divya Solomon[2], Shrinivas Badiger[2] and Ravi Chopra[1]

Contributors:

Amir Bazaz[1], Sumetee Pahwa Gajjar[1], Chandni Singh[1], Ritwika Basu[1]

Reviewer:

Aromar Revi[1]

Tribal agricultural labourers cultivating land in Gulliteripati, Tamil Nadu

Photo Divya Solomon

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[1]Indian Institute for Human Settlements, Bangalore, India; arahman@iihs.ac.in

[2]Ashoka Trust for Research in Ecology and Environment, Bangalore, India, divya.solomon@atree.org

[3]Watershed Organisation Trust, Pune, India; ramkumar.bendapudi@wotr.org.in

Executive Summary

a. What are the major socio-economic and environmental characteristics of the country and sub-regions?

The last two decades in India have been characterised by spectacular economic growth, but its distribution across regions, socio-economic groups and income classes has been an issue of concern. Despite some reduction in poverty, the number of people living below the national poverty line is substantially high. Stagnant agriculture and industrial growth, rural-urban inequality, poor quality of jobs, and exclusionary urbanisation are some of the potential impediments to sustain this growth. The Bangalore sub-region is characterised by a major transition in the rural-urban continuum, with impending challenges around fragility of the quality of life and resource conflicts. The Sangamner sub-region is highly dependent on rainfed agriculture. It is one of the four worst performing districts in terms of crop productivity, water use and soil fertility in Maharashtra. The Moyar-Bhavani sub-region is predominantly arid and receives relatively lower rainfall than the rest of the state, resulting in a fragile livelihood base that is predominantly dependent on agro-forestry systems.

b. Describe key socio-ecological systems and dominant livelihoods specific to the region.

Agriculture still remains the dominant livelihood in India and agricultural production is mostly dependent upon rainfall since irrigation expansion has been slow. With a thrust towards industrialisation and an increasing demand for land, the forest cover is declining and water availability is under stress. Key aspects of Bangalore's ecology are its green cover and lakes, which played an important role in local drainage and moderated the impact of climate extremes. However, they show a declining trend in both quantity and quality. Jobs in the city are mostly in services and the industrial sector with questionable quality (in terms of its nature and runemeration).

Bangalore is often seen as having a corporate identity with commercial offices of international financial establishments, retail chains, entertainment, and recreation facilities built in the central business districts. High real estate prices have pushed the urban poor to the city periphery and informal settlements, which are prone to climatic hazards.

Sangamner is a rainfall-deficient region with agriculture as the major source of livelihood. It mostly produces coarse cereals while crop productivity is quite low. Dairy and livestock are also an important source of livelihood in the region with a high dependency on natural resources. The Moyar-Bhavani sub-region has a diverse landscape with abundant natural resources, which is central to livelihood opportunities in the region. Agriculture, fisheries, pastoralism and collection of non-timber forest products (NTFPs) are the major livelihood options available. Canals are the major source of irrigation under the government-financed watershed development programmes.

c. What are important development dynamics in the region? What are the major drivers of change in the region, and what are important ways that climate interacts with these other drivers?

In India, developmental change is characterised by a decline in the population engaged in agriculture, increasing urbanisation, decreasing agricultural productivity, changes in land use pattern (often inequitable), deforestation, water scarcity and soil degradation. In Bangalore, the major development dynamic has been its rise as a 'global city', which has led to a phenomenal increase in the built-up area for commercial and residential purposes. This has changed the city's demography, spatial character and the natural ecosystem base (such as tree cover). A reduction in the number of lakes has led to water scarcity and problems of waste disposal. Rise in the value of real estate has made housing unaffordable leading to a proliferation of informal settlements, which not only lack adequate public services, but also are also prone to extreme weather events like flooding.

In Sangamner, there has been an increase in out-migration owing to poor rainfall and lower crop productivity. Even in rural areas, people are moving out of agriculture into non-agricultural activities. With the proliferation of irrigation facilities, there has been a decline in the production of cereals in favour of cash crops which are resource-intensive and therefore increase risk.

Since livelihood in the Moyar-Bhavani Basin is forest-based, the decline in the production of NTFP due to climate change is expected to have an adverse impact on forest communities, especially tribal and other indigenous communities. The government objective of furthering industrialisation, together with the objective of forest conservation, which sometimes involves relocation and rehabilitation of people, is further expected to have an adverse impact on forest dwellers.

The Regional to Sub-national Context

This chapter elaborates on India's progress over the last two decades. This progress in its multiple dimensions has underpinned the development discourse at multiple levels such as socio-economic transitions, environmental aspects and key formations in government and institutional regimes. At a sub-regional level, divergences from the emerging national discourse are often visible, moderated by developmental priorities and characteristics of each region. Together, discourse characterised at multiple scales in this chapter has shaped risks, impacts and vulnerability in the country and the sub-region of our interest.

2.1 National context

The last two decade has witnessed an unprecedented rate of economic growth in India. The country has graduated into a lower middle-income status by international standard, but concerns have been raised over growth, impact on poverty reduction and overall well-being (Jayaraj and Subramanian, 2015). While there is no doubt that the rate of poverty has declined considerably in the country, the rising inequality and differential benefits of economic growth are a deeply contested issue (Motiram and Naraparaju, 2014). Jobs and opportunities, which have emerged from this growth, have created differential benefits across various socio-economic classes, and divergence between regions (Dev, et al., 2013). The lack of adequate agricultural growth and rising rural-urban income divide, unemployment, decline in levels of formal employment, unbalanced regional economic growth and the inadequate access to public services for the poor are the major developmental challenges facing India. The last two decades have also seen a significant shift in the Indian policy framework, which has towards greater spending on the social protection and redistribution with the right to employment and food.

Increasing urbanization has been an important feature of India's recent economic development. The importance of rural-urban linkages has been recognized in India's XIth Five Year Plan which stated, "…3,682 urban local bodies in the country spread across the 593 districts in the country, such linkages could allow urban economic engines – with their access to markets, infrastructure and credit —to become the flywheel of rural growth, resulting in a more inclusive form of growth in the country" (Government of India 2007:93). Rural to urban migration has been a key element of emerging rural-urban dynamics. With greater economic growth and urbanization, societal and political fault lines have intensified, leading to competition around resources and contested governance regimes (Nagendra et al, 2014). The traditional model of agriculture and land use is under immense pressure owing to greater land and water scarcity, deforestation, and soil degradation. City boundaries have blurred as built up area along the urban-rural continuum has expanded (Shaw, 2005). Without undermining the role of growth in reducing poverty, prudent public policy stresses on "inclusive and sustainable growth" which does not compromise on the long run health of the economy.

This chapter is organized around the three sub-regions of our study, which are described in terms of their socio-economic characteristics, key socio-ecological systems and their major development dynamics and its interaction with climatic variability.

2.2 Bangalore sub-region

2.2.1 Characterising the Bangalore sub-region

Bangalore, the capital city of the state of Karnataka, is the fifth largest and one of the most rapidly growing metropolitan cities in India. With a population of over 9.5 million, it comprises 15.75 per cent of the state population and contributes to 34 per cent of the GDP. The population of the city has grown by more than 40 per cent between 2001 and 2011 (refer Annexe 2.1), much of which could be attributed to Bangalore's emergence as a global centre for 'new' service sector activities like information technology (IT) and biotechnology. The early economy of the city which was primarily driven by public investments in industrial and defence establishments, changed with the real estate boom in the mid-1990s which shaped the city's image as a corporate centre (Benjamin, 2000). The 1990s also saw a steady rise in information technology industries with several global IT giants setting up offices in Bangalore, and the tertiary (service) sector becoming the major driver of economy in the city contributing to over 60 per cent of Bangalore's District Domestic Product as of 2011 (IIHS Analysis). Along with IT-based industries, the economic landscape of present-day Bangalore is also characterised by textiles, manufacturing, and biotechnology-based industries. The city has over 20 industrial estates with several large, medium and small enterprises operating within it (Sudhira, et al, 2007).

Geographically, Bangalore is situated at 900 m above sea level delineating four major watersheds. Historically, its landscape has been dotted by several waterbodies and tanks because of its undulating terrain. Vegetation in the city could be classified as the tropical dry deciduous type. The Bangalore urban district also consists of 17 reserve forests as recognised by the Forest Department (EMPRI, 2008).

2.2.2 Key socio-ecological systems and dominant livelihoods

2.2.2.1 The growing city and its environment

While the economic growth of Bangalore largely driven by investment in physical infrastructure and commercial establishments such as industrial and IT parks and transport has increased livelihood opportunities and improved the standard of living, there has been tremendous pressure on the natural environment of the city. Decline in water table, urban flooding, increasing air pollution and urban heat island effect have led to the degradation of the natural eco-system in and around the city. This has affected the city's spatial structure and character and has had an overriding effect on its natural ecosystems. Decline in the number of waterbodies (almost 262 in 1961 to about 33 lakes in 2003) has affected groundwater replenishment, climate (Sundaresan, 2011) and associated livelihoods such as fishing and urban agriculture (Sudhira et al., 2007). Tree cover and green spaces, which constitute an important part of Bangalore's ecology and in the past helped moderate the impacts of climatic extremes (such as high temperature profiles), have seen a rapid decline (66 per cent over 2001-11)[2]. Only a few large parks and gardens such as Cubbon Park and Lalbagh form the green lungs of the city along with a few reserved forests that come under the control of the Forest Department.

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[2] http://www.deccanherald.com/content/400816/bangalore-garden-city-barren-city.html

2.2.2.2 Informal Settlements and the city

More than half a million people in Bangalore live in slums and informal settlements scattered throughout the city. The rising price of land and rentals have made housing a major issue. The promise of the city in providing livelihood opportunities attracts a massive inflow of migrants from all over the country. Slum settlements, which earlier used to be located primarily around factories and industrial centres on the city peripheries, have over time moved within the city along railway lines, tank beds, quarry pits, storm water drains and garbage dump sites (NIAS, 2002). Many cannot afford to live in the city and hence live on the peripheries, which are deficient in public infrastructural aspects such as water supply and sanitation amongst others. The location of many of these informal settlements and slums have made them more exposed to environmental and climatic hazards further adding to their vulnerability (Krishna, et al., 2014). In the absence of public services, there has been a proliferation of private water tankers, borewells and hand-pumps at a much higher cost. Lack of access to modern sanitation and (solid and liquid) sewerage facilities further adds to the huge environmental costs such as contamination of the soil and ground water (water pollution) and other health-impacts. The presence of greenery and vegetation in the slums of Bangalore which plays a significant role in providing social capital, livelihood, health and nutrition is limited (Gopal and Nagendra, 2014) although some of them do grow fruits and vegetables for self-consumption, medicinal value, shade, and for ornamental, cultural and religious importance.

2.2.2.3 Peri-urban dynamics

The peri-urban expansion of Bangalore is driven by the conversion of rural land for urban expansion. Construction for the sake of commercial and housing projects is driving land-use and land cover changes and transforming the rural economy into one centred around an urban real estate market (Goldman, 2011). This has not only resulted in loss of land for the pastoralists, but also a loss of identity, communities and livelihoods (ibid.). Such a rapid transformation of the rural landscapes has placed tremendous pressure on peri-urban ecosystems. Ecological and environmental degradation resulting in fragmented habitats, biodiversity loss and hydrological imbalances are visible. Ecological commons such as lakes, parks, and community gardens which provide livelihood options and other social and cultural services to the communities living here have been affected (Nagendra, et al., 2014). With the expansion of urban boundaries, the erstwhile community-based management system is transforming into a state-based management system with several actors and agencies (D'Souza, et al., 2011). This new system is at odds with the earlier system that provided livelihood, social and cultural services.

2.2.3 Major development dynamics in the region

Bangalore is Karnataka's primary city, both in terms of population as well as economic opportunities. Bangalore has changed from a metro city to a mega-city, to a world city (Goldman, 2011) and to, most recently, a global city (Udvardi, 2014). These transitions have shaped the development of Bangalore spatially, economically and socially. International financial establishments are further influencing the governance of the city (Goldman, 2011). Feeding into the global economy, Bangalore is becoming less dependent on its local economies and far less so on its rural economies with negative impacts on its natural and built environment (Goldman, 2011; Udvardi, 2014). Mounting pressures on agricultural and associated livelihoods in rural areas of the state have forced people to migrate to the city in search of better livelihood options, which has significantly contributed to the increase in population. However, limited and depleting natural resources will prove to be a challenge to sustain the above said development trajectory of the city, including risks from climate hazards such as flooding, risks to critical natural resources such as water and land and those associated with rising carbon emissions and energy intensity of development.

2.3 Sangamner, Maharashtra

2.3.1 Characterising the Sub-region

The Sangamner sub-region lies within Ahmednagar district of the state of Maharashtra and is primarily rural (Shivaji and Vaidya, 2012)[3]. Ahmednagar contributes close to 3 per cent of the state's GDP. According to the last census, the population growth in Ahmednagar in 2001–11 (12.4 per cent) has been slower than in 1991-2001 (19.8 per cent), but there has been an increase in the population density during the last decade (237–266 people per km^2 between 2001–11). Population density in Ahmednagar is lower than the rest of Maharashtra on account of migration to other cities (such as Nashik, Mumbai, Thane and Pune) since Ahmednagar is drought-prone and is located in a rain shadow area (Korade, 2012). There has been a rapid growth in urban population in Ahmednagar district during 1991–2011. The average literacy rate of Ahmednagar in 2011 was 79.05 compared to 75.3 in 2001. Male literacy was higher (86.82) as compared to female literacy (70.89).

Various agro-ecological characteristics are found this sub-region – the Konkan comprising the coastal area; Sahyadri hill ranges known as Western Ghats; and the Deccan plateau. There is a shift in the cropping pattern in Maharashtra towards commercial crops and the same trend is observed in the sub-region. Vegetable crops are becoming more popular, potentially due to improved access to agricultural market centres. The area under cash crops has increased due to increased surface water irrigation facilities during the period 1961–2001 (Pandit and Aher, 2013) and also because of increased access to irrigation facilities (wells and canals) (Rede et al. 2013).

2.3.2 Key socio-ecological systems and dominant livelihoods

Ahmednagar district largely falls in the hot semi-arid agro-ecological subzone of the Deccan Plateau, with black soil (Gajabeye, 2008). Major crops grown in this sub-region are coarse cereals — pearl millet, sorghum and fodder crops (Shinde, 2012). As mentioned above, there has been an increase in the surface water irrigation facilities in the district which has led to an increase in the share of commercial crops, such as sugarcane (Rede et al., 2013). There are about 22 sugar factories in the district and in 2011–12, these contributed to about 13.4 per cent of total sugar production in the state. Traditional subsistence agriculture is becoming semi-commercialised and more market-oriented. Ahmednagar District also has well developed dairy infrastructure and ranks first in milk production in Maharashtra (Ghule et al. 2012). A convenient geographical location with good connectivity linking the sub-region to the major marketing centres in the state, such as Mumbai, Thane, Pune, Nashik and Aurangabad gives it the added advantage of market access.

[3] 80% of the population in Ahmednagar lives in rural areas.

Water resources: In Ahmednagar district, watershed development has greatly benefited agriculture, leading to an increase in net sown area, gross cropped area, area under irrigation, yields and groundwater levels (Varat, 2013). Dugwells are the most important source of groundwater as 95 per cent of the area is covered by Deccan Trap Basalt, and hence borewells and tubewells are not very feasible. Maharashtra has taken a lead in experimenting with various participatory watershed management approaches for drought-proofing and providing water for drinking and irrigation (Tomar and Nair, 2008). These watershed programmes help augment crop production and promote livestock activities (Tilekar et al., 2009). Increased irrigation facilities and livestock have enhanced the annual employment of male and female workers by 43.19 per cent and 51.73 per cent, respectively. Participatory integrated watershed management in the neighbouring district of Aurangabad has improved the economic condition of farm households (Aher and Pawar, 2013).

Livestock: Agriculture and allied sectors are crucial sources of livelihoods in the sub-region. Within this, livestock rearing is an important livelihood source and risk spreading mechanism. Among cattle, cross-bred animals have increased whereas indigenous cattle declined in the same period. One reason could be the growth in the dairy sector in the district, which resulted in such increase in buffaloes and crossbred cattle. This is because high fat content in milk fetches a better price. There has been a decline in livestock (sheep and goats) at the district level and *taluka* level in Sangamner, especially during 1997–2003 which can be attributed to the drought in 2003 and distress sales during that time.

2.3.3 Development dynamics in the sub-region

In a sub-region largely dependent on agriculture for livelihood, there have been changes in the employment structure. Households depending on agriculture (i.e. agriculture labour and self-employment in agriculture) have reduced from 75.1 per cent to 65.7 per cent in the last 10 years, while those depending on self-employment in non-agricultural sectors and other kinds of labour have increased. This was partly driven by water constraints and poor agricultural productivity. There has been a transition from agricultural employment towards the rural non-farm sector, as certain linked livelihoods like livestock rearing and a local service economy around agricultural implements/inputs have emerged. Four districts including Ahmednagar, fare poorly in terms of crop productivity, remuneration from agriculture, water use and soil fertility. Similar to the rest of the country, the cropping pattern in Maharashtra is also shifting towards commercial crops such as pulses, cotton, sugarcane and soybean.

2.4 Moyar-Bhavani Basin, Tamil Nadu

2.4.1 Characterising the Transect

The combined catchment area of the Bhavani and Moyar rivers is referred to as the Upper Bhavani river basin. The basin covering 41,00km^2 is a high-altitude area at the confluence of the Eastern and Western Ghats, bounded to the north by the state of Karnataka, to the west by Kerala, to the east by the Bhavani Sagar reservoir and to the south by the Coimbatore plateau. For ASSAR, we are situating our research in the semi-arid part of this basin. The Moyar-Bhavani sub-region lies within the districts of Nilgiris, Erode, and Coimbatore. Major towns within the sub-region include Mettupalyam on the south and Bhavanisagar on the extreme east. The Moyar-Bhavani region lies in the central and south-central regions of Tamil Nadu, which are predominantly arid plains and receive relatively lower rainfall than the eastern and northern parts of the state. The elevation of the river basin ranges from 300m in the plains to 2,600m in the Nilgiris plateau. Accordingly, the annual rainfall varies from 700 mm on the low lands to nearly 3000 mm in the hills. Potential yearly evapotranspiration (PET) in the central upper Bhavani basin is about 800 mm mainly in the districts of Erode and Coimbatore and around 1,600 mm in the lower Bhavani basin (SOE report, 2001). The topography is undulating in the lower plateau and uplands while it is rugged to the west. The vegetation cover within the contributing catchment includes the high-elevation shola-grassland mosaic, tropical evergreen, moist and dry deciduous forests, in addition to extensive plantations and agriculture. The main part of the basin has a humid equatorial environment, although the low land plains are sub-humid and semi-arid. The soil is predominantly deep black and deep red soil; only in the south-eastern parts of the basin are there areas with more shallow soils, which exhibit poorer drainage.

Along with diverse wildlife and physiographic features, the landscape has very high human density and a long history of human use. Major livelihood activities include agriculture, fisheries, pastoralism and collection of NTFPs. Fishing is primarily practised by communities living adjacent to the Bhavanisagar reservoir. This area has diverse indigenous tribal communities such as the Kurumbas, Sholigas and Irulas as well as a large population of scheduled castes. These communities often live in or on the boundaries of protected areas. A collection of NTFPs such as honey, broom grass (*Thysanolaena maxima*), and soap nut (*Sapindus mukorossi*) constitutes a large part of their livelihood. The population in the larger Bhavani basin has doubled during the last three decades to about 2.5 million (Muthusamy et al. 2013).

The cropping intensity in this region is quite high averaging about 105 per cent. The largest source of irrigation in this area is lift irrigation followed by canal irrigation[4]. The Bhavani basin is primarily irrigated by the canal irrigation systems which are maintained by government-financed watershed development programmes. Irrigation through tank systems provide maximum productivity of water in the Bhavani basin but it covers less than the area irrigated by the canal system (Ramesh and Palanisami, *n.d.*). There has been a considerable reduction in crop area, yield, and agricultural income in the Bhavani basin due to water scarcity (Malaisamy, 2001). Major crops grown in the Moyar-Bhavani basin area include *cholam* (sorghum) and sugarcane (in Coimbatore); finger millet, maize and sesame in Erode; and cotton in the Nilgiris. While agriculture in Coimbatore and Erode involves extensive use of chemical fertilisers and pesticides, the Nilgiris region registers lower use of nitrogenous, phosphate and potassium fertilisers as well as lower pesticide usage (Government of Tamil Nadu, 2013).

2.4.2 The Agriculture Forestry SES in Moyar-Bhavani Basin

The Moyar-Bhavani sub-region comprises a diverse landscape with abundant natural resources units, complex systems of governance and a multitude of actors with varying degrees of influence and levels of interactions within the system.

[4] Agricultural contingency plan for Coimbatore District prepared by TNAU (Tamil Nadu Agricultural University)

Agriculture-dependent SES: Livelihood systems with the exception of fisheries are primarily dependent on agriculture. There are existing stressors within the agricultural system including groundwater dependency, decreasing labour, low productivity and low levels of mechanisation (SAPCC-TN, 2013).

Forest-Dependent SES: With ongoing impacts (deforestation, degradation, fragmentation, and local extinction) tropical forests suffer from rapid land use changes (Achard et al., 2002). Forests play an essential role in reinforcing tribal livelihoods. 70 per cent of communities within and around Protected Areas(PAs) are dependent on NTFP's (SAPCC-TN, 2013). Climate change represents an added dimension to existing risks to forest systems. NTFPs form the main stay of income and sustenance for many forest-dependent tribal communities Thus, decreasing NTFP yields will have an adverse impact on the livelihoods of forest communities particularly tribal communities (Rao, 1987; Gauraha, 1992; Chopra, 1993; Mallik, 2000).

2.4.3 Development Dynamics in the Region

The regional government is currently pursuing a development policy that lays more emphasis on ensuring accelerated industrial growth, with measured focus on rural development and infrastructure[5]. However, loss of agricultural land (owing to its converion to industrial use) can be severely detrimental to rural livelihoods. In its 12th Five-Year Plan, the government of Tamil Nadu aims to increase forest cover and reduce anthropogenic pressure on forests through wide-scale relocation and rehabilitation programmes from PAs. This will affect the livelihoods of forest-dwelling communities. Land use within forest agriculture ecotones are of vital importance to indigenous communities (Bawa et al., 2007). In order to ensure food security, the Tamil Nadu government aims to increase agricultural growth to 5 per cent through Farm Level Planning, large scale adoption of frontier techniques like System of Rice Intensification (SRI), Sustainable Sugarcane Initiatives (SSI), precision farming, Millets Mission, System of Pulses Intensification (SPI) as whole village concept, crop diversification through high value horticulture and commercial crops, market driven cropping pattern and rainfed area development. Aggressive agricultural intensification could have diverse biophysical impacts and lead to erosion of traditional methods of agriculture which might have been more resilient (Doughlas et al., 2005).

2.5 Mapping changes in the biophysical state in the sub-regions (1999 to 2011)

In order to explore the broad dimensions of biophysical changes at the sub-regional level, land use change was mapped using standard land use classifications (e.g. settlements, agriculture, forest, and water). Detailed maps demonstrating changes from 1999 to 2011 are provided in Annexe 2.2[6].

The following table captures the quantitative aspects of the changes in the biophysical space.

[5] Twelfth Five year plan Of Tamil Nadu (2013-17) prepared by the Planning Commission

[6] Annex 2.3 details the methodology used for land use land cover (LULC) classification

Table 2.1 Biophysical changes in the three sub-regions from 1999 to 2011.

	Bangalore				Sangamner				Bhavani-Moyar			
	1999	2011	1999	2011	1999	2011	1999	2011	1999	2011	1999	2011
Land-use classes	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Settlements	436.5	5.4	866	10.8	70.7	1.3	80.2	1.5	33	2.1	49	3.2
Agriculture	1158	14.4	2071	25.8	1900	36.2	2090	40	214	13.7	231	15
Forest	2640	32.9	2045	25.5	257	4.9	146.7	2.8	638	41	554	36
Water	210.0	2.6	57.7	0.7	56	1.1	60.5	1.2	64.7	4.2	49.5	3.2
Others	3573	44.6	2978	37.1	2971	56.5	2878	55	608	39.1	674	43
Total	8018	100	8018	100	5256	100	5256	100	1558	100	1558	100

Summarily, the main conclusions are:

1. Forest cover is decreasing, especially in the Bangalore sub-region
2. Area under agriculture does not see a significant change. However, since population is increasing, resource dependency (on existing food producing systems) is intensifying.
3. Water resources are decreasing which is symptomatic of increasing stress.

Coupled with rainfall variability, these changes in the sub-regions denote a significant risk.

2.6 Conclusion

There are various socio-economic and environmental challenges India and the sub-regions face. Poverty alleviation, creating jobs, remunerative agriculture, and balanced urbanisation, together with a check on environmental damage make up the most important challenges. Climate change is appearing to be an additional stress in these sub-regions. The Bangalore sub-region is facing a myriad challenges due to the evolving processes of urbanisation. Such processes are entrenched in huge environmental costs, and they are continuously manifesting themselves around resource conflicts causing further stress to the 'rural-urban' continuum. In the Moyar-Bhawani sub-region where livelihood is centred on agro-forests ecosystems, industrialisation and climate change remain the major threat to local livelihoods, as these often involves relocation and rehabilitation of the people. In the Sangamner sub-region— a predominantly agricultural region— rainfall is often deficit, agriculture yields are low, and poverty levels are high, resulting in huge out-migration to cities.

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CHAPTER 3

Climate Change trends and projections

Lead authors:

M Bunyan[1,] J Krishnaswamy[1], J Sanjay[4], V Raskar[3] and A Bazaz[2]

Contributors:

Rajeev Chaturvedi[2,] Shashikala Gowda[2] , Nilakshi Chatterji[2] and Ravi Chopra[2]

Reviewer:

Aromar Revi[2]

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Photo: Prathigna Poonacha

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[1]Ashoka Trust for Research in Ecology and Environment, Bangalore, India, milind.bunyan@atree.org

[2]Indian Institute for Human Settlements, Bangalore, India; abazaz@iihs.ac.in

[3]Watershed Organization Trust, Pune, India; vinit.raskar@wotr.org.in

[4]Indian Institute of Tropical Meteorology, Pune, India

Executive Summary

a. What is the state of the evidence with respect to changing climate baselines in the region? Are there discernible trends?

Accelerated warming was observed in India from 1971–2007 caused primarily by an intense warming observed from 1998 to 2007. A noticeable increase in heat waves and hot days was also reported. The Indian monsoon has weakened in recent decades along with an increase in the frequency of intense precipitation events in some areas. This increase in frequency has been attributed to the increasing influence of the Indian Ocean Dipole (IOD), warming, and land-use change. Increasing trends in temperature and significant declines in precipitation were observed in the Bangalore and Moyar-Bhavani ASSAR sub-regions, but temperature trends were more uncertain in the Sangamner sub-region. Precipitation in the Sangamner sub-region was observed to be highly variable and has increased modestly since the 1990s.

b. What information is available from regional downscaled climate model projections about future climate change? How robust are the projections? Where are the important contradictions?

Climate projections based on an ensemble of recently developed multiple CMIP5 GCMs/ESMs suggest that under business-as-usual (between RCP6.0 and RCP8.5) scenarios, mean warming in India is projected to be in the range of 1.7–2°C by the 2030s and 3.3–4.8°C by the 2080s relative to pre-industrial times. The precipitation over India is not simulated well by the CMIP5 models. Nevertheless, the multi-model mean is closer to observed data than individual models. Recent simulations using a three-member climate ensemble and its constituent models have indicated an increase of more than 2˚C over central and northern parts of India (2066–2095). Projected changes in the precipitation by the end of the 21st century were not observed to be significant, potentially reflecting a disagreement between the models. Our analysis has therefore focused on the historical record of climate change and variability within these sub-regions. La Niña was linked to increased rainfall in the Moyar-Bhavani and Bangalore sub-regions, but its impact on the Sangamner sub-region was minimal.

c. How relevant is this climate (model) information to near and medium-term decision making? What are the limits of climate model information for supporting decision-making?

Currently available climate information is too coarse to be relevant to the local decision-making processes. This is because some ASSAR sub-regions are located entirely within a couple of RCM cells. Statistical downscaling of climate projections is envisaged during the upcoming RRP phase. To improve attribution, the impact of, and feedback from, ecosystem degradation and land use land cover (LULC) change need to be considered in addition to climatic drivers.

Climate change, trends and projections

3.1 Historical Climate

India has already witnessed a temperature rise of about 0.6°C over the last century (Attri and Tyagi, 2010). Though summer monsoon rainfall largely remains stable, a recent weakening in the monsoon as well as an increase in very-heavy precipitation events is being reported (Kulkarni et al. 2012, Goswami et al. 2006, Ghosh et al. 2011). Trends in the semi-arid regions under study are largely consistent with national trends, although regional differences have been observed.

3.1.1 Overview of Temperature Trends

Accelerated warming has been observed in India from 1971 until 2007, caused by intense warming observed in the recent decade (1998–2007). Temperatures (mean, maximum and minimum) have increased by about 0.2°C per decade for the period 1971–2007, with a much steeper increase in minimum temperature than maximum temperature. In the most recent decade, the maximum temperature was significantly higher than the long-term mean between 1901 till 2007. Minimum temperatures have also increased at a rate that nearly equals what was observed between 1971 and 2007 (Kothawale et al. 2010; Annexe A3.1). Revadekar et al. (2012) have also reported an increase in the intensity and frequency of hot events and a decrease in the frequency of cold events.

Box 3.1

Summary of precipitation and temperature trends over India (1901–2009)

Mean annual temperature has increased in India during the 20th century. On the contrary, there is no discernible change in the trend in annual precipitation for India over the past century. This could be due to a lack of sufficient observational records to draw conclusive trends. The Indian summer monsoon is, however, known to have undergone abrupt shifts in the past millennium, giving rise to prolonged and intense droughts. South Asia has reported inter-decadal variability in seasonal mean rainfall, with an increasing frequency of deficit monsoons although this is not uniform across regions. The increase in the number of monsoon break days and the decline in the number of monsoon depressions are consistent with the overall decrease in seasonal mean rainfall. There is also an observed increase in heavy rain events and a concomitant decrease in light rain events. Changes in precipitation and the direct impact of atmospheric carbon dioxide (CO_2) concentrations could be especially important for semi-arid ecosystems, making responses harder to predict. The recent weakening in seasonal rainfall as well as the regional redistribution has been partially attributed to factors such as changes in black carbon and/or sulphate aerosols, land use and sea surface temperatures. The confidence in precipitation changes over the Indian land area over the last century (from 1901 until 2009) remains low, with long-term positive or negative trends seen with different datasets.

Source: IPCC's Fifth Assessment Report (AR5), Working Group.

Using heat wave information of 103 stations across India, during the hot weather season (March to July) between 1961 and 2010, Pai et al. (2013) observed a noticeable increase in heat waves or severe heat wave days between 2001 and 2010. This also corresponds with the warmest decade for the country as well as for the globe. In their analysis of heatwaves using station data for 217 urban areas across the globe, Mishra et al. (2015) reported an increase (albeit non-significant) in heat waves over Indian urban areas over a 40-year period. The authors also observed that hot nights had not increased significantly over India.

3.1.2 Overview of Precipitation Trends

India, especially its semi-arid-regions, receives much of its share of rainfall from the summer monsoon. The observed precipitation records during the 20th century indicate an absence of any significant long-term trend in the summer monsoon rainfall for the country, although there are specific areas where monsoon rainfall trends are significant (Guhatakurtha and Rajeevan 2006). The Indian Meteorological Department (Attri and Tyagi, 2010) also observes that **'***the all India annual and monsoon rainfall for the period 1901-2009 does not show any significant trend***'**. However, Kulkarni et al. (2012) concluded in a recent paper that although the Indian summer monsoon rainfall (ISMR) series has been stable between 1871 and 2010, there is a decreasing trend over the last three decades of the 20th century. A significant decrease of summer monsoon precipitation over the Western Ghats and some SARs has been found in the APHRODITE (Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation) and the IMD (Indian Metrological Department) observed daily gridded rainfall datasets for the period 1951 to 2007 (Krishnan et al. 2013).

A large amount of precipitation variability is related to extreme rainfall events. Several researchers have noted an increasing trend in observed frequency of heavy precipitation events (Rajeevan et al. 2008; Krishnamurthy et al. 2009; Sen Roy 2009; Pattanaik and Rajeevan 2010), and a decreasing trend in light rainfall events (Goswami et al. 2006). Simultaneously, Krishnan et al. (20130) reported a decreasing trend in moderate to heavy rainfall events over the Western Ghats. Gridded daily rainfall data from the IMD for the period 1951–2000 indicates a significant increase in the frequency of heavy rainfall events during the summer monsoon over Central India and a concurrent decrease in the frequency of moderate and low rainfall events (Goswami et al. 2006, Figure 3.2), with the latter trend also being observed by Dash et al. (2009). These observations have recently been corroborated by Krishnaswamy et al. (2014); they observed that low-intensity rainfall events have decreased in the last three decades while high-intensity rainfall events have increased.

In their analysis of extreme rainfall indices over 57 major urban areas in India over the last century (1901–2010), Mishra et al. (2014) concluded that only four urban areas (i.e., Coimbatore, Kolkata, Solapur and Surat) showed a significant (p-value <0.05) increase in the maximum monsoon rainfall. They also observed that changes in the extreme rainfall in most of these urban areas were driven by large-scale climate variability. Krishnaswamy et al. (2014) also investigated the influence of larger climate drivers, i.e., the Indian Ocean Dipole (IOD) and El Niño Southern Oscillation (ENSO) on monsoon variability and frequency of Extreme Rain Events (EREs). Their study suggests that the IOD has evolved independently of ENSO, and its influence on the monsoon and EREs has been strengthening in recent decades. In contrast, the influence of ENSO on the monsoon seems to be weakening, and is more uncertain over the same period. The authors suggest that improvements in modelling this complex system can enhance forecasting accuracy of the monsoon and EREs, and advocate mapping of spatially explicit influences of ENSO and IOD for larger regions to identify vulnerable and sensitive areas.

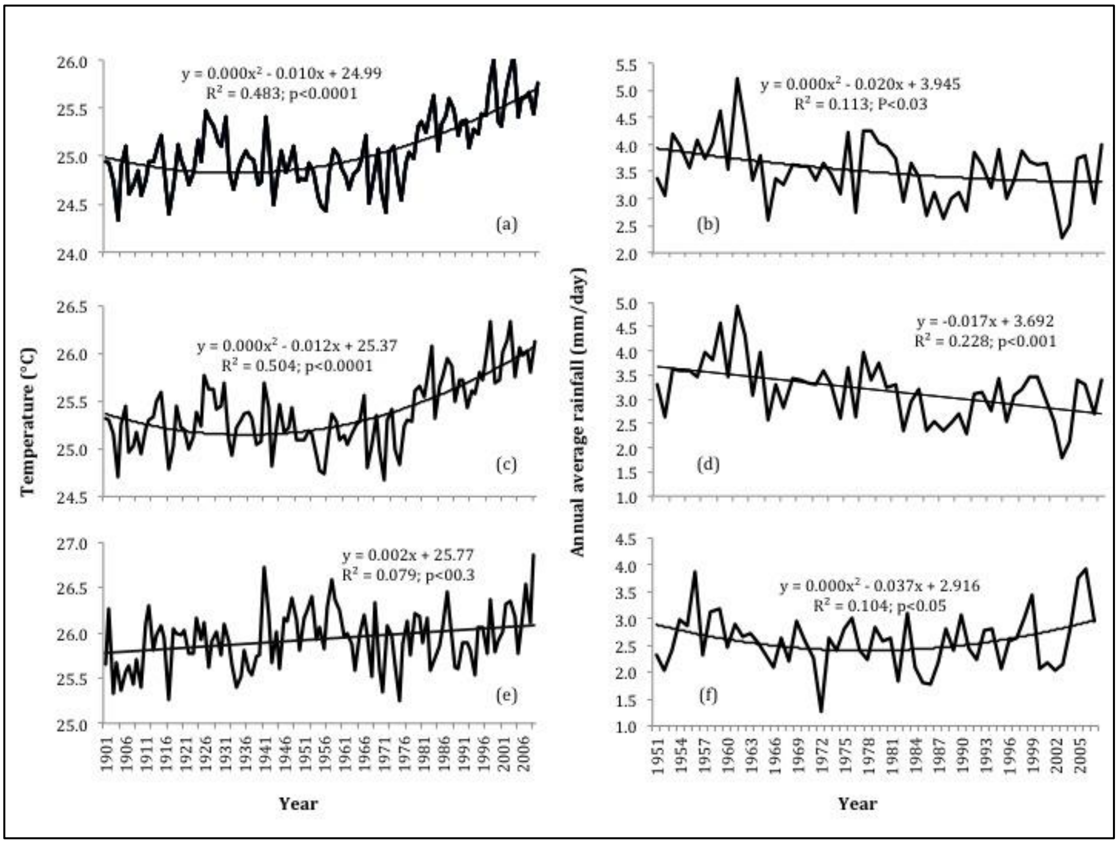
3.1.3 Climate trends in the Indian ASSAR sub-regions

To enhance our understanding of historical climate change and climate variability in the three ASSAR sub-regions, we investigated trends in temperature and precipitation in the broader landscape surrounding the sub-regions (hereafter ASSAR sub-region envelopes). Although the spatial extent of these regions (Annexes 3.3–3.5) was chosen to permit a comparison between the observed historical precipitation (i.e., APHRODITE) and temperature (i.e., CRU, Climate Research Unit) data, and the modelled historical climate (e.g., CORDEX) data, this report only presents the analysis of the former data. We used the gridded temperature dataset from the University of East Anglia's CRU (1901–2009; Harris et al., 2014) to assess trends in temperature. To evaluate trends in precipitation and changes in precipitation regimes, especially extreme rain events, we used the APHRODITE gridded dataset (1951–2007; Yatagai et al., 2009). These analyses were conducted using the Climate Data Operator tool (Schulzweida, 2014) and the R statistical software environment (R Core Team, 2014).

We observed an increasing trend in temperatures in two ASSAR sub-region envelopes (i.e., Bangalore and Moyar-Bhavani sub-region envelopes; Fig. 3.1). Within the Moyar-Bhavani sub-region envelope, this increase has been observed in the last 50 years, while temperatures in the Bangalore sub-region envelope have increased over a shorter 30-year period. No significant trend in temperature was observed in the Sangamner sub-region envelope (SRE).

Figure 3.1

Historical trends (1901–2009) in mean annual temperature (left panels) and precipitation (right panels) in the Bangalore (a, b) Moyar-Bhavani (c, d) and Sangamner (e, f) sub-region envelopes



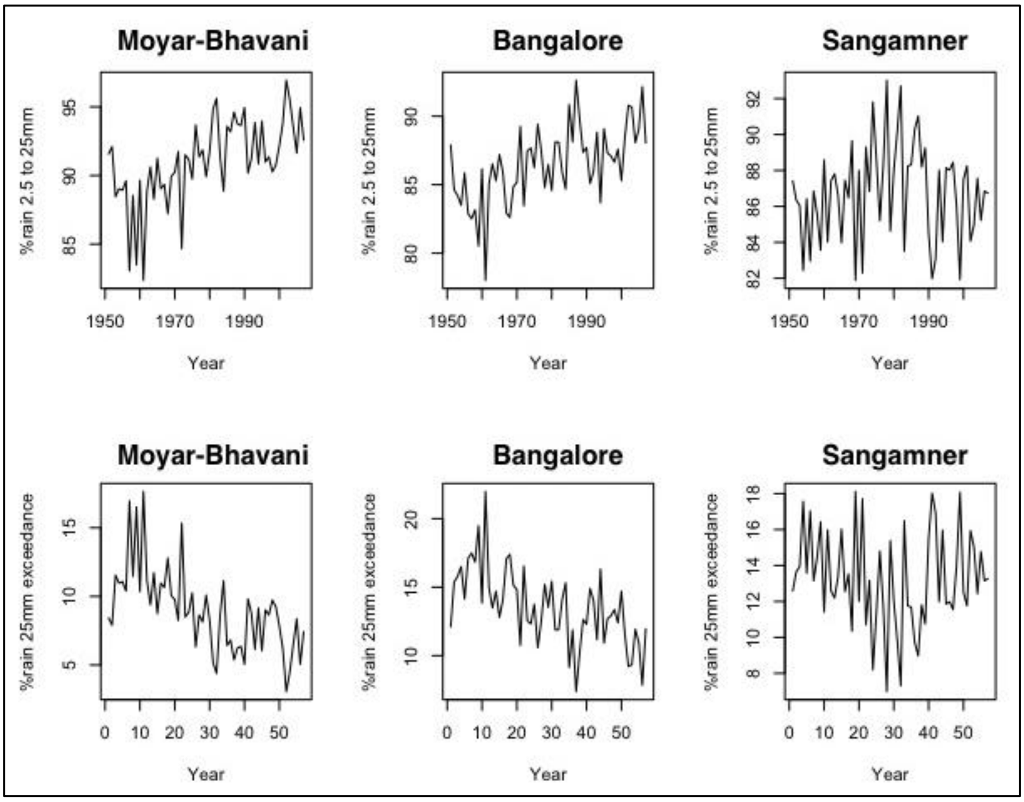
Source: Climatic Research Unit, University of East Anglia (temperature data); Yatagai et al. 2012 (precipitation data)

Our assessment of precipitation trends using the APHRODITE dataset revealed a significant decrease in annual average rainfall in the Bangalore and Moyar-Bhavani sub-region envelopes since the 1950s (Figure 3.1). In the Sangamner sub-region envelope, however, there has been a modest increase in annual average rainfall since the early 1990s. We also recorded high variability in the contribution of sparse rain and moderate rain events in the Sangamner sub-region envelope while these events decreased in the Moyar-Bhavani and Bangalore-sub-region envelopes (Figure 3.2). The observations in the Bangalore and Moyar-Bhavani sub-region envelopes are consistent with broader national trends that have been previously reported (Goswami et al. 2006, Krishnaswamy et al. 2014, Annexe 3.6). We do however note, that the ASSAR sub-region envelopes (defined above; also see Annexes 3.3–3.5) often include the sub-humid and humid contributing catchment, and may not be indicative of patterns specific to the semi-arid part of the sub-regions (warranting caution in attributing influence).

We also noted that observed trends were not always consistent across a sub-region envelope. For instance, rainfall in the Moyar-Bhavani has been observed to decrease significantly at Grid27 (Annexe 3.4; p = 0.03) while a weaker trend was observed at Grid28 (Annexe 3.4; p = 0.063). Finally, the similarity in trends observed between the Bangalore and Moyar-Bhavani sub-region envelopes might be a result of the proximity between these two areas.

Figure 3.2

Historical (1951–2007) trends in percentage contribution of sparse rain events (2.5 mm–25 mm) and moderate rain events (25mm exceedance) as a proportion of total rainy days in the Bangalore, Moyar-Bhavani and Sangamner sub-region envelopes

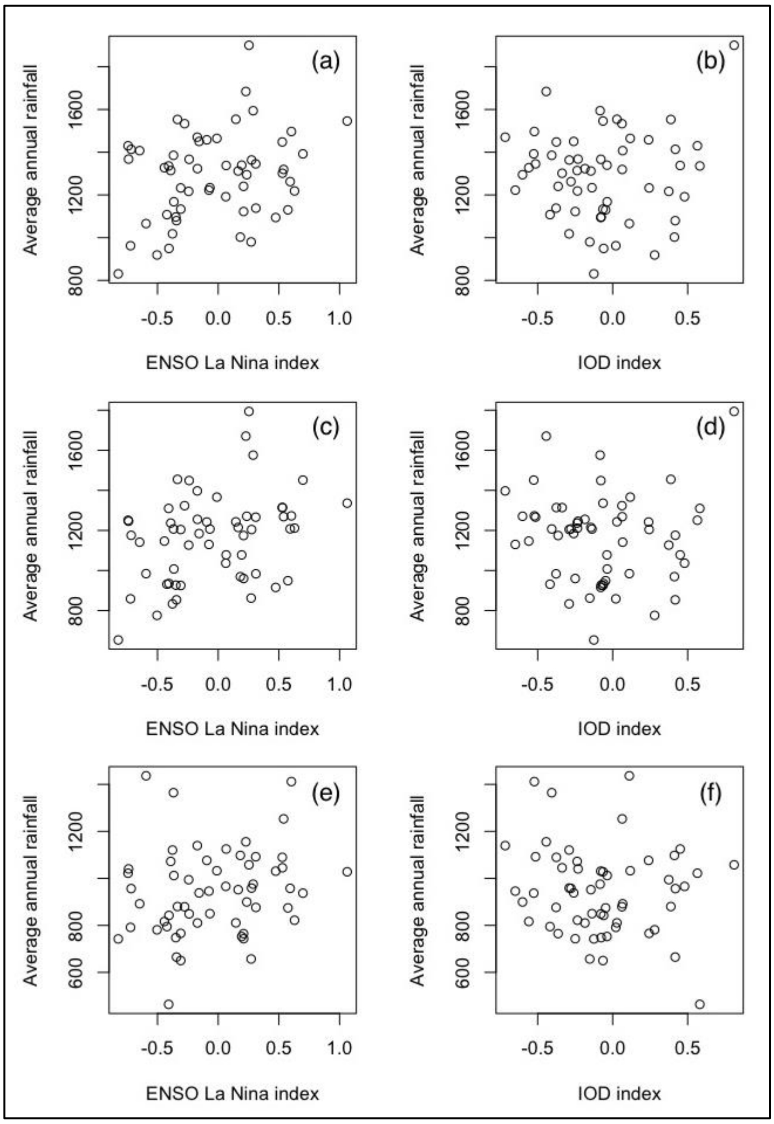


Source: APHRODITE data, Yatagai et al. 2012

We also assessed the influence of larger climate drivers in the region, i.e., the ENSO and IOD, on average annual rainfall across the ASSAR sub-region envelopes. The La Niña phase of ENSO was observed to have a significant positive impact on rainfall in the Moyar-Bhavani ($p = 0.01$) and Bangalore ($p = 0.02$) sub-region envelopes, but its influence on the Sangamner sub-region envelope was minimal ($p= 0.23$). Geethalakshmi et al., (2009) have also observed that the La Niña phase of ENSO has been linked with higher rainfall during the northeast monsoon in the state of Tamil Nadu, which overlaps with the Moyar-Bhavani ASSAR sub-region envelope. In contrast, the impact of the IOD on average annual rainfall was not significant across the Bangalore, Moyar-Bhavani and Sangamner sub-region envelopes ($p \geq 0.31$). Our conclusions are based on historical trends in rainfall (1951–2007) and we expect these relationships to have changed in the recent past as reported elsewhere (Krishnaswamy et al. 2014).

Figure 3.3

Influence of the El-Niño Southern Oscillation (ENSO La Niña index) and Indian Ocean Dipole (IOD) on average annual rainfall in Bangalore (a, b), Moyar-Bhavani (c, d) and Sangamner (e, f) sub-region envelopes



Source: APHRODITE data, Yatagai et al. 2012

3.2 Future Climate

Most climate projection studies in India are based on GCMs included in the CMIP3 (Coupled Model Inter-Comparison Project Phase 3) under different emissions scenarios. Climate projections for India's Second National Communication to the UNFCCC-used simulations from the QUMP project, which is based on HadCM3 (Hadley Centre Coupled Model version 3), to drive PRECIS experiments over the short- (2020s), medium- (2050s) and long-term (2080s) time periods (MoEF 2012). For a detailed perspective on climate projection studies for India, refer to Annexe 3.8. MoEF (2012) projects an increase in annual mean surface air temperature rise from 3.5°C to 4.3°C by the end of the century. No significant decrease in the monsoon rainfall has been projected over the same period, except in some parts of the southern peninsula. However, there is, likely to be a decrease in the number of rainy days, and an increase in rainfall intensity, which suggests an increase in extreme rain events.

Global climate projections are now available as part of the more recent CMIP5 that includes more than 40 GCMs. An evaluation of CMIP5 models revealed that the annual mean surface air temperature (at 2m) over most areas in the multi-model mean agrees with the ECMWF (European Centre for Medium-Range Weather Forecasts) re-analysis of the global atmosphere and surface conditions (ERA)-Interim to within 2°C, but there are several locations where biases are much larger (see AR5 WG1 Fig.9.2). The precipitation over India is not simulated well by the CMIP5 models, and the assessment is hampered by observational uncertainties. However, the CMIP5 multi-model mean is closer to observed records than most of the individual models and there is an evident improvement in South Asia in the rainy season (Sanjay et al. 2013).

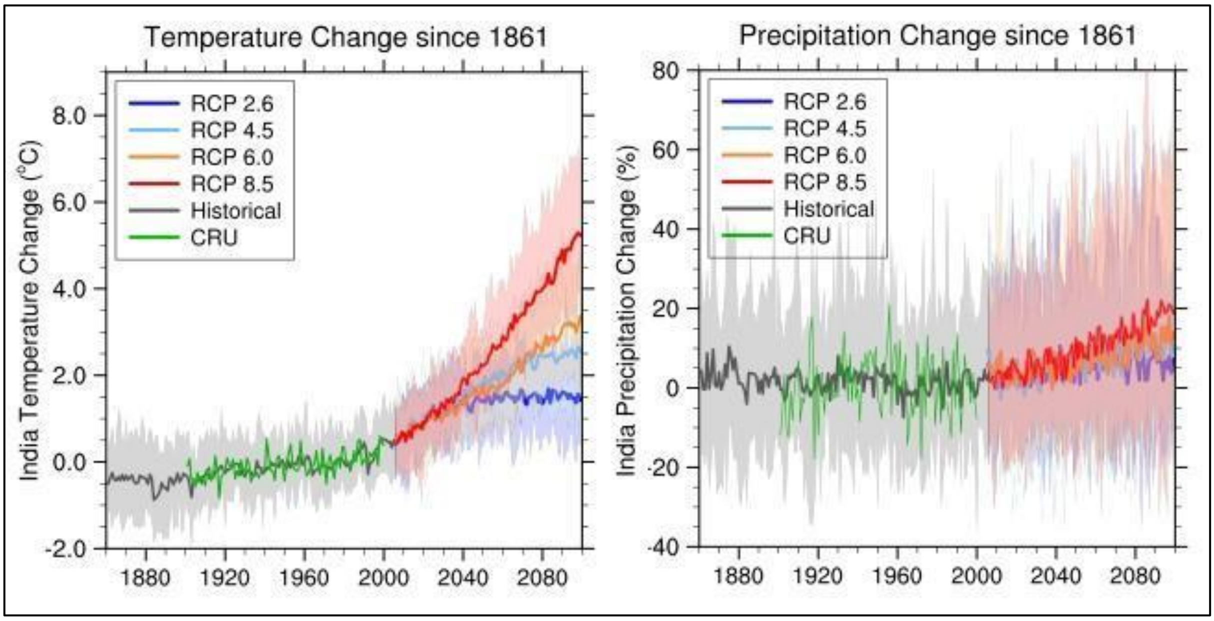
In a comparison of five atmosphere-ocean GCMs and their statistically downscaled counterparts, the CMIP5 simulations did not show improvements in the simulation of the Indian summer monsoon rainfall (ISMR) over the corresponding CMIP3 simulations. The CMIP5 original simulations had more multi-model uncertainty than those of CMIP3 and the statistically downscaled simulations have similar statistical biases. However, the uncertainty in the CMIP5 downscaled rainfall projections was lower than that of CMIP3 (Shashikanth et al. 2014)

In their evaluation of CMIP5 models, Chaturvedi et al. (2012) observed that the ensemble mean climate is closer to observed climate than any individual model for the period 1971–2000 (Annexe 3.7). The authors evaluate future climate using the recently developed Representative Concentration Pathways (RCPs; Hibbard et al. 2011). RCP values are linked to the atmospheric radiative forcing (W/m^2) due to emissions by the year 2100. Four scenarios: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 have been chosen by the IPCC to represent the full range of emission scenarios available in the literature. Of these, RCP 8.5 is considered representative of the business-as-usual scenario and RCP 4.5 that of the balanced mitigation scenario. In their evaluation, Chaturvedi et al. (2012) observed that precipitation under the business-as-usual scenario is projected to increase from 4 per cent to 5 per cent by the 2030s and from 6 per cent to 14per cent towards the end of the century (2080s) compared to the 1961–1990 baseline (Figure 3.4). The authors also observed that long-term precipitation projections are generally more robust than they are over the short term.

Recently, the Indian Institute of Tropical Meteorology (IITM) performed a simulation of surface mean air temperature and precipitation using two RCMs, one variable grid atmosphere global climate model (AGCM) simulation and an ensemble of these three, for the period 1976–2100 (Annexe 3.12). Boundary conditions for these models were taken from coupled atmosphere-ocean global climate models (AOGCMs) that participated in the Coupled Model Intercomparison Project phase 5 (CMIP5; Taylor et al. 2012) medium forcing scenario (RCP4.5) experiments. This analysis conducted at a relatively fine horizontal resolution of 50 km was assessed against the CRU temperature and precipitation data for 1976–2005 (v 3.1; Mitchell & Jones 2005) over the Indian summer monsoon, (June–September, JJAS) and winter (December–-February; DJF) months.

Figure 3.4

CMIP5 model-based temperature and precipitation anomalies for India (1861–2099) relative to 1961–1990 baseline for four Representative Concentration Pathways (RCPs)



Note: The shaded area represents the range of changes projected by the 18 models and model ensemble averages are represented as solid lines. The observed temperature and precipitation trends from CRU are shown by the green line and the solid black line refers to model ensemble values for historical simulations.

Source: Chaturvedi et al. 2012; http://eprints.iisc.ernet.in/id/eprint/45488

Simulated air temperatures agreed reasonably well with the observed climate. However, systematic biases were more common during winter months when compared to the summer monsoon months, with biases exceeding 2˚C across most of South India. Compared to the CRU data set, precipitation in the three-member ensemble mean is underestimated in a large fraction of the Indian subcontinent during summer, while statistically significant overestimation is found over the southern peninsula during winter. For future climates (2066–2095), the three-member ensemble mean indicates a large increase of more than 2˚C over central and northern parts of India (Annexe 3.9). The ensemble mean precipitation changes by the end of the 21st century over most parts of India are not found to be significant in both summer monsoon (Annexe 3.10) and winter (Annexe 3.11) seasons. This may be caused by large changes of opposite signs in the individual models that tend to cancel each other when added, implying that the simulated precipitation change over India is uncertain not just in magnitude but also in sign in large parts of the year.

3.3 Relevance of Climate Information and Conclusions

Our understanding of climate change and climate variability over the Indian subcontinent has benefited from recent advances in understanding the Indian climate system. Nonetheless, the peculiarities of the Indian monsoon, and the influence of both larger and regional climate drivers, necessitate further study of this system. For instance, the Centre for Climate Change Research (CCCR, IITM) is building an earth system model (ESM) that uses high-resolution coupled ocean-atmosphere modelling that aids in attribution and projection of global and regional climate change. CCCR is also involved with the use of high-resolution models and dynamic downscaling of regional climate and monsoons to provide reliable input for impact assessment studies. Concurrently, Mondal and Mujumdar (2015) have recently investigated the spatially explicit influence of ENSO and warming on EREs. A similar investigation currently underway, attempts to explore the influence of ENSO and IOD on rainfall (Krishnaswamy and Vaidyanathan, forthcoming).

Despite these efforts, researchers (assessed through an intense literature review process and aided by inputs from focused Key Information Interviews (KIIs)) acknowledge that the production of reliable downscaled data may not be achieved with current models. For example, several climatic interactions such as the impact of wind velocity on monsoons have not been modelled accurately, which hamper predictions regarding the Indian monsoon. Additionally, the spatial scale of currently available downscaled climate products (RCMs) may preclude its use in the local decision-making process. The Moyar-Bhavani and Sangamner sub-regions, for example are located entirely within a couple of RCM cells (Fig 3.4, 3.5). Further, neighbouring RCM cells in these sub-regions are located in sub-humid and humid areas, confounding the attribution of observed changes. In order to enhance the grain of our analysis, we intend to explore the statistical downscaling of climate projections during the upcoming Regional Research Programme (RRP) phase. Most studies that consider the impacts of climate on the biophysical environment are at large spatial scales and lack granular detail. This detracts from their use at smaller scales that are more relevant to local stakeholders (Box 3.2).

Box 3.2

AGRO-MET: Locale-specific agro-advisories for farmers in rain-fed areas

Information and communication technologies (ICT) play an important role in facilitating advanced planning by farmers to cope with potential climatic and non-climatic risks (e.g., market information) and thereby reduce risk exposure through active adaptation. AGRO-MET is a locale-specific agro-advisory provided to farmers as a component of the Climate Change Adaptation (CCA) project implemented in India by the Watershed Organisation Trust (WOTR). The system consists of a dense network of automated weather stations (AWS) collecting hourly data. This data is aggregated and processed by WOTR and sent to IMD, which then provides three-day weather forecasts. Agricultural experts at WOTR and national and state research institutions then customise these forecasts to provide highly specific advisories on integrated nutrient-water-pest and disease management recommendations to farmers.

Agro-advisories are issued in local language at least twice a week in the summer months and more frequently during the agricultural season. In addition, unusual weather events such as unseasonal rain, frost or temperature spikes are conveyed directly to participating farmers using technological (e.g., SMS) or traditional (word-of-mouth) channels. Besides this, information from the village- based AWSs are displayed daily on black boards at accessible places in the village, by village youth trained to read the weather data. There is also a feedback mechanism wherein local community level workers collect information from selected farmers in case they were unable to follow up on the advisories.

The WOTR experience indicates that the ICT system is an important mechanism to bridge the last mile gap in agricultural extension communication but it is also equally important to have a feedback system at the grassroots level in order to make the system more effective.

Impact studies are also often limited in scope and restricted to the water sector and major agricultural crops (e.g., rice, wheat). Additional research is needed to understand climatic impacts on other natural and agro-ecosystems (however, see MoEF 2012). Often, locally significant drivers such as land use-land cover change overwhelm the influence of climatic drivers. Research needs to assess trends in the response of coupled socio-ecological systems to climate-induced perturbations at global and local scales. A system of long-term ecological and agro-ecological observatories needs to be established to understand changes in these systems and attribute these changes appropriately. Additionally, understanding the northeast monsoon (typically in certain ASSAR sub-regions) behaviour is a major gap that needs focused attention/research.

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CHAPTER 4

Risks, Vulnerability and Impacts

Lead authors:

Prathigna Poonacha[1], Divya Solomon[2], Ramkumar Bendapudi[2], Andaleeb Rahman[1], Ritwika Basu[1] and Shrinivas Badiger[2]

Contributors:

Amir Bazaz[1], Chandni Singh[1], Tanvi Deshpande[1], Sumetee Pahwa Gajjar[1], Garima Jain[1], Manish Gautam[1]

Reviewer:

Aromar Revi[1]

(Left) Households in Maharashtra face biophysical and socio-economic vulnerabilities. Photo: P Poonacha; (Right) Slum dwellers in Bangalore (right) have limited access to resources. Photo: M Gautam

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[1]Indian Institute for Human Settlements, Bangalore, India; ppoonacha@iihs.ac.in

[2]Ashoka Trust for Research in Ecology and Environment, Bangalore, India, divya.solomon@atree.org

[3]Watershed Organization Trust, Pune, India; ramkumar.bendapudi@wotr.org.in

Executive Summary

a. What are important risks and impacts (climatic and non-climatic) facing vulnerable groups?

Livelihoods of rural communities in the Indian SAR's are directly dependent on natural resource-based systems. These are increasingly impacted by rainfall and temperature variability. The lack of institutional support reinforces existing vulnerabilities and risks posed due to a variable climate. Contested developmental transformations in the rural landscape and development regimes exacerbate the impacts of these risks.

Urban areas in the selected sub-regions are grappling with historical and emergent risks. Unplanned urbanisation is continuously accumulating and creating new risks: climatic (manifested in the form of extreme events) and non-climatic (high rates of in-migration with limited livelihood opportunities). Bangalore faces significant risks from climate related hazards such as flooding, water scarcity, rising carbon emissions with impacts on food and water systems, infrastructure, health, natural ecosystem, and biodiversity. Non-climatic risks are manifested in the form of poverty, inequality, inequitable access to resources, and a large dependence on the informal sector for livelihood.

b. Who is vulnerable, how are they vulnerable, and what factors make them so? What are important gender and other socially differentiated dimensions of vulnerability?

Climate change negatively affects agrarian livelihood systems such as farming. Such impacts are felt primarily by farmers with small land holdings, subsistence agriculturalists, and indigenous communities with limited access to state sponsored subsidies and welfare schemes. Studies have also revealed that climate change will have a significant negative impact on crop productivity, particularly in the SARs. This, coupled with projected changes in precipitation patterns, is anticipated to severely affect agrarian livelihood systems.

The Bangalore sub-region faces increasing risks due to extreme climate weather events leading to flooding and stress to critical resources such as water. Major vulnerabilities in the sub-region are differentially experienced by slum/informal settlements due to their fragile livelihood base. Insecure livelihoods, coupled with increased exposure to hazards as a characteristic of their physical setting, compound intrinsic vulnerability. Many informal settlements exist and function outside the purview of formal planning mechanisms, resulting in exclusion of dwellers from institutional support to manage risks.

The Sangamner sub-region is primarily rural. Rain-fed agriculture and pastoralism are the main livelihoods in this region. Variations in rainfall result in major crop yield fluctuations. This area is also particularly susceptible to drought, with livestock severely affected. Among rural communities, small and marginal farmers, and landless peasants are among the most vulnerable in this region due to limited resource access, poor social capital and underdeveloped institutions leading to mismanagement of natural resources.

The Moyar-Bhavani sub-region is an agriculture- and forest-based landscape. Communities in this area include: (1) tribal and non-tribal communities living within protected areas who are dependent on agriculture and rely on Non Timber Forest Produce (NTFP) for their livelihood, (2) agrarian communities living outside the protected areas, and (3) fishing communities located near the Bhavani reservoir. Agriculture in this area is rain-fed as well as irrigated and precariously impacted by changing climatic patterns. High poverty rates, poor access to basic amenities, lack of health infrastructure, poor nutritional intake, and inadequate financial resources render these communities socially vulnerable.

Women constitute one of the most vulnerable groups in the sub-regions. Unequal pay, poor access, control, and ownership of land and other productive assets along with intrinsically embedded socio-cultural inequalities increase their vulnerability to climate-induced stresses. Differential incidence of health impacts is an important aspect of 'gendered' vulnerability. Migrant woman labourers have little access to quality health care leading to high mortality rates. In rural areas, crop failure usually affects women the hardest; increasing their workloads and reducing nutritional values, which has severe detrimental effects on their health and wellbeing.

c. How have recent development trends changed vulnerability? What are important climate dimensions of changed vulnerability?

Existing development transitions in all the ASSAR sub-regions have had limited impact in reducing poverty and inequality. Climate-induced shocks are increasingly stressing existing rural and urban livelihood regimes. Fragmented land-holdings and high dependence of rural population on rural livelihood sources that are inherently dependent on climatic drivers are intensifying the fragile existence of millions. Unequal access to resources and distribution of public services, growing inequity in spite of economic growth in urban centres have rendered the poor and the marginal in cities even more vulnerable to climatic risks. Emerging governance and institutional regimes have been largely inadequate in addressing the critical vulnerabilities in key sectors and responding to inherent poor adaptive capacities in rural and urban areas alike.

d. What are key governance dimensions of vulnerability?

Addressing climate change vulnerability in India has been largely mainstreamed into the developmental agenda. Economic development and poverty alleviation are seen as major drivers for reducing vulnerability. Governance responses to critical vulnerabilities are fragmented, making coordination across different agencies and scales challenging. Planning, often takes place at higher levels of government, with the role of local bodies, civil society, and communities circumscribed to implementation with little room for innovation. The fiscal regime has not been uniformly supportive in achieving large-scale vulnerability reduction.

e. Where are these important knowledge gaps in risks, impacts, and vulnerability?

The literature review process and insights from Key Informant Interviews (KII) have identified several knowledge gaps. Studies on climate change impacts are impaired by lack of regional data, coupled with insufficient impact assessments under the changing climate system especially in a coupled socio-ecological frame. Increased accuracy and evidence is required in studies related to the inter-linkages between climate change, agricultural productivity, and water availability. Assessing climatic risks at much finer scales and the corresponding impacts remains a major challenge. There is lack of a nuanced understanding on the determinants and drivers of key vulnerabilities—in both rural and urban areas and insufficient research on differential vulnerability—particularly with a gendered perspective.

Risks, Impacts and Vulnerability

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4.1 Characterising Risks, Vulnerability and Impacts

4.1.1 Framing Risk

Risks don't occur—they unfold. They can either be slow-onset hazards such as drought and famine that develop slowly, where acute distress may extend over a period of months and years, or rapid-onset events like flooding where sudden severe events may last only for a few seconds or days, with longer ranging impacts on the quality of lives and livelihoods (Jain, et al., 2014). However, the pre-conditions for risk from these hazards develop over a long period and exacerbate the impact of sudden events. Slow-developing hazards such as drought may be low intensive, but due to their recurring characteristic, they accumulate risks, which are larger and more destructive than sudden impacts. Loss of lives and assets are often seen within weeks of the sudden impacts, whereas, change in class relations, increased inequality, limited opportunities for livelihoods, adjustments in household budgets towards medical treatments, and accessing food rather than investing in education and other assets ,often leads to far reaching changes in the ways people would have lived. Broadly, risks and vulnerabilities have a biophysical component (directly impacted by the changing climate) and a social dimension that renders some people less able to cope with impacts due to poor adaptive capacities.

Box 4.1

Characterising risk: intensive and extensive risks

Risk is a composite of extrinsic factors such as exposure to hazard, state of infrastructure or unstable political environment as well as intrinsic factors such as structural vulnerabilities arising from socio-economic processes, historical marginalisation, etc. Intrinsic factors may determine why, given similar exposure to a hazard, some people are more vulnerable than others. The United Nations International Strategy for Disaster Reduction (UNISDR) defines risks as:

- **Intensive risks**: where large concentrations of people and economic activities are exposed to intense hazard events such as high intensity earthquakes, severe floods and cyclones. These may lead to potentially catastrophic disaster impacts involving high mortality and asset loss.
- **Extensive risks**: where dispersed populations are exposed to repeated or persistent hazard conditions of low or moderate intensity, often of a highly localised nature, which can lead to debilitating cumulative disaster impacts.

Source: Adapted from UNISDR http://www.unisdr.org/we/inform/terminology

4.1.2 What is at Risk?

Since rural livelihoods in Indian SARs are predominantly dependent on natural resources, they operate in a highly dynamic and uncertain context. This uncertainty is a function of climatic risks (e.g. drought, extreme temperatures, erratic rainfall, high wind speed) (MoEF, 2008) as well as dynamic non-climatic risks such as market fluctuations, irregular employment availability, poor infrastructure, inadequate credit facilities, and erosion of traditional social safety nets (Murali and Afifi, 2014; Berrang-Ford et al., 2011, Deshingkar, 2003; Agrawal, 2010). The high sensitivity of SARs to climate change is compounded by eroding natural resource bases, changing land use, poor development profiles, and international trade and policy dynamics. Empirical research demonstrates Indian agriculture is 'doubly' exposed (O'Brien et al., 2004) and sensitivity of the agricultural system to climatic and non-climatic risks is increasing in SARs (Singh, 2014; Taylor, 2013).

In India's urban areas, climate change is likely to exacerbate existing risks, further eroding the resilience of poor and vulnerable communities (Revi, 2008; Mukhopadhyay and Revi, 2009) as well have negative effects on human health (Kovats and Akhtar, 2008). As a developing country with a substantial development deficit and widespread poverty, adaptive capacity is limited (Dubash, 2012), and thus, urban centres are faced with the dual challenge of maintaining economic growth while dealing with climatic risks (MoEF, 2008). An example from the water sector in Chennai, Tamil Nadu shows that urban vulnerability to water shortage depends not only on ground and surface water levels, but also on formal water infrastructure, the rate and spatial pattern of land use change, household-level adaptation, and formal and informal institutional structures that mediate adaptive action (Srinivasan et al., 2013b). There is growing international concern about how to address the implications of climate change for urban areas, particularly in low income countries, where cities are growing rapidly and a high proportion of urban populations are poor or otherwise vulnerable to climate-related disruptions (Satterthwaite et al. 2007; Moser and Satterthwaite, 2008; IPCC, 2014). A study by IIHS (Jain et al., 2014) shows that looking at hazard exposure alone, most vulnerable urban areas fall in the coastal regions or the Indo-Gangetic plains. However, once vulnerabilities and capacities are integrated into the analysis, cities in semi-arid regions and poorer states of Bihar, Madhya Pradesh, Uttar Pradesh, Orissa and Maharashtra are seen as most risk-prone. Cities such as Delhi, Bangalore, Guwahati, Chennai, Bhubaneshwar, Kolkata, Surat, and Hyderabad are at high-risk primarily owing to their exposure to most major hazards coupled with high concentrations of people and assets.

In the semi-arid regions of India, vulnerabilities are multi-dimensional and occur across different sectors at multiple scales (see Annexe 4.2). Semi-arid and arid areas are characterised by low erratic rainfall and periodic droughts associated with high temperatures, which impose fundamental limits on animal and plant populations, and on human activities such as agriculture (Ribot et al. 2009). The most important effects of climate change will be felt by smallholders who include rural producers in developing countries with small land holdings, subsistence farmers and also pastoralists, and people dependent on artisanal fisheries and aquaculture enterprises. Their vulnerability comes from their biophysical surroundings and socio-economic conditions that limit their ability to adapt (Morton, 2007).

Climatic risks in India are posed to exacerbate the existing socio-economic vulnerabilities. Annual mean surface air temperature is projected to increase between 3.5 to 4.3 °C by 2100 (Refer to Chapter 3, 3.2) (MoEF, 2012). These climate-induced impacts, along with changes in the frequency and intensity of extreme events such as floods and droughts, are likely to impact human health, agriculture, water resources, natural ecosystems, and biodiversity (MoEF, 2012; Srinivasan, 2012).

In this chapter, risk is captured at two scales: national processes and situational dynamics in the three sub-regions. The chapter begins by examining the nature of climate-induced biophysical impacts on certain key sectors like water, forests, and agriculture. It then develops a narrative around how issues of poverty, inequality, social differentiation, and urbanisation are challenging existing livelihoods regimes (either in conjunction with biophysical state or separately through influencing adaptive capacities). The chapter demonstrates how biophysical and social vulnerabilities interact and create pockets of risk (see Annexe 4.1). It finally draws on sub-region level details to give a more nuanced understanding of who are vulnerable and how recent development trajectories intersect with climatic variability to shape local vulnerabilities.

4.2 Vulnerabilities of Biophysical Systems and Impacts

IPCC's Assessment Report (AR) 5 points towards significant climatic impacts on certain key sectors like agriculture, water, forests, and other natural systems in South Asia. For e.g., AR5 (IPCC, 2014) suggests that "... climate change will affect food security by the middle of the 21st century, with the largest numbers of food-insecure people located in South Asia". The IPCC (2014) further cautions that "there is very limited data globally on the observed impacts of climate change on food production". National-level studies, which also include SARs, have projected certain impacts in specific contexts (refer Annexe 4.3) and on certain key sectors. These biophysical impacts indicate that critical sectors in the SARs of India are projected to be severely affected and impacting the millions dependent on natural resources for their livelihoods.

4.2.1 Impact of Climate Change on Food Production and Food Security

ICRISAT data shows that increase in temperature will have a significant (8–30 per cent) reduction in grain yields of dryland crops. Consequently, farmers in the semi-arid tropics will have to adapt their farming practices to cope with future environmental, social, and economic constraints (Singh and Bantilan, 2009). Overuse of marginal lands, deteriorating soil health, diversion of agricultural land for non-agricultural uses, depleting aquifers and irrigation sources, salinisation of fertile lands and water-logging are other pressing issue facing agriculture currently. Over time, the agricultural growth strategy of the country has moved towards raising productivity by supporting high-density plantations given the increasing pressure on land by promoting protected cultivation, micro irrigation, quality planting material, rejuvenation of senile orchards and post-harvest management.
Perspectives on the current framing of climate change impacts on agriculture and possible adaptation measures is summarised in Box 5.2.

4.2.2 Impact of Climate Change on Freshwater Resources

Gosain et al. (2006) projected increased water scarcity in the semi-arid basins of Indian rivers due to decreasing rainfall and increasing evapo-transpiration (ET). Further Gosain et al. (2011) projected the impact of climate change on 17 most important river basins in India up to mid-century and towards the end of the century, estimating a decline in rainfall in 14 out of the 17 river basins towards the 2030s (mid- century) and the 2080s (end century)—including the relevant ASSAR sub regions.

Box 4.2

Climate Change and Agriculture: Perspectives on Current Understanding of Impacts and Adaptation

After Independence, Indian agriculture faced several challenges, such as food insecurity and frequent famines. India attained self-sufficiency in food production by the end of the 1970s through the Green Revolution. The Green Revolution in India stands for major technological breakthroughs in food grain production based on (i) improved seeds of high-yielding varieties, (ii) adequate and stable supply of water for irrigation, and (iii) increased and appropriate application of chemical fertilisers for increasing agricultural yield (Fujita, 2010). Indian agriculture now faces a multitude of challenges due to increased climate variability. Climate change is projected to affect food crops because of increases in temperature, variations in the amount of rainfall, increased frequency of extreme climatic events and increased atmospheric CO_2 concentrations. Global studies on climate change impacts on agriculture do not capture finer aspects of regional variability and hence are not very useful for developing effective adaptation strategies at regional and local levels. A comprehensive review of regional and local studies for India (Kumar, 2010) brings out the following points:

Since Indian agriculture is predominantly monsoon-dependent, climate has played a major role in agricultural production. For instance, the national drought year of 2002 led to a reduction of more than 15 million hectares in the area coverage of rainy-season crops, resulting in a loss of more than 10 per cent in food production (Samra and Singh, 2002). High temperatures in the Indo-Gangetic plains during March in 2004 caused wheat crop to mature earlier by 10–20 days resulting in the reduction of wheat production by more than 4 million tonnes (Samra and Singh, 2004). Significant losses were witnessed in other vegetable and fruit crops, such as mustard, peas, tomatoes, onion, garlic, and other vegetable (Samra and Singh, 2004). Analysis of the historical trends in yields of rice and wheat crops in the Indo-Gangetic plains has shown that rice yields over the last three decades have shown a declining trend. This may be related partly to the gradual change in weather conditions coinciding this period (Aggarwal et al. 2000). Apple productivity at upto 1500mm declined in Himachal Pradesh by 40–50 per cent due to warmer climate. Further, the lack of the fulfilment of the chilling requirement has also led to shifting of apple belt to higher elevations (2700 mm) (Bhagat et al., 2009). High temperature and moisture stress resulted in sun-burn and cracking in fruits like apples, apricot, cherries and litchi; it also caused dehydration injury to panicles and low fruit set in mango (Samra and Singh, 2004). Unseasonal rainfall during March 2008 affected cashew nut yield and quality in northern Kerala (Yadukumar et al., 2010). Consecutive droughts in Coimbatore district reduced coconut production by about 3 lakh nuts/year for four (Kumar et al., 2010).

In spite of beneficial effects to crops due to elevated concentrations of CO_2, the projected increase in temperature, changes in rainfall and increased frequency of extreme events of weather pose immense challenge for food production in India. Several studies conducted in India using controlled environment facilities such as OTCs, FACE, TGTs and growth chambers have quantified the change in growth, yield and quality of Indian varieties of certain crops owing to elevated temperature and CO_2 concentrations.

Simulation studies indicate that climate change is likely to reduce yields of wheat, rice, maize, sorghum, potato, and coconut with spatial variations. Some regions will benefit from climate change. An integrated approach is needed to quantify climate change impacts. Moreover, adaptation and vulnerability assessments are required for bridging knowledge gaps. These strategies can accelerate the development of ‘adverse climate-tolerant varieties’ or ‘climate-resilient varieties’. Adaptation technologies and regional assessments are required for minimizing the adverse impacts and maximizing the benefits, if any, due to climate change.

4.2.3 Impact of Climate Change on Livestock

India's large cattle population is an integral part of prevalent mixed farming practices (Sirohi, 2007; Chauhan and Ghosh, 2014). Climate change poses quite a few challenges for the development of this sector in India. The livestock sector not only plays a vital role in enhancing farm energy and nutrition security (nutrition to human diet through milk, eggs, meat and products such as hide and bones), but also assumes centrality in the context of sustainability and stability of the national economy[7]. Among the environmental constraints affecting farm animals, one of the severest threats is heat stress, challenging animal production and performance across several geographies round the world (Chauhan and Ghosh, 2014). Studies (Upadhaya et al., 2008; Sirohi and Michaelowa, 2007) have attempted to quantify range and stress levels attributed to the rise in temperature, using Temperature Humidity Index (THI) and its influence on livestock production. The current estimation scenario projects more distressful days and is expected to have dire effects on livestock production, both direct and indirect (ibid)—including declining milk production due to changes in the behavioural and metabolic patterns of the livestock. A nationwide study conducted by Chauhan and Ghosh (2014), estimated an annual loss of about 1.8 million tonnes of milk (equivalent of 2661.62 crores INR) accounting for a 2 per cent decline in national milk production.

The country's huge livestock population is entirely contingent on agricultural by-products (crop residues etc.,) and grass and weeds obtained from pasture lands under both permanent and temporary cover (Chauhan and Ghosh, 2014, Sirohi and Michaelowa, 2007). The recent projections which are expected to affect grassland ecosystems, are also expected to affect animal fodder (together with effects on ruminant digestibility and nutritional quality of forage (Thornton et al., 2009)), thereby adversely influencing the livestock population, adding to the economic constraints of rearing cattle (Sirohi and Michaelowa, 2007).

Research studies cited by Sirohi and Michaelowa (2007) found that seasonality of diseases such as Foot and Mouth disease (FMD) in hot and dry weather and clinical mastitis in hot and humid weather showed significant variations (52 and 84 per cent respectively), directly attributable to changes in meteorological parameters (temperature, humidity and rainfall). Studies have also correlated the incidence of disease outbreak and mass movement in animals, also an impact of changing climate (Sirohi and Michaelowa, 2007).

[7] During the last one decade, the livestock sector has maintained a steady growth of 4.8- 6.6 % as against crop production which has shown marginal increase (Chauhan and Ghosh, 2014)

Box 4.3

Livestock Sector in India – Taking Stock of the Current Situation

The livestock sector is an important agricultural sector that provides livelihood security to the poor in the semi-arid regions of India. This sector alone contributes makes up nearly 25.6 per cent of the total value of output in the agriculture, fishing & forestry sector (at current prices) and it contributed nearly 4.11 per cent of the total GDP during 2012–2013 (current prices). Since 1992, the livestock population in India has steadily increased from 471 million to 512 million by about 9 per cent. As per the All India Livestock Census 2007, India has 304.42 million bovines, 71.56 million sheep and 140.54 million goats, 0.61 million equines, 0.52 million camels, which constitute about 20 per cent of world's livestock population. However, the livestock population declined over the period 2007–12 by 3.3 per cent. Sheep, goats and cattle, which are important for livelihood security in SARs also saw their numbers dramatically declining.

An analysis of changing livestock populations in the three states, where our study sub-regions are located, suggest dramatic changes in the livestock population in some cases. For example, in Maharashtra, the populations of goat, sheep and cattle have declined by 18 per cent, 11 per cent and 4 per cent respectively over the period 2007–12 whereas poultry and buffalo has increased by 20 per cent and 5 per cent. In Karnataka, the populations of goat and cattle have declined by 22 per cent and 9 per cent whereas poultry has seen an increase of 27 per cent. Similarly, in Tamil Nadu, goat, sheep and cattle populations have declined by 12 per cent, 40 per cent and 21 per cent over the same period. Poultry has decreased by 8.4 per cent unlike in the other two states, which has seen an increase in the same.

Source: 19th Livestock Census, 2014

4.2.4 Impacts on Climate Change Freshwater Fisheries

Fisheries comprise a significant proportion of exports, and the dietary charts of a major section of India's population are dependent on this sector (Sannadurgappa, 2011). Freshwater fisheries thrive on large river systems and thus face the risk of reduced flows as a result of direct impacts of climate change on the changing precipitation patterns (ibid).

The fisheries sector is an important source of rural income diversification. However, this sector is highly vulnerable to changing patterns of precipiation and terrestrial climate, especially in states such Karnataka, Tamil Nadu and Maharashtra due to poor adaptive capacities (Sannadurgappa, 2011). Regional assessments concerning these regions, reveal marked shifts in fishery production in all kinds of aquatic systems due to climatic variation (Dulvy et al., 2009; Sannadurgappa, 2011).

4.2.5 Impact of Climate Change on Human Health

Climatic variations and extreme events have adverse impacts on human health (such as extreme heat events, refer Box 4.4). University College London and Lancet Global Health Commission (2009) concludes that 'Climate change is the biggest global health threat of the 21st century'. It further elaborates that 'Effects of climate change on health will affect most populations in the next decades and put the lives and wellbeing of billions of people at increased risk'. Health is impacted by excessive heat and floods, and through various water-borne and vector-borne systems (Majra and Gur, 2009). For e.g., epidemics have been reported after floods and storms (Bagchi, 2007) as drinking water quality gets compromised and due to excessive mosquito proliferation (Pawar et al., 2008). Sohan et al., (2008) have documented how contaminated urban flood waters have caused exposure to pathogens and toxic compounds in India. A relationship between high temperatures and mortality has been shown for populations in India (McMichael et al 2008). Intense heat waves have been shown to affect outdoor workers in South Asia (Nag et al 2007; Hyatt et al 2010). Heat stress and its various health implications are especially relevant to the SARs. Studies from India have found correlations between malaria prevalence and rainfall variability, though malaria is often influenced by non-climate variability factors as well (e.g. Dev and Dash, 2007). Using a simple transmission window approach, Bhattacharya et al., (2006) projected malaria transmission suitability for different parts of India using climate change projections from HadRM2 model till 2050. The study finds the central and eastern Indian regions (including areas around the sub-regions) to be the most malaria endemic areas under current climate.

There is some evidence that captures the impact of heat exposure on occupational health, and according to one of the exposure indices, namely the Wet Bulb Globe Temperature (WBGT), work capacity rapidly reduces as the WBGT exceeds 26–30°C. Thus, climate change could seriously affect occupational health especially in the tropical countries like India (Kjellstrom et al., 2009). While malaria prevalence is often influenced by non-climate variability factors, studies from India have found correlations with rainfall (Devi and Juahar, 2006; Dev and Dash, 2007; Laneri et al, 2010).

Due to the density within cities and city regions, they are able to influence the local micro-climate (Revi et al., 2014). A case in point is the urban heat island (UHI) effect. For cities in India, the implications of future climate for connections between urbanisation and the development of UHI have been established. Increased warming and physiological stress on human comfort level, and therefore productivity, is predicted in many cities (Thorsson et al., 2011). Hot days are known to have significant health impacts, which can be worsened by both drought conditions and high humidity. Effects of high temperatures on morbidity and mortality have been shown for populations in India (McMichael et al., 2008).

Box 4.4

Heat Stress and Health Impacts - Case of Ahmedabad, Gujarat

In May 2010, the city of Ahmedabad, faced a heat wave where the temperatures reached a high of 46.8°C. Azhar et al., (2014) investigated the impact of the heat wave on (excess) mortality in the city. The study concludes that this heat wave was associated with a significant increase in mortality. It elaborates that during the month of May 2010, a total of 4462 all-cause deaths were reported, while the reference years over the same period reported 3118 deaths. May 2010 accounted for an excess of 1344 all-cause deaths, with an estimated 43.1 per cent increase when compared to the reference period. The study also reported high correlation between mortality and daily maximum temperature in monthly pair-wise comparisons for 2010 during the locally hottest 'summer' months of April (r = 0.69, p, 0.001), May (r = 0.77, p, 0.001), and June (r = 0.39, p, 0.05).

4.2.6 Impact of Climate Change on Urban Areas

Climate change and variability is now known to have primary and secondary impacts on urban areas. Climate change will lead to increased frequency, intensity and/or duration of extreme weather events and some of the aspects of these impacts would include urban temperature variation;

drought and water scarcity; coastal flooding, sea level rise and storm surge; inland flooding, hydrological and geo-hydrological hazards at urban scale; and other emerging human health, disease and epidemiological issues (Revi et al., 2014). Moreover, climate variability is also known to affect the timing and intensities of regular climatic events such as monsoons in India and therefore have multiple adverse impacts in urban areas (through water, food, migration connections). In India, contaminated urban flood waters have caused exposure to pathogens and toxic compounds (Sohan et al., 2008).

Table 4.1

Short summary of impact assessment studies for India for the natural systems (for more detailed assessment of impact studies, refer to Annexe 4.3).

SECTOR		MAJOR IMPACTS
Water	Water stress and water related extremes	Increased water scarcity in the semi-arid basins. Drought weeks during monsoon are projected to increase.
Agriculture	Wheat	Wheat yields in India declined by >5 per cent over the last three decades, relative to a counterfactual without climate trends and projection of higher decline.
	Rice	Rice yields in India declined by about 2 per cent over the last three decades, relative to a counterfactual without climate trends, impact projection suggest a decline of 2.5 to 10 per cent by 2080s (in Cauvery delta rice yield is projected to range from a modest increase of 24 kg/ha/decade to a severe decline of 356 kg/ha/decade)
	Sorghum	Projected to decline from 14 per cent to 32 per cent by 2080s
Forests	Vegetation distribution Net Primary Productivity (NPP)	87 per cent of the 124 endemic species showed geographical range shifts in response to observed warming Increasing NPP trend of 3.9 per cent per decade. Projections suggest large scale shift in vegetation distribution and increase in NPP

4.3 Socio-economic Dimensions of Vulnerability

Climatic risks are quite significant for a country like India whose economy is closely tied to its natural resource based livelihoods. The high welfare costs of climate change are expected to vary across geographies, sectors and income levels of households in India (Jacoby et al., 2011). Sectors such as agriculture, water, and forestry, which employ a large share of the total population, are highly sensitive to climatic change[8]. Morever, climate change has differential impacts on the adaptive capacity of people across different income groups. A significant part of the population is poor and ill equipped to cope and adapt to such changes. Lack of adaptive capacity, weak institutional

[8] According to Census 2011, 68.5% of India's population is rural

mechanisms, and inadequate access to resources further exacerbate the vulnerability of the poor to climate change.

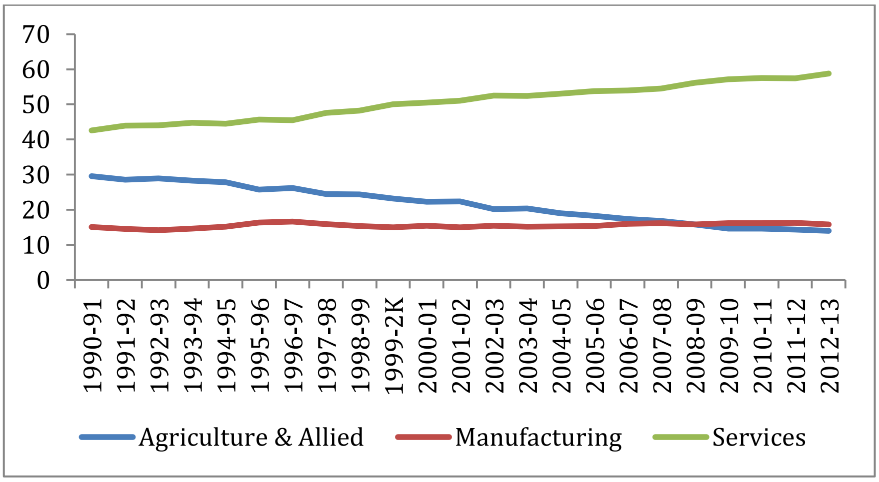
This section of the report describes the socio-economic characteristics of India at a national level. It presents the socio-economic factors that shape social vulnerability, such as the state of economy, governance structures, overall development trajectory, and household vulnerability, the levels of poverty, employment structure, and dominant livelihood strategies. It also deliberates on the role of urbanisation and rural-urban linkages, which is expected to be a major driver of social and economic change in the coming decade.

4.3.1 Economic Structure

The most striking feature of India's economic growth has been the rising contribution of the services sector to the total GDP (Figure 4.1). While the growth in agriculture has slowed down, share of the industrial sector to national income has remained constant. In 1990–91, almost 30 per cent of the total GDP was from the agriculture and allied sector, which has almost halved to 14 per cent in 2013–14. The contribution of the services sector during the same period has increased from 38 to 58 per cent. The sustainability of a services sector-led growth model with a stagnant manufacturing sector has been a much-debated issue in India (Banga, 2005).

Figure 4.1

Sectoral Composition of GDP (in %)



Source: National Accounts Statistics, Various Rounds

4.3.2 Poverty and Inequality

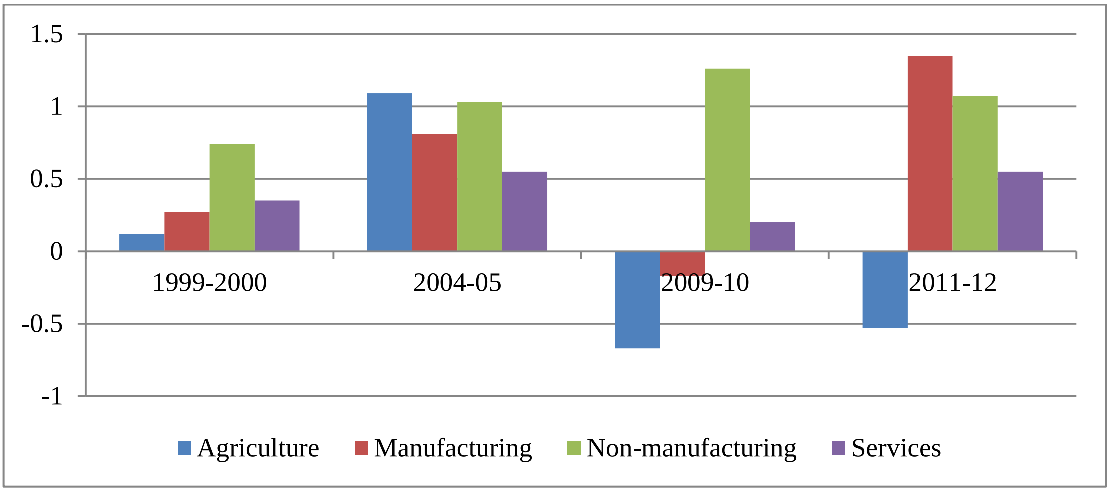
As per the official estimates, there has been a substantial decline in the poverty levels over the last two decades in India. The proportion of the population living below the poverty line has come down from 45 per cent of the total population in 1993–94 to 22 per cent in 2011–12. For the urban population, poverty levels have come down from 32 per cent to 14 per cent, while the population of poor people has halved from 50 per cent to 26 per cent between 1993–94 and 2011–12. Though there has been a substantial decline in poverty levels, the level of inequality remains high (Motiram and Vakalabharanam, 2013). The rate of poverty decline has been the lowest for socially marginalised groups such as the scheduled castes and tribes (Thorat and Dubey, 2012). Poverty has declined at the fastest pace for regular wage earners or salaried households in urban areas and those self-employed in non-agricultural activities in rural areas, both of which constitute a smaller fraction of the total population. States with a higher level of income growth have witnessed an increase in the level of inequality (Motiram and Vakalabharanam, 2013). When compared to median consumption expenditure, the lower income groups, such as labourers, marginal farmers in small rural areas, and casual labourers and the self-employed in urban areas have not seen much increase in their welfare (Motiram and Naraparaju, 2014).

4.3.3 State of Livelihoods - Employment Structure

Agriculture continues to be the largest sector in terms of employment, though its share in the total GDP has declined. The size of employment in non-agricultural sectors such as manufacturing and services has continued to increase but the share of jobs in the services sector remain far below their total contribution to the GDP. The changing nature of employment structure is also evident through the employment elasticity of the sectoral output. Employment elasticity for agriculture sector has seen a clear decline going down to below zero since 2009–10 (Figure 4.2). Inability of the non-agriculture sector especially the manufacturing sector to create sufficient jobs during the period of rapid growth has been dubbed as a period of 'jobless growth' primarily since the incremental output expansion has come through very few and narrowly defined industries such as the automotive industry telecommunications and other tertiary sectors (Nagaraj, 2008).

Figure 4.2

Employment elasticity by sector



Source: Mehrotra et al. (2014)

Some of the key trends in employment structure as identified by Anand et al., (2014) are:

- Decline in the workforce participation rate (WPR) during the rapid growth period of 1993–94 and 2011–12.
- Lower employment in agriculture, while increase in the service sector employment, especially in the construction sector
- Poor quality of jobs and greater incidences of informal employment, especially for women.

4.3.4 Urbanisation

According the latest Census figures, 31.7 per cent of the population lives in areas classified as urban. The number of people living in urban areas is further expected to increase given the growth in population, the importance of cities in generating jobs, and labour moving out of agriculture to look for employment in urban areas (Anand et al., 2014). The 12th Five Year Plan document also acknowledges the fact that urbanisation would be central to achieving faster and more inclusive growth in India. Urbanisation has played a positive role in the reduction of rural poverty in the surrounding rural areas through greater rural-urban linkages such as greater demand for rural products in the urban areas, increased non-farm employment opportunities, remittances from migrants and higher rural land prices (Lanjouw and Murgai, 2010; Cali and Menon, 2012). Industries and the service sector have higher employment elasticity which could provide gainful employment to those working in the agricultural sector. The rural-urban linkages have strengthened over time with the growing importance of small towns in accommodating people and providing services (Denis and Z´erah, 2014). At the same time, greater urbanisation has increasingly pressurised land use in urban areas and created other environmental concerns (IIHS, 2014).

4.3.5 Migration

Migration has been an important factor in the increase in urban population over the last two decades. During the period 2011–11, 24 per cent of the increase in urban population could be attributed to rural-urban migration, which is an increase from 21 per cent in the preceding decade (IIHS, 2014). Inter-state migration largely happens from the poorer states of Uttar Pradesh, Bihar and Rajasthan. Migration may not necessarily arise out of distress and poverty as demonstrated by Kundu and Sarangi (2007). Rather, they argue that both poor and rich households migrate, though the reasons for migration and the nature of jobs sought are different. Using NSSO data, they find that the poorer households in urban areas send one or more members outside as a source of additional livelihood support. On the other hand, for households that are relatively wealthier, often the whole family migrates. For rural households, migration to urban areas is not shown to have lowered poverty levels, but for those migrating to urban areas from urban areas, there is a lower risk of poverty than non-migrants.

Box 4.5

Role of the Urban Economy in Generating Employment and Sustaining Growth

For sustaining growth over the medium and long term, there needs to be an explicit policy on the creation of labour-intensive jobs and cities will have to be the centres of such activities. Currently, most of the newly created jobs have been in the informal sector, especially in the construction sector. A focus on more avenues for urban employment is essential to unlock the potential of India's urban economy, thereby also benefitting rural areas. The current policy framework has been unable to address this issue due to several limitations in the design and implementation of various policies. A recent policy document by the Indian Institute of Human Settlements (2014) has come up with the following policy recommendations for urban areas to be engines of growth:

- Focus on small and medium towns, which comprise of a third of the urban population through improved infrastructure, connectivity and power as well as stricter adherence to the environmental and pollution norms.
- Greater focus on small and medium enterprises while investments in large industrial estates to continue.
- Greater focus on education and training needs of the workforce, particularly women.

Source: Anand, Revi, and Koduganti, (2014). Cities as Engines of Inclusive Development, IIHS-RF Paper on Indian Urban Economy, Indian Institute for Human Settlements.

Another feature of migration in India is its seasonal nature, wherein migration is driven by the annual agricultural cycle where workers spend less than six months away from their village of residence (Coffey et al., 2013). These short-term migrants are mostly employed in low productive and non-contractual jobs with low earnings. Chandrasekhar et al., (2014) find that the short-term workers are worse off than those who did not migrate.

4.3.6 Exclusion and Public Services

With rapid urbanisation and increasing urban population, there is an increased pressure on the government to provide adequate urban infrastructure and civic amenities. One of the biggest challenges facing the policy makers in India is the ability to manage urbanisation, plan, build, and maintain adequate infrastructure and ensure access to basic public services. Nearly 40 per cent of the urban households in India lack access to public provision of water and 12 per cent defecate in the open (IIHS, 2014). This has potentially disastrous consequences for public health and therefore necessitates swift action and greater accountability of public service providers to the citizens.

4.3.7 Gender Dynamics

Broadly, women and climate change inter-linkages are moderated by climate-sensitive sectors (such as agriculture, water), their indispensable role in rural production systems and thereby increasingly exacerbating the risk exposure of women. Women make essential contributions to rural economies as farmers, laborers and entrepreneurs, yet they have lower access than men to agricultural assets, inputs and services, and rural employment opportunities. This lack of access to resources and finance, combined with a limited asset base, reduces limits women's capacity to abate their existing vulnerabilities, as well as those which are induced by climate change. In India, 53 per cent of all male workers and 75 per cent of all female workers are in the agricultural sector (Planning Commission, 2008). However, this involvement in agriculture, forest, and livestock has not resulted in higher ownership or rights to control livelihood resources, including limited decision making abilities. In terms of outputs there is a stark differential in remuneration (Singh 2014), for instance the daily agricultural wage of women was reported to be in the range of $0.5-0.6, while that of men was $0.7-0.8 (Parikh et al., 2004).

In India, apart from very rich landlords, manual work related to cultivation and processing is an integral part of the work performed by women in rural households (Duvvury, 1989). Women have lower assets and bargaining power in the family, and are often discriminated against with regard to nutrition and education (Pande 2003). As a result, they are more vulnerable to any kind of economic shock including weather variability. Sekhri and Storeygard (2011) find that adverse rainfall shocks are associated with a significant increase in dowry deaths and domestic violence in rural India. Mahajan (2012) says that while women generally earn lower wages than men, the male-female gender gap in agriculture employment is higher in the rain-fed rice growing regions of India during low rainfall years, indicating differential vulnerability.

Case studies from SARs in India show that gender differentiated impacts of climate variability are caused by differences in risk perception, unequal distribution of roles and responsibilities of men and women, differences in asset ownership, and power over decision-making leading to unequal adaptive capacities (Brahme 2014; Singh 2014, Ahmed and Fajber, 2009).

Health is an important determinant of women's participation in agricultural activities and research shows women at a higher risk of developing diseases from pesticide exposure during agricultural activities (McDuffie, 1994; Dich et al., 1997). Furthermore, the nutritional requirements of female laborers are largely ignored leading to a dismal state of health among women agricultural laborers in India. Although their working hours are often longer they are the last to eat in the family and in cases of financial stress in the household their nutrition is compromised for the sake of other members of the family (Duvvury, 1989).

Table 4.2

Impact of Climate Change on Vulnerability from a Gendered Perspective

CLIMATE CHANGE IMPACT	RESULTING GENDERED VULNERABILITIES
Crop failure, lower food production	Reduced food and nutritional provision— reduced ability to grow, process, manage food, maintain kitchen gardens, increased agricultural work, women are the last to eat, required to undertake extra work (typically wage labour)
Fuel shortage	Household fuel provision, drudgery in collecting fuel and fodder, inability to raise small livestock, food-fuel conflicts, impact on food consumption, and nutrition levels
Shortage of safe, clean water	Household water provision, drudgery in collecting water over long distances, exposure to contaminated sources
Resource insecurity	Economic drawbacks, erosion of natural resource-dependent livelihoods, pressure on time to diversify livelihoods, school dropouts
Extreme events and disasters (water-logging, floods, drought)	Greater incidence of mortality and morbidity, reduction in life expectancy, longer walks to get water and fuel, loss of fodder and livestock (typically female livelihoods in SARs), drought leading to harder soil for manual work
Higher temperatures	Lower milk production, increased effort to work in fields (especially weeding, harvesting which women do), longer working hours (women wake up early because afternoons are too hot to work)
Higher rainfall	More weeding required, less fodder fuelwood available,
Species loss	Some medicinal herbs and fodder unavailable or difficult to find
Health and disease	Lack of access to healthcare, increased burden of caring for young, sick and elderly, malnutrition, limited healthcare options for pregnant women
Distress migration	Loss of livelihoods, lack of adequate shelter, conflicts, more workload on women when men migrate, reduced social capital if moving to urban centres for work

Source: Adapted from Brahme (2014) and Kapoor (2011)

4.3.8 Environmental Governance

The government of India promulgated the National Environmental Policy (NEP) in 2006 to provide a strategic direction to environmental governance in India. The NEP places humans at the centre of development to ensure secure livelihoods for those dependent on natural resources. It also emphasises the need to maintain inter-generational equity in terms of access to resources. However, NEP has not been overtly effective in managing ecologically critical sites. Despite a large set of regulatory instruments which exist to protect natural resources, failure on the part of government and non-compliance of statutory norms by polluting industries has led to rapid environmental degradation (in some sites, the impacts have been irreversible). Unclear roles, responsibilities and lack of independence of the regulatory arms of national line ministries and their affiliates are among the major constraints that plague the implementation of the NEP (Lele et al., 2010). Hence, environmental governance is an increasingly challenging task in India, with much to be desired in terms of sustainability of both eco-systems and natural resource based livelihoods, in the current framing of economic developmental objectives. A concern that has been raised on the issue of environmental governance is its federal structure. Centralisation of environmental governance is severely criticised, given the varying ecosystems and socio-political structure that characterises India. A more decentralised mode of environmental governance is considered to be empowering and conducive for better implementation of environmental protection and conservation schemes (Damodaran, 2012b).

4.3.9 Peri-urban Areas

Peri-urban areas refer to areas with specific forms of urbanisation evolving on the periphery of large developing metropolitan cities (Dupont, 2007). Peri-urban spaces are the interface of rural and urban spaces undergoing rapid and multiple transformations in terms of their physical, morphological, socio-demographic, cultural, economic and functional landscapes. They undergo intense land use changes and occupational diversification while the ownership and use of natural resources are deeply contested. Managing peri-urban environment has significant implications not only for the livelihoods of those who live there but also for the sustainability of the overall urban and rural development. This is because the ecological, economic and social functions performed in peri-urban interfaces affect both the city and the countryside (Allen, 2003). Narain (2009) presents a case study of Gurgaon, which is a large urban agglomerate bordering the national capital Delhi where peri-urban areas have led to the erosion of rural natural resources. Moreover, farmers in Gurgaon have switched to subsistence and commercial farming, and there is a change in occupational structure. However, most of the benefits of this urbanisation process have been lopsided in favour of those who are economically better off.

4.4 Sub-region level Risks and Vulnerabilities

4.4.1 Bangalore Sub-region

4.4.1.1 Key Climatic Risks and Impacts Facing Bangalore

As the population and the geographic expanse of Bangalore increases, the city faces significant risks to its future development, including risks from climate-related hazards such as flooding and water scarcity, rising carbon emissions and energy intensity of development.

Encroachment of lakes, natural flood plains and drainage channels due to rapid and uncontrolled urbanisation has exacerbated local flooding in the city. In case of extreme rainfall events, infrastructure (housing, transport and other public infrastructure) situated in flood prone areas are exposed to numerous hazard risks. Many poor and marginalised households living in slum and informal settlements located in low-lying and vulnerable areas lack appropriate flood protection or flood resilient infrastructure (IIHS, 2014).

Much of Bangalore's drainage systems were designed for a smaller and less dense city and are therefore unable to cope with the increased volumes of run-off water. Indiscriminate disposal of solid waste in drains often result in blockage, causing the drains to over-flow. Rainwater infiltration has decreased due to rise in built-up and paved areas.

Bangalore's built-up area has increased by 632 per cent from 1973 to 2009 while the coverage of water bodies has declined by 79 per cent during the same period. Tree cover in the city has reduced by almost 63 per cent in the period 2002–09. Air pollution, urban expansion, increase in built mass have contributed to an enhanced urban heat island (UHI) effect inducing local temperature variations and irregular rain showers (Ramachandra and Kumar, 2010; Ramachandra and Kumar, 2009) resulting in local health impacts (IIHS, 2014).

A diagnostic study of future climate risks for Bangalore projected a range of impacts on food and water systems, health, buildings, transport, and natural ecosystems and biodiversity (IIHS, 2014).

One of the serious challenges the city faces is the reduced availability and access to regular quality of water supply. Half of the city's growing demand is met by drawing water from the Cauvery River, 100km away, pumping about 1200 MLD up a 900m gradient. The remaining demand is met by extracting ground water or supply via private water tankers. This has resulted in the severe depletion of the ground water table in the peripheries and having to use polluted groundwater in the core areas of the city.

Water availability in Bangalore will depend on rainfall within the Cauvery River catchment area, which is fed predominantly by monsoon rains, and replenishable groundwater resources within the city boundary. With the Karnataka State Climate Change Plan estimating that total rainfall could reduce by as much as 10–20 per cent by 2050, existing water stress will deepen due to increasing demand. With issues of water scarcity, poor distribution and contamination of groundwater supplies, Bangalore faces a serious constraint to its growth trajectory (IIHS, 2014).

4.4.1.2 Key Non-climatic Risks Facing Bangalore

Bangalore, at best, can be described as a city of dichotomies. High-rise, air-conditioned glass office complexes, private residential enclaves and 'gated-communities' in contrast with poorly or unserviced, dense informal settlements and slums. Widespread disparities exist between the rich and the poor, and the benefits of growth over the decades have not been equitable. Contrary to public perception, only 10 per cent of the total workforce in Bangalore is employed in the ICT sector (Mahadevia, 2008), whereas the informal economy characterised by low wages, low quality of jobs, poor working conditions, and low job security is expanding. Approximately 43 per cent of the city's population lives in multi-dimensional poverty.

While the formal economy of the city is driven by the IT and ITES sector supported by manufacturing, textile and service sectors, there exists a vibrant informal economy built around employment in the construction and transport sector, waste collection, catering and food industry, handicraft trade, home-based fabric industry, and a range of other domestic activities such as cleaners and helpers. The number of people employed in the informal sectors is greater than employment in all formal sectors put together (Mahadevia, 2008).

A large number of migrants arrive in the city in search of employment opportunities, most notably from rural Karnataka and surrounding states but also from distant parts of the country. Uncertain and diminished rural livelihoods, agriculture burdened by erratic rainfall and droughts have forced many rural residents to partially or fully move to the city as first generation migrants in an effort to pay off accumulated debts (Krishna, et al., 2014). Informal settlements often provide an entry to live in the city. Although these settlements are spaces of poverty, they contribute significantly to the city's economy through home-based informal economic activities (JnNURM, 2009; NIAS, 2002).

Disparities in access to resources have also shaped inequity in the city. While a small privileged group in the city consumes large quantities of natural resources such as water and land, the poor and the marginalised have low levels of access to water and sanitation services. Almost a third of the total population of Bangalore have partial or no access to piped water (Benjamin, 2000).

4.4.1.3 Dimensions of Vulnerability

Bangalore faces significant climatic and non-climatic risks. Disparities in wealth distribution, access to livelihood opportunities, resources, living standards, and unequal distribution of environmental risks make the poor and the marginalised even more vulnerable.

Slum dwellers are particularly vulnerable owing to the location of their settlements. Located usually on environmentally marginal lands such as next to storm water drains, low-lying areas and garbage dumpsites they are the hardest to be hit by flooding or extreme rainfall events.

Slum settlements have limited access to safe water supply, especially unrecognised and non-notified slums that are located in unauthorised areas, which are not serviced by piped water supply or sanitation networks (IIHS, 2014). In the absence of piped water, they depend either on ground water supply or tanker-supplied water which may be of poor quality. The lack of toilets has forced these citizens to resort to open defecation, thereby contributing to increased health risks. Rising prices of essential commodities such as water, fuel, electricity, and food also affect the poor tremendously.

A large section of the society is dependent on the marginal work available within the informal economy, characterised by low wages and job insecurity. Bangalore also has a high proportion of people that are illiterate, or are literate but have not completed primary school. The big challenge emerging from this situation is the large cohort of 20–29 year olds that are entering the workforce with very low levels of education and literacy (IIHS, 2014).

Most migrant workers who arrive in the city in search of livelihood opportunities are already vulnerable owing to their caste backgrounds, negligible rural land holding and prior occupation. Newer migrants live in poor quality houses located in small informal settlements, built often with temporary plastic roofing material. Many first generation migrants work as casual labourers in the construction industry, considered to be the 'lowest paid and least secure sector in the occupational spectrum' (Krishna, et al., 2014: 581).

Women and children are particularly vulnerable to climatic and non-climatic risks in the city. Structural gender based inequality such as illiteracy, inequality in social rights, inadequate access to information and resources, and limited health care facilities exacerbate women's vulnerabilities. Gender disaggregated data on employment shows that percentage employment of men was higher in technical and managerial jobs. Although women were employed in low-skill, low-wage manual labour, the share of men in such jobs was still higher. The high gender disparity in quality of employment has serious implications on income disparity and thus quality of life and well-being.

4.4.1.4 Recent Development Trends and Climatic Risks

Economic growth and employment creation has been the primary focus of the city and state governments. A number of large-scale infrastructure development projects have dotted the landscape of the city funded by national and international investment in order to support this growth.

This model of urban development (characterised by zone-based infrastructural development, including large scale 'urban mega-schemes' (Goldman, 2011) like the development corridors) intensifies inequity and widens the gap between the rich and the poor in the city in terms of access to services, employment opportunities and development benefits. Additionally, it contributes to the transformation of the economic, social and physical landscape of the city, especially along the peripheries.

4.4.1.5 Key Governance Dimensions of Vulnerability

Multiplicity of planning and governing agencies, overlapping administrative boundaries and jurisdictions result in conflicts and fragmentation of governance processes that aid in dealing with climatic and non-climatic risks. The municipal government is often financially strapped, understaffed and lacks capacity to tackle urban problems associated with planning and development functions (IIHS, 2014).

The growth of inequality and poverty in Bangalore is often result of the skewed focus of public policy on the globalised hi-tech growth sector (Benjamin, 2000). Multi-dimensional poverty and vulnerability have not been adequately addressed by most of the policies and hence fail to support people that lie within this vast spectrum (Krishna et al., 2014).

Most informal economies function outside the purview of formal planning mechanisms such as Master Plans and City Development Plans (Benjamin, 2000). Recognition of slums and informal settlements as legitimate parts of the city is still problematic, leading to insecurity in tenure and a persistent fear of eviction.

4.4.2 Sangamner Sub-region

4.4.2.1 Key Vulnerabilities and Risks in Sangamner

In rain fed systems of the semi-arid tropics, constant risk of drought increases the vulnerability of livelihoods and decreases human security (ICRISAT, 2006). Over the past three decades, cultivation area under sorghum and millet in the Sangamner sub-region has fallen by nearly one-third and new crops like maize, soybean, and cotton have become popular because of their rising market demand (Singh and Bantilan, 2009). For almost all crops, the productivity in Maharashtra is much lower than the national average and there are fluctuations in yield, which indicates the implications of failure of monsoons on agricultural output (Shroff and Kajale, 2013).

Livestock plays an important role in the agricultural economy of the Sangamner sub-region reflecting the national trend for SARs in which livestock contributes to 40 per cent of agricultural GDP (Watershed Organisation Trust, 2013). Statistics reveal that nationally, resource-poor small, and marginal farmers and landless labourers own 71 per cent cattle, 63 per cent buffaloes, 66 per cent small ruminants, 70 per cent pigs and 74 per cent poultry (GoI, 2003). With respect to sheep and goats in India, almost all belong to smallholders who own 1 ha of land or less, or are landless (Birthal and Taneja, 2006). These owners depend entirely on common property resources (CPR) for their survival, and rear livestock through this extensive system. These trends are indicative of the livestock situation in Sangamner sub-region where livestock rearing is practiced as an important source of income diversification. Evidence shows that smallholders obtain nearly half of their income from livestock (Birthal et al., 2003). It is generally considered that the environmental impacts of livestock production in India have more positive implications than negative ones as the production system is still largely dominated by the rural livestock-crop integrated smallholder mixed farming system (Chacko et al., 2006). The emergence of large-scale industrial production units, declining grazing resource base, climate change impacting livestock productivity, including milk yields are important concerns around livestock production in the context of sustainability.

Apart from rainfall scarcity, key water-related risks stem from the ineffectiveness of legal institutions. There is also no clarity around 'competitive deepening of wells' occurring between neighboring farmers. Dug wells are most suitable for groundwater development in Ahmednagar district as 95 per cent of the area is covered by the Deccan Trap Basalt. Wherever feasible, sites for borewells and tubewells must be selected after proper investigation. The expected yield of dugwells may vary from 20–120 m^3/day depending on the local hydrogeological conditions (GoI, 2011).

4.4.2.2 Dimensions of Vulnerability

To understand the various dimensions of vulnerability, a tool called CoDrive-PD[9] was used to gather information from different categories of farmers, namely, large, medium, small and marginal farmers and the landless.

Major climatic risks identified by the community included droughts, heavy downpours in a short period and irregular rainfall. The results indicated that soil quality is an important constraint across all farmer categories. Vulnerability ranking reveals that small and marginal farmers are relatively more vulnerable than large farmers. Other constraints identified are that new seed varieties and crossbred cattle are not tolerant to stress conditions and that farmers incur losses but continue to use them because of their higher production potential when compared to indigenous seed and livestock. Risks are higher for small and marginal farmers who do not have the financial capacity to bear losses, potentially pushing them into debt traps.

All farmer categories scored low on social capital. Village institutions for natural resource management such as farmer groups, cooperative societies or committees have not yet evolved. This is a major constraint and risk of mismanagement of natural resources is high. This could result in over exploitation or degradation of resources like land and water as well as cause social problems (e.g. conflicts and inequities in resource use). For the landless, access to natural capital is most critical. However, having no land make them less vulnerable when compared to landed households and their higher mobility is an advantage.

[9] Watershed Organization Trust (WOTR) developed a tool called "Community Driven Vulnerability Evaluation – Programme Designer (CoDrive-PD)" to factor in key climate related and other vulnerabilities early on in the project as well as to research design and integrate these variables within the project/research objectives. The CoDrive-PD tool was applied in *Warudi Pathar* village in Sangamner region (study area).

4.4.3 Moyar-Bhavani Sub-region

4.4.3.1 Existing Livelihoods and Property Rights for Common Pool Resource Use

Communities dependent on agriculture and forest products:

Tribal communities living within Protected Areas (PAs): Most tribal forest dwellers depend upon Non Timber Forest Products (NTFP) collection as a secondary source of income. They are 'authorised users' i.e. they have the rights to enter into forests areas and harvest some forms of forest produce (Ostrom, 2001). These rights are governed by laws and regulations, which are enforced by the Forest Department (FD). NTFP collected include high value products such as honey which are sold in the external market and products such as soap nut (*Sapindus mukarossi)* and turkey berry (*Solanum torvum)* which is primarily collected for household consumption. Land is generally leased to these communities by the FD primarily for agricultural processes over a fixed period. The ownership of this land lies with the FD. The tribal people are usually 'proprietors' of the land i.e. they do not have the right to sell the land although they most commonly have the right to bequeath the land (Ostrom, 2001). Digging borewells by individuals within the PAs is also not allowed. The Panchayat[10] digs a few borewells to be used by the entire village for household requirements and the community monitors and regulates water usage. These communities are primarily governed by the local Panchayats, which settles local disputes. Communities are allowed to utilise water flowing in nalas and streams. However the use of motorised pumps is not allowed in order to regulate water usage. Agriculture in these areas is usually rainfed and not very profitable unless there is a canal system in place for irrigation. Agricultural practices are highly dependent on water availability and access to roads for transport.

Non-tribal communities living within PAs: Communities living within the PAs often do not have legal ownership of the land; rather they have 'proprietorship' over the land and the land is under the ownership of the FD, which is a state government entity. Sometimes revenue land is present as an enclosure within the PA in which case, the ownership of the land can be with individuals. Only tribal communities are allowed to collect NTFPs within the PA and collection by other communities is illegal and regulated by the FD.

Communities living outside PAs: These communities usually own their land and possess the right to transfer it. Decisions regarding cultivation on the land primarily lies with the land owner (Ostrom, 2001). The resource system is agricultural and resource units include crops grown for self-consumption and commercial value. Contract farming is also predominant in some areas of the sub-region; agents set a fixed price for the crop and provide seeds and other inputs required for the crop. Most of farming in these areas is irrigated either from a nearby water source or from borewells. The level of irrigation depends on a farmer's monetary ability to dig borewells and install pumps. Some farmers maintain a certain area of irrigated land where they grow high value crops, and crops for self-consumption are grown in non-irrigated areas. Governance systems in the area include farmer cooperatives and village Panchayats.

[10] **Panchayati Raj**, a decentralised form of Government where each village is responsible for its own affairs

Fishing communities dependent on fishing as their primary source of livelihood live along the edges of the Bhavani Sagar reservoir. They are 'authorised users' of the reservoir and have rights over collection of fish from the reservoir, which is governed by rules set by the Fisheries Department. Graduated sanctions in the form of fines imposed by local guards employed by the fisheries department are used to penalise fishermen who break rules. Continuous non-compliance can result in complaints registered with the local police. The rights for fishing cannot be bought or sold but can be passed down within families. The right to the fish harvest from the reservoir is sold from the fisheries department to private individuals through auction. This individual is the 'proprietor' and maintains the fish stock within the reservoir. Fishing is done by 'authorised user' who then sell the fish to the 'proprietor' (Ostrom, 2001) for a fixed price. Issues faced by fisherman are addressed at the Fisherman's Union which conduct regular meetings and an elected head.

4.4.3.2 Resource Conflicts

Equitable distribution of water particularly from the Bhavani Sagar Reservoir is a contentious issue in surrounding villages and towns in the sub-region. Competition between urban water usage and agricultural water usage has been increasing in the Bhavani basin just as it has in the entire Indian subcontinent (Krihnamoorthy, 2013). Drinking water accounts for 10 per cent of abstraction from the Bhavani Sagar reservoir. About two third of this abstraction is transferred out to Coimbatore city and Tiruppur which is a major textile centre in southern India. These abstractions are projected to increase by 30 per cent in the coming decade. There has been a considerable reduction in crop area, yield and agricultural income in the Bhavani basin due to water scarcity (Joy, K. J., et al. 2006; Rajagopal and Jayakumar, 2006; Malaisamy, 2001). This has resulted in farmers demanding more water from the reservoir for agriculture.

Other issues include unauthorised water pumping from the river and unregulated groundwater extraction encouraged by liberal institutional financing and susbsidy for free electricity (Rajagopal and Jayakumar, 2006).

The growing proximity of human settlements to protected areas within the sub-region has led to increasing instances of human-wildlife conflict (Krishnamoorthy, 2013; Maheswari, 2007). Instances of elephant and wild boar damaging crops in the area are common and often attributed to depleting resources within forests and increasing agricultural lands (Maheswari, 2007).

4.4.3.3 Dimensions of Vulnerability

Much of the agriculture practiced within the sub-region is rain-fed (Geethalaxmi, 2011). Rain-fed farmers are especially vulnerable to the effects of climate change owing to the unpredictable nature of rains in the area (CSTEP, 2014). The Bhavani basin has a unique and ancient system of canals; the water does not reach many of the villages, as the canals are almost defunct. This is due to encroachment and clogging from waste and the rampant mining of sand. Further, erratic rainfall and increases in temperature have left the agricultural communities vulnerable to the changing climate (CSTEP, 2014). Climate sensitive forms of livelihood practiced by people within SARs makes them especially sensitive to the effects of climate change (GoI, 2004).

There are many number of tribal hamlets within the Sathyamangalam and Bandipur tiger reserves (Krishnamoorthy, 2013; Chinnappa, 2013). Agriculture ecotones are of vital importance to these indigenous communities (Bawa, et al., 2007). High poverty rates combined with higher decadal growth rates, low sex ratio, poor access to basic amenities, and financial resources render these communities especially vulnerable (CSTEP, 2014). Many of the communities living within the Sathyamangalam and Bandipur PAs are under the constant threat of relocation (Krishnamoorthy, 2013; Chinnappa,2013), which could threaten their existing livelihood practices further enhancing their existing vulnerabilities (Lasgorceix and Kothari, 2009). Women within these communities are especially vulnerable due to their added responsibilities in terms of child rearing and care giving activities and the added burden of low productive activities like collection of water, firewood and NTFPs apart from their agricultural work. In these remote areas women spend nearly half their time on survival related activities. Access to maternal health care and other medical facilities is limited leading to high rates of child mortality[11]. Crop failure usually impacts women the hardest, increasing their workloads and reducing nutritional intake, which has detrimental effects upon their health and wellbeing (Sinu and Mahadevan, 2013) in turn affecting their ability to adapt to climate change (Nelson et al., 2002).

Pastoralists, especially in isolated rural settings who are solely dependent on the sale of livestock and livestock products, are challenged with isolation, access to low levels of technology, markets and facilities that promote livestock wellbeing. They are highly vulnerable to unpredictable climate effects (Morton, 2007). Pastoralists in the Moyar-Bhavani sub-region suffer persistent losses due to attacks by wildlife owing to their close proximity to forested areas and often government compensation is not provided[12]. Livestock is also vulnerable to diseases such as foot and mouth disease, which often take a toll on livestock rearing communities in this area. Livestock is not insured and the communities suffer consequent devastating losses (Shamsudeen et al., 2013).

Many farmers in the sub-region are moving away from food crops to cash crops and commercial crops. This is especially true in areas around Mettupalyam and Erode where crops such as marigold and sugar cane are grown. Increased water availability through government policies enable and enhance irrigation allowing for increased access to water for agricultural purposes (Senthilkumar et al., 2008) contributing to the shift towards water intensive cash crops.

The extra income generated from the shift to cash crops often does not flow back into the household nutritional intake (Agarwal, 1985). Compromising on nutrition can lead to lowered labour productivity, reduced tolerance to disease, and low educational achievements leading to increased poverty (Haines et al., 2006; Heltberg et al., 2009 and Fischer et al., 2002).

In a bid to reinforce rural livelihood and reduce vulnerability, the Tamil Nadu government has sought to augment milk production in the state[13]. There are various schemes aggressively promoting the rearing of hybrid cows leading to increased milk production. However, these animals are not habituated to local climatic conditions and are prone to risk from disease particularly during drought conditions (Watershed Organisation Trust, 2013), that are prevalent in the sub-region.

State schemes to distribute free ration to scheduled tribes has made many of the tribal populations dependent on the government.

Climate change will add further dimensions to the existing vulnerabilities. It is estimated that the frequency and intensity of droughts will increase, thereby increasing the frequency of crop failures.

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[11] Primary interviews with women living in tribal communities within the transect
[12] Primary interviews with pastoralist communities in the area
[13] State of The Environment Report (SOE) 2008-2009 prepared by Ministry of Environment and Forest

Increasing temperatures will affect crop yields; studies have indicated that the rice yield will decrease with increasing temperatures (Geethalaxmi et al., 2008). Declining yields will also be seen in other food and fodder crops such as red gram, maize and millets (SAPCC-TN, 2013). Reduced fodder intake affects the milk yield of cattle, and increasing temperatures also affects the health and mortality of livestock (SAPCC-TN, 2013).

The increased irregularity of rainfall and frequency of extreme events (IPCC, 2014) is causing many farmers to look for alternate means of livelihood. There has been increasing mobility of rural populations to urban centres in the search for jobs and better facilities (Deshingkar and Start, 2003). This is particularly observed in the PAs of the Moyar-Bhavani sub-region, where additional pressure of relocation and lack of facilities is pushing farmers to give up agriculture and move to nearby cities[14]. This has also led to a severe labour shortage in rural areas. Interviews with farmers in the sub-region showed that one of the biggest obstacles in their agricultural practice was the lack of labour (Chand et al., 2007). It also indicated that labour is one of the dominant factors that influence crop choice. Lack of farm workers is the major cause for decrease in paddy cultivation and other labour-intensive crops in the area[15]. Table 4.3 summarizes the key risks, vulnerabilities and development dynamics of the sub-regions.

[14] Primary interviews with farmers
[15] Primary interviews with farmers

Table 4.3

Key risks, vulnerabilities and development dynamics of the three sub-regions.

	BANGALORE	SANGAMNER	BHAVANI-MOYAR
Key livelihoods	• IT and ITES sectors supported by manufacturing, textile and service sectors. • Informal economy: construction and transport sector, waste collection, catering and food industry, handicraft trade, home-based fabric industry and other domestic activities such as cleaners and helpers.	• Agriculture • Livestock	• Rainfed agriculture • Non-timber forest products • Pastoralism • Fishing
Climatic risks	• Reduction in rainfall by 10-20% by 2050 (Government of Karnataka) • Urban heat island effect (UHI) (Ramachandra and Kumar, 2010)	• Drought • Increasingly erratic rainfall (shift in season start, more frequent dry spells, heavy downpours in a short period, failure of monsoons)	• Erratic rainfall • Temperature increase
Biophysical risks	• Encroachment of lakes, natural flood plains and drainage channels • Reduction in tree cover by 79% between 2002-2009	• Erosion of common property resources such as pasturelands and forests • Decreasing soil fertility	• Water abstractions in the basin are projected to increase by 30% in the coming decade
Non-climatic risks	• Lack appropriate flood protection or flood resilient infrastructure • Reduced availability and access to regular quality water. One-third of the population has partial or no access to piped water (Benjamin, 2000) • 43% population lives in multi-dimensional poverty • Poor solid waste management and sewage water	• Lack of legal measures to stop indiscriminate dug wells • New seed varieties and crossbred cattle are not tolerant to stress conditions • Lack of robust and well-functioning village institutions for natural resource management.	• Competition between urban water usage and agricultural water usage (Krishnamoorthy, 2013) • Unauthorised water pumping from the river and unregulated groundwater extraction • Defunct water cannels • Increasing human-wildlife conflict (Maheswari, 2007)

	• treatment • Rising carbon emissions		
Development dynamics	• Uncontrolled urbanisation and increase in built up area (632% increase from 1973-2009) • Increasing income inequality	• Increasing digging of wells leading to over-extraction of groundwater • Rural mobility to neighbouring towns	• Threat of relocation of tribal hamlets from protected areas • Increasing population • Shift from food crops to cash crops and commercial crops (e.g. marigold, sugarcane) • Increasing irrigation due to policies favouring extraction (Senthilkumar et al., 2008) • Rearing of hybrid cows • More rural mobility
Resulting vulnerabilities	• Low lying areas are prone to floods • Over-extraction of groundwater and water from neighbouring basins is driving water prices • Health impacts of UHI and increasing pollution • Slum dwellers face multiple vulnerabilities (limited asset base, low access to public services, low levels of literacy, employment in the informal sector)	• Impact on livestock productivity which are a crucial subsidiary livelihood • Small and marginal farmers most vulnerable to erratic rains	• High poverty rates, high decadal growth rates, low sex ratio, poor access to basic amenities and financial resources make tribal communities especially vulnerable (CSTEP, 2014). • Women especially vulnerable because of the added burden of low productive activities like collection of water, firewood and NTFPs apart from agricultural work.

4.5 Key Research and Knowledge Gaps

The literature review process and feedback from key informant interviews (including national stakeholder consultation) provided key insights into critical gaps that exists in the domain of risks, vulnerability and impact assessments. Broadly, the gaps span biophysical and social dimensions as follows:

1. There is a dearth of studies that assesses medium- to long-term impacts on key sectors in the Indian & sub-regional context (even model building blocks lack an understanding of the local dynamics and peculiarities). This can be seen particularly in the interface of climate change and health impacts. Furthermore, there is limited understanding of globally and locally-driven ecosystem and biodiversity impacts, partly due to the poor quality of data

availability. The same can be said if impacts on other terrestrial system impacts, especially in the context of specie response. There is also insufficient understanding of climatic impacts on multiple crops, with a high degree of certainty (rice is the most studied crop in the Indian context but still suffers from significant model uncertainties).

2. There is a lack of reliable and sufficient climate data (at very high resolution, with limited bias) to understand local level natural and physical changes, with lower levels of uncertainities or bias. Most of the impact assessment has been primarily based on mean climate conditions whereas climate extremes are the principal source of maximum damage. One of the key gaps emerges from a dominant dependence on single climate and impact model (leading to poor reliability), coupled with incomplete sensitivity analysis. Uncertainty surrounding medium- to long-term projections in precipitation remains a single dominant source of unreliable impact assessment studies (see Table 4.3 for the state of information gaps that exists with regard to Indian SARs).

3. Regarding social and other related vulnerabilities, lack of a more nuanced understanding of local determinants & drivers (particularly in the rural context) is a significant emerging gap. This gap is particularly relevant in the context of credit constraints (including access), increased exposure to output and input price shocks, poorly remunerative livelihood structures, lack of adequate rural infrastructure, inadequate investment in the social sector (e.g. expenditure on health and education is very low especially with respect to other countries) and inadequate/expensive provision/availability of public amenities like health services. In the urban context, there are gaps that enlarge the understanding on the formal-informal binary, with insufficient understanding of the role of human and social capital, access to public good services, health, housing, and mobility patterns and their roles in reducing urban vulnerabilities. Social cleavages determining the state of vulnerability emerged as a critical gap in literature, with lack of studies that understand their causality in determining regional inequalities and poor developmental outcomes, particularly within the poor and the marginalised.

4. Poverty has significantly shaped the state of vulnerability in India but the dynamics of poverty has evolved and is increasingly not well understood. Currently, the focus is on measuring poverty, with added challenges on lack of adequate and relevant data. There is an urgent need to understand the dynamics of poverty in the local context, to build evidence in support of theoretical propositions (such as educational attainment leading to poverty alleviation).

5. There is a lack of understanding about pastoralism as a livelihood source, particularly in the context of regional and local political economy systems, and specific pastoral landscapes being considered as wastelands.

6. There is an insufficient understanding of the dynamic concomitant impacts of climatic and non-climatic drivers (in various sectors and contexts) in shaping risk and vulnerability profiles, particularly in the context of forest-based systems with the associated challenges of a large population dependent on the resource output from forests. There is insufficient understanding about the impact of climatic and non-climatic changes on a coupled social and ecological system including individual species response to climate change.

Table 4.4

State of the Knowledge on the Impact of Climate Change in South Asia on Different Natural Systems Eelevant to SARs (Hijoka et al 2014).

SECTOR	TOPIC/ISSUES	OBSERVED IMPACTS	PROJECTED IMPACTS
Freshwater resources	Major river runoff	√	X
	Water supply	X	X
Terrestrial Ecosystems	Phenology and growth rates	X	X
	Distributions of species and biomes	X	√
Inland water systems	Inland waters	X	X
Food production systems and Food security	Rice yield	X	√
	Wheat yield	X	√
	Corn yield	X	X
	Other crops (e.g. Barley, Potato)	X	X
	Vegetables	X	X
	Fruits	X	X
	Fisheries	X	X
	Pest and disease occurrence	X	√
Human settlements, Industry and Infrastructure	Flood-plains	√	√
	Population and assets	√	√
	Industry and Infra	√	√
Human health and Livelihood	Flood related	√	X
	Drought related	X	X
	Heat related	X	X
	Water-borne	√	X
	Vector-borne	√	X
	Livelihood and poverty	√	X
Livestock	Livestock	X	X

Key: **√**= relatively abundant/sufficient information; knowledge gaps need to be addressed but conclusions can be drawn based on existing information; **X** = Limited information/no data; critical knowledge gaps, difficult to draw conclusions

4.6 Conclusion

Risks, impacts and vulnerability in the Indian context are diverse, complex and lack robustness in asssessment. Differentially, pockets of evidence exist, in both in the biophysical and social space. Although the broad social dimensions of risks, impacts and vulnerability, as dimensions of underlying socio-economic processes are reasonably analysed and understood in literature; their interaction with climatic changes at finer scales lacks evidence, particularly in the rural context. Moreover, cities in India have a critical role to play in reducing vulnerability and building resilience, enabling growth and development through employment generation and poverty reduction, as well as planned infrastructure and housing transitions. While there are considerable innovations taking place across regions, experience and information of these is insufficient and fragmented. Through the RRP, we hope to understand what innovations, including those that are institutional, would enable effective risk management and thereby contribute towards vulnerability reduction—of people and systems.

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CHAPTER 5

The Adaptation Development Spectrum

Lead authors:

Chandni Singh[1], Ramkumar Bendapudi[3], Tanvi Deshpande[1] and Divya Solomon[2]

Contributors:

Amir Bazaz[1], Sumetee Pahwa Gajjar[1], Rajiv Chaturvedi[1], Bhavana Rao[3], Shrinivas Badiger[2]

Reviewer:

Aromar Revi[1]

Village farm ponds (left) and weather advisories (right) are emerging as risk management strategies in Maharashtra.
Photo: Prathigna Poonacha

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[1]Indian Institute for Human Settlements, Bangalore, India; csingh@iihs.ac.in

[2]Ashoka Trust for Research in Ecology and Environment, Bangalore, India, divya.solomon@atree.org

[3]Watershed Organisation Trust, Pune, India; ramkumar.bendapudi@wotr.org.in

Executive Summary

a. What are the prominent coping and risk management strategies, by whom and for what reason?

Risk management strategies in SARs in India traverse a response continuum from short-term coping, to long-term adapting and finally, at a larger spatial and temporal transformation (Section 5.2). Coping and risk management decisions are undertaken singly or concurrently, *ex-ante* or *ex-post*, to climatic and non-climatic risks. In rural households, current adaptation strategies include adjusting agricultural practices, livelihood diversification, engaging in storage of food and seeds, improved management of natural resources, strategic use of information such as agro-advisories, and leveraging financial tools such as weather-based insurance (Section 5.3.3). Community-based adaptation, typically NGO-led, is a key collective risk management process which promotes responses such as participatory watershed development, community forest management, local capacity building, and livelihood diversification.

In urban areas, adaptation is mainstreamed either through government-led development interventions and national and state-level climate change action plans, or through private sector and individual-led action (Section 5.3.4). While development planning has traditionally focussed on infrastructure and service provision in cities and towns, risk management has been primarily undertaken through disaster risk reduction, especially as climate proofing to extreme events. Seasonal or permanent migration emerged as a risk management strategy that traverses the rural-urban continuum. While it helps cope with temporary, seasonal risks, migration can erode present and future capacities (e.g. migrants have lower access to social safety nets and public services) and exacerbate existing vulnerabilities (women, children and elders left behind often are increasingly vulnerable).

b. How have existing risk management strategies for a range of impacts helped reduce climate risks and build adaptive capacities?

The evidence from adaptation projects suggests that risk management strategies at various scales, initiated by various actors, are helping build local adaptive capacity but this is not uniform across regions, sectors or scales (Section 5.3.2). Rural areas have seen relatively higher and longer investment in adaptation projects, through interventions aimed at helping climate adaptation directly, as well as those that have adaptation co-benefits such as interventions around livelihood diversification, biodiversity conservation, sustainable agriculture, or natural resource management. Given the large development deficits and vulnerabilities of the rural poor, coping strategies to manage risk are more common than adaptive action. Urban areas do not fare distinctly different and lack a coherent frame (such as a lack of implementing a co-benefits regime) to address climatic risks and build adaptive capacity creating pockets of intensive poverty, fragile livelihoods regime, and disregard towards preserving local ecosystems.

c. What are the key governance dimensions of risk management that are explicitly or directly relevant to climate change?

Risk management has traditionally been done through development planning in India, mostly triggered by concerns such as meeting basic food demands. Climate change adaptation is mainstreamed in response to the changing global discourse on climate change, resulting in the formation of the National Action Plan on Climate Change (NAPCC). This Plan aims to integrate climate-sensitive planning for development through eight missions. Three of these are focussed on adaptation, predominantly the agriculture, water, and forest sectors (Section 5.1.2). In addition to the missions, risk management is operationalised through disaster management interventions with scant regard for multiple co-benefits in human development and climate change adaptation, participatory natural resource management and livelihood generation and strengthening programmes at the national, state, and local levels. At the state level, State Action Plans on Climate Change (SAPCC) dealing with climate change exist for 22 out of 29 states (Section 5.1.3), but lack structured fiscal support. The involvement of donor agencies and private actors in the risk management space has implications for adaptation practice both at national and local levels.

d. How is adaptation planning being developed, promoted and implemented? By whom? What aspects of governance need to be strengthened to support further adaptation?

India has long argued that current national development goals outweigh the need for climate change action. Recent government policies have broadened this understanding of development as moving beyond poverty reduction to enhancing capabilities and ensuring wellbeing. The National Action Plan on Climate Change is the key policy directing action on climate change adaptation and mitigation (Section 5.1). India’s Second National Communication to the UNFCCC demonstrates how policies and programmes aimed at poverty alleviation, improved delivery of public services, and securing equitable access to natural, financial, and social resources, enhance adaptive capacity. There is a growing consensus that climate-resilient development should integrate adaptation and mitigation responses to generate multiple co-benefits. Increasing awareness, political will, committed financial mechanisms, and on-ground interventions are helping mainstream climate change adaptation. In Indian cities, climate adaptation is increasingly being mainstreamed into policy planning but unplanned urbanisation circumscribes the role of planned interventions, creating new risks and broadening the existing risks.

e. What is motivating and supporting adaptation action? Is adaptation driven by government policies, external agents, communities (top down and bottom up dynamics)?

Adaptation action in India is motivated by national development goals, existing social vulnerabilities, and increasing awareness of climate change impacts on different sectors (Section 5.1.2). Adaptation is driven by various actors at multiple scales—government and public institutions, civil society organisations, private sector actors, international donor agencies, international/national academic, development and research organisations. Individuals and community groups such as farmer cooperatives and self-help groups also drive local adaptation. Adaptation is thereby mediated by top-down and bottom-up processes with its concomitant tensions and contested imperatives.

f. Is adaptation strengthening or impeding development? Are some adaptation efforts potentially maladaptive? Are development trajectories impeding adaptation or leading to maladaptation? Is there evidence of adaptation being mainstreamed into development?

Identifying certain pathways and strategies as maladaptive is tricky because of asynchronous temporal issues, spatial issues (e.g., trade-offs between catchments within a larger river basin) and data insufficiencies (e.g., missing/unclear analysis of trade-offs between interventions) (Section 5.4.2). Some apparent adaptation strategies can be potentially maladaptive such as policies subsidising diesel, which locks agricultural systems into an unsustainable, energy-intensive pathway or the transformational shift from traditional subsistence agriculture towards a market oriented, semi-commercialised farming system. In Bangalore, unplanned urbanisation, inadequate service provisioning and governance gaps have created conditions for extensive resource exploitation, entrenching inequalities, and erosion of ecosystem services.

In India, climate change adaptation is mainstreamed through national and state policy planning processes, largely situated in local contexts but multi-scalar, linked to risk management practice through international actors, and partly triggered by project-based and NGO-led collective responses. While mainstreaming climate risk management into existing development programmes is critical, it may not be sufficient to reduce vulnerability.

g. Where are the important knowledge gaps in informing adaptation policy and practice?

Literature review and key informant interviews helped identify several gaps in knowledge (Section 5.6). There is a lack of understanding around factors that constrain effective implementation of adaptation plans. India-specific adaptation strategies need to be identified and prioritised at a landscape level based on a thorough understanding of how social and ecological systems interact. Research gaps include understanding 1) cross-scalar impacts of risk management 2) underlying financial, capacity, and institutional requirements for scaling up local adaptation 3) building evidence for adaptation that clearly addresses issues of attribution and 4) how different decision-making time scales affect risk management strategies (for example, policymakers plan for the long-term while individual households may exercise short-term, seasonal adaptation). Finally, it is important to address issues specific to SARs, centred on understanding and sustaining existing livelihoods regimes (e.g., livestock and forest-based livelihoods) and creating new ones where required.

The Adaptation-Development Spectrum

5.1 The Evolution of Climate Policy

5.1.1 The International Discourse

The IPCC has traditionally proposed mitigation and adaptation strategies as a response to address challenges due to climate change. Mitigation responses have been the main priority for experts, governments, and development agencies until recently (SDC, 2014). Given the inevitable impacts of climate change, adaptation has emerged as equally central to climate change policy (partly due to large-scale differential impacts experienced by vulnerable populations). The policy evolution shows a discursive shift towards merging the sustainable development agenda (with new re-aligned development goals) with concerns around climate-induced impacts. This expansive frame merges the development agenda (through building adaptive capacities) with goals exclusively aligned with climate change mitigation and adaptation strategies (Box 5.1).

Box 5.1

	A brief history of the evolution of global discourses around climate change action
1972	United Nations Conference on the Human Environment held in Stockholm. Recognised that poverty alleviation is crucial for protecting the environment.
1987	World Commission on Environment and Development (WCED) publishes the Brundtland Report (*Our Common Future*), emphasising sustainable development as a process to address environment and development dilemmas, fore fronted the need for intergenerational equity, and marked the emergence of the environment as a critical facet of international governance.
1990	The Intergovernmental Panel on Climate Change (IPCC) publishes its first assessment report (AR1) which finds that the world has been warming and future warming seems likely.
1992	The United Nations Conference on Environment and Development (UNCED) or Earth Summit takes place in Rio where agreements on preserving the climate, forests, deserts, oceans, and biodiversity were produced. The UN Framework Convention on Climate Change (UNFCCC) is produced. The Kyoto Protocol becomes an international treaty that commits nations to reduce greenhouse gases emissions.
2000	Eight Millennium Development Goals (MDGs) are established following the UN Millennium Summit. MDG progress seen as an important mechanism to address vulnerability drivers.
2007	Fourth IPCC report (AR4) warns that serious effects of warming have become evident; cost of reducing emissions would be far less than the damage they will cause; propose mitigation and adaptation as twin strategies. CoP13 in Bali ends in Bali Roadmap, which emphasises the need for deep cuts in global emissions. Adaptation Fund is launched.
2009	CoP15 results in the Copenhagen Accord, which recognises the scientific case for keeping temperature rises below 2°C, but does not contain commitments for reduced emissions that would be necessary to achieve the target.
2011	CoP17 in Durban. A management framework to create a Green Climate Fund of US$100 billion per year to help poor countries adapt to climate impacts was adopted.
2012	Rio +20 takes place 20 years after the Earth Summit and a report titled *The Future We Want* is released. The main message was to propose that sustainable development can be achieved through social inclusion, economic development and environmental protection.
2014	IPCC releases AR5 which uses a risk management framing and forefronts adaptation as a necessary strategy to deal with present and future climate change. Cities emerge to the forefront.

Internationally, adaptation has witnessed a shift from a focus on biophysical vulnerability to a wider framing of adaptation needs, that include social drivers of vulnerability and people's ability to respond (adaptive capacity) (IPCC 2014). Key framings of adaptation are:

- **Adaptation as necessary for development:** Since climate change is a 'threat multiplier' that affects key development sectors, development goals and decision-making needs to explore and incorporate adaptation options (Huq et al., 2006; Sharma and Tomar, 2010; Lebel et al., 2012). Mainstreaming climate change adaptation in development is a process of systematically including climate risk and adaptation considerations in planning decisions and processes instead of implementing adaptation measures as isolated, distinct projects. It can occur at multiple scales (international, national, sectoral, or project level) and in different areas of decision-making (policy-making, decision-making to screen for adaptation-oriented projects, planning, implementation and monitoring) (OECD, 2009). In India, adaptation has been embedded in the development agenda though the National Adaptation Programmes of Action (NAPAs) and National Action Plan on Climate Change (NAPCC).

- **Disaster risk management (DRM) and adaptation:** Since climate change is projected to increase the frequency and intensity of extreme events, the UN Hyogo Convention helped create national and local-level DRM plans that identifies 'low-regrets measures' and thus incorporates climate projects into adaptation plans. Convergence of climate change adaptation (CCA), DRM, and social protection programmes is an effective way to operationalise CCA mainstreaming (Sharma, et al., 2014; Davies et al., 2013; Adhikari and Taylor, 2012). Integration of CCA and DRR is also seen as a more holistic way of framing and operationalising risk reduction (Mimura et al., 2014; Adhikari and Taylor, 2012) and can reduce the risk of unintended maladaptation (Mimura et al., 2014). However, although CCA and DRR share similar objectives and challenges, they are within separate agencies and thus integration and coordination is a challenge (ibid.).
- **Risk-based frameworks:** More recently, risk-based frameworks explain adaptation as a behavioural change in response to climatic and non-climatic risks (IPCC 2014a). These risks can be categorised as extensive or everyday risks (e.g. food insecurity) and intensive or one-time risks (e.g. flooding). Such a framing acknowledges that in reality, people, communities, and policymakers do not respond to climate change alone and negotiate multiple risks when deciding on a response strategy. A risk management lens also puts the focus on how people's values, objectives, asset bases, and planning horizons shape their perceptions of climate change impacts (and risks), mediate their decision making, and finally motivate ongoing and potential adaptation responses.

In the light of the Conference of Parties (CoP) 15 to be held in 2015, it remains to be seen where developing countries such as India will stand vis-à-vis adaptation within the UNFCCC framework. Regarding long-term and global adaptation, the UNFCCC notes that all parties *"commit to increase efforts to adapt to climate change impacts, reduce vulnerability and increase resilience in the context of the actual increase in global mean temperature, taking into account the relationship between mitigation ambition, associated climate change impacts, and consequent adaptation needs, costs, and co-benefits"* (UNFCCC, 2014:14).

5.1.2 The Indian Context

5.1.2.1 Development Focus

As a developing country with 22 per cent of its population falling below the poverty line[16] and home to one out of every three malnourished children in the world[17], India has long argued that current

[16] Planning Commission of India (2013) http://planningcommission.nic.in/news/pre_pov2307.pdf

[17] UNICEF: http://www.unicef.org/india/children_2356.htm (Date accessed: 5.12.2014)

national development goals outweigh the need for climate change action. Over the past 65 years, India has been focussed on addressing underlying drivers of poverty and vulnerability in addition to environmental concerns. India's post-independence development strategy was shaped by a state-led socialist vision facilitated by centralised planning (Tandon, 2013). Development planning was led by the Planning Commission and a federal frame that revolved around Five Year Plans. Economic liberalisation, starting in the 1990s, exposed India to globalisation and led to a spurt in growth, expansion of the services sector as a rise in GDP, a decline in poverty but an increase in inequality. Recent government policies have also broadened the understanding of development as moving beyond poverty reduction to enhancing capabilities and ensuring wellbeing. Gains made by enhanced growth have simultaneously created problems such as rising income inequality, environmental degradation and poor performance on many human development indicators.

5.1.2.2 Evolution of Climate Policies in India

The National Environmental Policy (MoEF, 2006) is the earliest policy document, which addresses climate change. While it reiterates the principle of common but differentiated responsibilities and respective capabilities and prioritises the 'right to development,' it identifies key climatic vulnerabilities and recognises the need to "assess the need for adaptation to future climate change, and the scope for incorporating these in relevant programmes" (MoEF, 2006:43). The NEP however, had an over-emphasis on economic efficiency and lacked democratic and participatory approaches in its formulation (Badami and Kohli, 2006).

After the fourth IPCC Assessment Report (AR4) in 2007, CCA received significant policy emphasis. In 2007, a High-Level Advisory Group (HAG) on climate change was formed and helped prepare and coordinate National Action Plans for climate change, impact assessment, adaptation and mitigation agendas (Lok Sabha Secretariat, 2013). India's first National Action Plan on Climate Change (NAPCC), released in 2008, identified eight core missions, which represented a "multi-pronged, long-term, and integrated strategies for achieving key goals in the context of climate change" (MoEF, 2008:3). The NAPCC introduced into the policy discourse, the concept of co-benefits as measures that simultaneously promote development while addressing climate change effectively. However, the prioritisation of domestic, economic, and social development objectives over environmental concerns weakens the co-benefit frame in guiding policy trade-offs and priorities (Dubash et al., 2013).

Over the last decade, the discussion of climate change has transitioned from being a foreign policy issue to a broader debate on whether and how development trajectories should incorporate climate change measures and goals (Dubash, 2012). Inspite of this progress, there has been more emphasis on mitigation, overlooking the pressing issue of adaptation. Only three of the eight national missions have a strong adaptation focus. These are discussed next in Table 5.1.

Table 5.1: India's national missions addressing climate change adaptation. Critique based on authors' analysis

MISSION	AIM	MECHANISM OF IMPLEMENTATION	DRAWBACKS
National Mission on Green India (GIM)	To address climate change by enabling forest-dependent communities to adapt to climatic variability and by enhancing carbon sinks of vulnerable species/ecosystems	Implementation of activities will be in conjunction with existing programmes and policies such as the MGNREGA, Compensatory Afforestation Fund Management and Planning Authority (CAMPA), and the National Afforestation Programme (NAP).	Timely decentralisation and implementation will prove difficult Absence of addressing the crucial issue of reducing the rate of diversion of forest land for non-forest use The danger that the mission will be reduced to a plantation programme for commercial purpose, rather than addressing local needs.
National Mission for Sustainable Agriculture	To transform Indian agriculture into a climate resilient production system through suitable adaptation and mitigation measures in the domain of agriculture and animal husbandry.	Adaptation and mitigation strategies are embedded in existing R&D programmes and flagship schemes such as including Rashtriya Krishi Vikas Yojana (RKVY), National Horticulture Mission (NHM), National Food Security Mission (NFSM) and National Agricultural Insurance Scheme (NIAS). The Indian Council of Agricultural Research is undertaking the National Initiative on Climate Resilient Agriculture (NICRA), which seeks to scale up outputs through Krishi Vigyan Kendras and the NMSA for wider adoption by farmers. Components of NICRA include strategic research on adaptation and mitigation in 100 vulnerable districts.	Need to address currently weak agricultural extension services and insufficient credit and insurance availability to poor farmers New regulatory frameworks and capacity to address climate change are missing in institutions responsible for implementing agricultural policy.
National Water Mission	To conserve water, minimise wastage and ensure its more equitable distribution both across and within states	Adaptation planning is developed by putting in place appropriate mechanisms (for coordinated actions), capacity building and awareness programme (rural and urban local bodies), active participation of the youth in the process	The water sector is poorly integrated with climate change and development concerns. Demand management of water has not been prioritised.

In addition to the above Missions, the NAPCC envisages effective disaster management through mainstreaming disaster risk reduction into infrastructure project design, strengthening communication networks and disaster management facilities at all levels, protecting coastal areas, providing enhanced public health care services, and assessing increased burden of disease due to climate change (MoEF 2008). The NAPCC also highlights the role of various levels of government in enabling fair and equitable local adaptation measures.

5.1.2.3 The Way Forward: the Post-2015 Development Agenda

While some of the interventions enumerated under the NAPCC are already being undertaken (Box 5.2Box 5.2), a change in 'direction, enhancement of scope, and accelerated implementation' (MoEF, 2008:3) is required, given the range of climatic impacts on different sectors (Section 4.2) and existing vulnerabilities in India (Section 4.1).

Box 5.2

Key achievements under National Missions related to adaptation.

National Water Mission	**National Mission for Sustainable Agriculture**
• Revised National Water Policy (2012) adopted by National Water Resources Council • Created 1,082 new Ground Water Monitoring wells • Several capacity building and training programmes are underway	• Developed 11,000 hectares of degraded land • 1 million hectares brought under micro-irrigation to promote water efficiency • Created 5.4 million metric tonne agricultural storage capacity
National Mission for a Green India	**National Mission on Strategic Knowledge for Climate Change**
• Preparatory activities underway in 27 states • 11 Indian states have submitted perspective plans that cover 33 landscapes and working area of 85,000 hectares • Finalised implementation guidelines after extensive consultations with state governments and civil society	• Established 12 thematic knowledge networks • Developed 3 regional climate models • Trained 75 high quality climate change professionals

Source: http://envfor.nic.in/sites/default/files/press-releases/Indian_Country_Paper_Low_Res.pdf

The Second National Communication to the UNFCCC (MoEF, 2012) reiterates the urgency of effective adaptation measures in different sectors and acknowledges the importance of both win-win and no-regrets strategies. There is increasing recognition that successful adaptation will require mainstreaming climate considerations into broader developmental programmes (IPCC, 2014a) as well as the Sustainable Development Goals (SDGs).

Annex 5.1 illustrates the link between the objectives of three national missions that take into account adaptation, and the SDGs. The Missions under analysis are comprehensive and their objectives broadly align with the SDGs. However, the missions fail to address the most marginal and vulnerable population, as recognised in SDGs 1.5, 2.4, and 3.d. For sustainable development, an explicit link between poverty alleviation, livelihoods and climate change is essential, where significant gaps exist. While internationally, the Government of India, has reiterated its intentions to focus on development and economic growth (MoEF, 2014) the policy evolution illustrates increasing investment and political will towards CCA. This shift is occurring in rhetoric and reality (Dubash, 2013). First, a number of impact and vulnerability assessment studies are emerging (for a comprehensive list see MoEF 2012). While these have traditionally been top-down approaches aimed at assessing biophysical impacts and sectoral vulnerabilities, more recently, community-based vulnerability assessments are being done (Patra, 2014). Second, despite its current limitations, the co-benefits concept[18] could become an effective instrument to achieve multiple goals. Finally, since 2010, the central government has requested states to develop State Action Plans on Climate Change (SAPCC), which aim to achieve coherence across states in design and implementation of climate measures, as well as recognise the state jurisdiction over several areas within the NAPCC, particularly those related to adaptation (Dubash, 2013).

5.1.2.4 Climate Resilient Development

There is an emerging policy focus in India on resilience planning because of a range of climatic and non-climatic risks, a diversity of vulnerability profiles, and multiple institutional regimes. Coupled with this, India has a wide variety of settlement sizes from villages to small towns to secondary and million cities. India, with a large area of multi-hazard environments and climate hot spots, has significant populations in extreme poverty, highly vulnerable to both everyday risks as well as from extreme events. These groups are disproportionately impacted by environmental and health risks. Simultaneously, Indian cities and urban regions face serious institutional and governance challenges, compounded by contested growth dynamics, migration, and a circumscribed role for cities that is in variance with lived reality.

There is growing consensus that climate-resilient development should integrate adaptation and mitigation responses to generate mutual benefits and introduce co-benefits with development. The SRI system of rice cultivation produces significantly higher yields than average with 30-50 per cent less water producing relatively lower GHG emissions as a mitigation by-product. Agroforestry, which helps enhance and diversify income, and conserves soil and water resources, has a mitigation co-benefit through natural carbon capture and storage.

[18] Co-benefit measures "promote our development objectives while also yielding co-benefits for addressing climate change effectively" (Government of India, 2008).

Increasing awareness, political will, funding, and on-ground interventions are helping mainstream CCA (Box 5.3). In Indian cities, CCA is increasingly being mainstreamed into policy planning but it remains to be seen how this translates into implementation. The Asian Cities Climate Change Resilience (ACCCRN) experience shows there is a strong need to institutionalise resilience-building actions such as city adaptation. Surat has been the only city to go forward to institutionalise urban climate resilience agenda into the city government's agenda (Sharma et al., 2014).

The importance of mainstreaming climate resilience in development planning is put into perceptive by the recent devastating floods in Srinagar, northern India, where the damage to property and assets has been calculated to be Rs.44,000 crore with intangible losses such as unaccounted for damage to heritage buildings and ancestral property (The Hindu, 2014)[19]. The flood was a direct result of extraordinarily heavy rainfall and poor urban planning. It serves as a clear example of how climatic and non-climatic risks interface and expose populations to extreme risk. The Srinagar flood has put the spotlight back on the magnitude of loss and damage caused by not preparing for climate-induced impacts and carrying out *ex ante* disaster management.

[19] Kashmir flood victims pin hope on Modi's Diwali visit, The Hindu http://www.thehindu.com/news/national/other-states/jammu-and-kashmir-flood-victims-pin-hope-on-modis-diwali-visit-to-srinagar/article6523508.ece Accessed on 20.02.2014

Box 5.3

Is India mainstreaming climate change adaptation?

Two illustrations of development planning converging with climate change adaptation and building local adaptive capacity are:

- In rural India, the Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGA) is a state-led programme aimed at alleviating poverty through employment generation. It also encompasses objectives of drought proofing, building resilience to climate risks, and reversing/slowing natural resource degradation. Although functional and methodological limitations prevent MNREGA from being a truly transformative policy intervention, it is positioned well to address climate change vulnerability (Adam, 2014).
- In urban India, the Asian Cities Climate Change Resilience (ACCCRN) is a Rockefeller Foundation funded initiative (2008-2015) to build resilience through processes and practices addresing urban vulnerabilities. In India, two groups of cities were involved: core cities Surat, Indore, and Gorakhpur; and replications in Mysore, Guwahati, Shimla, and Bhubaneswar. ACCCRN involved multiple partner organisations, engaged at different stages, but using a common processes in all cities: (1) Shared Learning Dialogue (SLD) techniques for stakeholder engagement, (2) vulnerability assessments, (3) sectoral studies, and (4) city resilience planning.

CITY	CLIMATIC RISKS	ORGANISATIONS	ADAPTATION INTERVENTIONS
Surat	Flooding; sea level rise; urban heat island effect	TARU Leading Edge-Private Limited	Cool roof and passive ventilation; establishment of urban health and climate resilience centre
Indore	Flooding; water scarcity; increased temperature; urban heat island effect	TARU Leading Edge-Private Limited	Urban lake restoration; cool roof and passive ventilation
Gorakhpur	Flooding; water logging	Gorakhpur Environmental Action Group, Institute of Social and Environmental Transition, Arup, TERI	Multi-scale activities: integrated farming, waste management, flood-resilient construction, climate-resilient agricultural planning, maintenance of municipal services, conservation of water bodies

5.1.2.5 The Co-benefit Frame: Bringing Adaptation and Mitigation Together

The IPCC notes that 'adaptation action that delivers mitigation co-benefits is a powerful, resource-efficient means to address climate change and to realise sustainable development goals' (Revi et al., 2014:3). However, mitigation to address climate change impacts is constrained by several factors. First, mitigation measures are high on investment (because they are typically infrastructure-heavy, technical interventions) and time consuming (involving relatively long periods of investment and maintenance). Second, they result in pathway dependency where development trajectories are locked-in to certain processes. Third, uncertainty around climate change projections and impacts acts as a disincentive for investment in mitigation.

Given this context, the co-benefits frame has emerged as a middle path, which argues that mitigation and adaptation, if done concurrently, can help mainstream climate-related issues into dominant development pathways. However, there can be positive and negative interactions between adaptation and mitigation strategies (for example, see Annex 5.2 for co-benefits and side effects on agriculture and forests). A key research gap is the lack of substantial evidence in rural and urban landscapes across sectors around how mitigation and adaptation strategies interact. For example, in the areas of conjunctive water use, there is local evidence suggesting that use of drip and sprinkler irrigation (adaptive strategy) can help reduce energy used for groundwater extraction (mitigation strategy). However, there is a lack of evidence at large scales, across scales and sectors, and in urban areas.

5.1.2.6 Financing Adaptation-development Transitions

This chapter discusses different development and adaptation-focussed projects in SARs (Section 5.2) and finds finance as a major barrier to scale up local interventions. Currently, India's expenditure on CCA is 2.6 per cent of its GDP (MoF, 2014b) but it is enmeshed in development plans. This makes it difficult to monitor funds available and invested into adaptation, and to understand their efficacy. Recent policy shifts have increased fiscal federalism where financial powers are increasingly been devolved to states. This has implications for key vulnerable sectors such as agriculture, which fall under state jurisdiction and would probably provide adequate fiscal space for states to respond to regional climate-induced challenges. The recent formula to share central tax revenues with states has introduced forest cover as an important lever to determine the quantum of financial transfer (thus contributing to incentivising conservation processes, which in turn institutionalises conjoint adaptation and mitigation responses).[20] This decision to distribute the central tax revenue to the states depending upon their forest cover, not only recognises climate protection as a public good, but also puts the onus on state governments to maintain a balance between economic growth and 'sustainable' development. This reformulated tax revenue distribution formula is a potent tool encouraging environmental conservation by incentivising the conservation and expansion of forest cover.

[20] http://www.cgdev.org/blog/indias-big-climate-move Accessed on 02.02.2015

Box 5.4

India's National Adaptation Fund. Source: Adapted from MoF, 2014a
The National Bank for Agriculture and Rural Development (NABARD) is India's National Implementing Entity (NIE) for UNFCCC's Adaptation Fund and is the only NIE in Asia-Pacific. Some successful initiatives are: • Two projects submitted by NABARD, amounting to $3.2 million have been sanctioned by the Adaptation Fund Board. • NABARD is implementing several CCA and natural resource management projects across the country. • It finances green investments in solar power and improved electricity distribution • It anchors the National Adaptation Fund of Rs.100 crores (as announced in the 2014-15) annual budget.

A study by Sachs and Schmidt-Traub (2014) found that $60–100 billion would be required until 2030 to meet climate adaptation goals within the SDG framework. They note that 100 nper cent of this will be public, non-commercial financing, bringing into focus the reluctance of the private sector to invest in adaptation because of the lack of guarantee of returns in a sector as uncertain and risky as climate change and emphasising on the public sector being the key agent of change.

In India, the climate finance landscape is highly fragmented (Jha, 2014) with actors from the central and state governments, civil society, and private sector having different but significant contributions in mediating climate resilient development. While there are several actors in this space, formal planning, prioritisation and coordination mechanisms are lacking. Thus, there is a need to build a comprehensive climate finance strategy that leverages national and international opportunities that creates climate-focused strategic investment regimes.

5.1.3 State-level Story

In 2010, the Government of India asked each state to prepare State Action Plans on Climate Change (SAPCC) to deal with climate change challenges. Out of 29 Indian states, 22 have submitted their SAPCC to the Ministry of Environment and Forests. Of these, 19 have been endorsed by the National Steering Committee and three (including Karnataka) are currently under consideration)[21] (see Annex 5.3). Reviewing five SAPCC (including Karnataka's), Dubash and Jogesh (2014) found that while these plans provide a mechanism to mainstream environmental sustainability concerns into development planning, they remain short of including climate resilience in their policy framing. The lack of an SAPCC in Maharashtra reflects a crucial gap between policymakers and institutions working to mainstream climate

[21] Ministry of Environment and Forests. http://www.moef.nic.in/ccd-sapcc

adaptation. ASSAR India's work will help highlight this gap and potentially address it through processes of stakeholder engagement and research into use.

5.2 Framing Risk Management

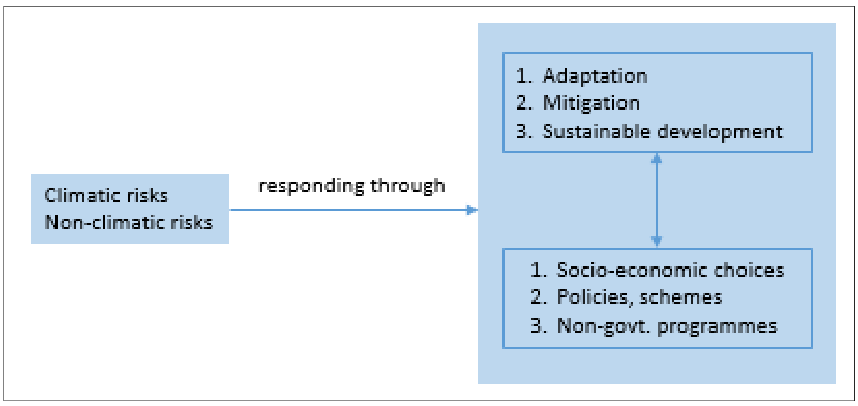
Risk management encompasses plans, actions, or policies to reduce risk, or respond to the consequences of risks (IPCC 2014b). As discussed earlier (Chapter 4), these risks can be climatic and non-climatic and can interact with one another to exacerbate vulnerabilities. They may also be extensive or intensive in nature. Risk management theoretically draws from hazard management studies, disaster risk reduction, poverty and food security studies, and more recently, climate change and vulnerability research.

Individuals, households, and communities in SARs regularly respond to short-term climatic variability and long-term climatic changes. They also respond to non-climatic risks arising from multi-scalar dynamics in socio-ecological systems. Risk management strategies encompass coping (short-term negative or positive response), adjustments, and adaptation—longer-term, more permanent and sustainable change integrated with reflexive action (Annex 5.4).

Risk management can be undertaken through adaptation (proactive, reactive, or transformative), mitigation, and sustainable development (Figure 5.1). Since priorities for development and adaptation are closely related, indicators of adaptive capacity to respond to climate impact and indicators of sustainable development overlap (Denton et al., 2014). Recognising this, India's national plan explicitly discusses development of human, institutional, infrastructural capabilities (Planning Commission, 2013) that builds overall adaptive capacity signified by building human, social, natural, financial and physical capitals (Jones et al., 2010).

Figure 5.1

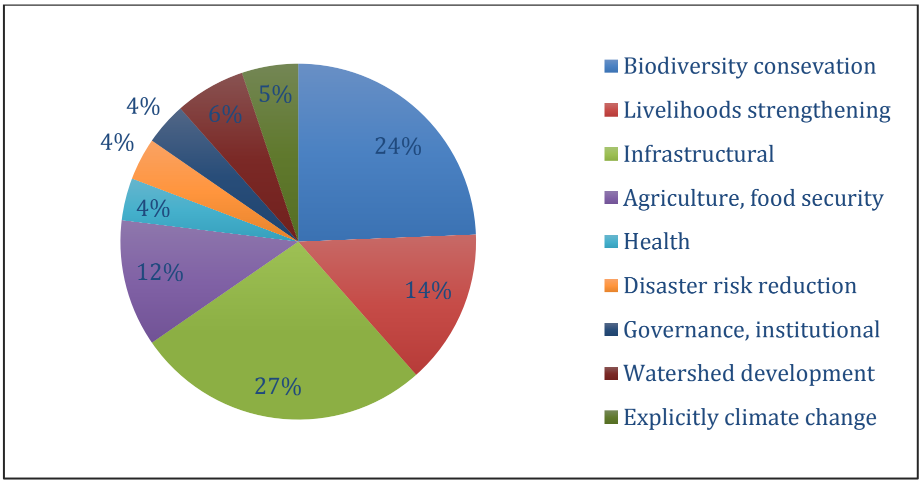
Elements of risk management



The following sections discuss risk management strategies (which include coping, adapting and meeting human survival and security goals) in SARs in India deployed by different actors across scales. The first part covers strategies in rural landscapes while the second section discusses urban risk management. To understand different adaptation interventions in India, 78 projects were reviewed (Annex 5.4) funded by ten prominent funding agencies operating in India[22]. Twenty-one of these projects are completed and 57 are ongoing. They were operational at different scales (35 per cent at national and 65per cent at regional or local scales) and followed different approaches (Figure 5.2). Projects focused extensively on water and agricultural sectors as these sectors are most directly affected by climate variability and change.

Figure 5.2

Approaches and entry points used by a sample of adaptation projects in India (2005-2014)



Adaptation interventions in SARs are fewer than in coastal areas because the latter are expected to be more severely affected by extreme events such as cyclones and sea level rise while SARs mainly experience slow onset events such as droughts, desertification and heat island effect in cities, which have long-term, less visible impacts. Another interesting finding was that completed projects (both at national and state level) are focused on development and reducing vulnerabilities while more recent, on-going projects have explicit climate change adaptation objectives.

[22] The funding agencies reviewed include World Bank,, Asian Development Bank (ADB), Swiss Agency for Development and Cooperation (SDC), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), UN-Habitat, United States Agency for International Development (USAID), Global Environment Facility (GEF), Department for International Development (DFID), United Nations Environment Programme (UNEP), Japan International Cooperation Agency (JICA), International Development Research Centre (IDRC) and International Fund for Agricultural Development (IFAD).

5.2.1 Actors and Institutions in the Adaptation-Development Spectrum

The primary actors in the adaptation-development arena (mapped in Figure 1) are:

- **Public:** Government (national, state, and district level) officials and extension workers as well as elected representatives (state, district, Panchayat levels)
- **Civil society:** Non-governmental organisations (national, local levels), farmer cooperatives, grassroots movements, and activist groups etc.
- **Market:** business and private sector actors (e.g. firms, banks, microfinance institutions), private sector actors (especially through CSR activities)
- **International actors:** donor agencies, international NGOs and research organisations
- **Research:** academic institutions, think tanks, research for development organisations

Institutions play a crucial role in mediating CCA at multiple scales (Thompson et al., 2006; Agarwal, 2010). In rural areas, adaptation is predominantly local and incentives for individual or collective action are mediated by local or extra-local institutions (Box 5.5).

Box 5.5

Institutions and their role in mediating adaptation

From an evaluation of 118 cases of adaptation worldwide, Agarwal (2010) identified three ways in which local institutions shape climate change impacts on livelihoods and define available response strategies.

- **Institutions structure the manner in which resources are accessed, managed, and negotiated**. This directly drives the adaptation options that are available to households and communities. For example, the absence of proper sharing norms for a commonly owned pond may lead to appropriation of the resource by powerful actors. Thus, certain households may not be able to use the pond's water for protective irrigation, which is a useful coping strategy in rainfed agriculture.
- **Institutions shape incentives for individual and collective action**. Depending on the robustness of incentive structures, households and communities are motivated to undertaken adaptation action. Thus, norms of labour sharing among extended family members may allow small households to undertake adaptive measures such as land levelling which they could not have done if they did not have access to extra labour.
- **Institutions mediate external adaptation and development interventions** and can help or hinder ongoing risk management. For example, externally implemented interventions that form women's groups to improve financial access are successful only if the groups have access to capital, expertise to maintain financial accounts, and proximity to banking facilities.

5.2.2 Risk Management Options and Strategies

India's hierarchical federal structure divides legislative power between the Union and states. Subjects that fall within the purview of states include agriculture, water (supply, irrigation and canals, drainage and embankments, storage), land (rights, tenures, transfer and alienation of agricultural land, land improvement, and agricultural loans), livestock, public health, and local government functioning. Against this context, the SAPCCs were envisioned as a decentralisation mechanism to take action beyond the NAPCC missions. Examples of policies that mediate and shape risk management are discussed in Table 5.2. For a detailed review of national, state and sub-regional risk management policies, programmes and schemes, see Annexure 5.5.

Table 5.2: Risk management at multiple scale and across multiple sectors – examples from evidence

SECTORS	NATIONAL	REGIONAL
Natural ecosyste ms (e.g.	- Green India Mission - India Forest Act - Hariyali enabling the rural	- Reclamation of Alkali Soil was launched as part of the VII five-year plan in order to address the problem of soils affected by alkalinity

forests)	population to conserve water for drinking, irrigation, fisheries and afforestation as well as generate employment opportunities	
Agriculture	- National Initiative for Climate Resilient Agriculture (NICRA) - National Mission for Sustainable Agriculture (NMSA) - National Agroforestry Policy, 2014 - Rashtriya Krishi Vikas Yojana (RKVY) - National Horticulture Mission (NHM) - National Food Security Mission (NFSM) - National Agricultural Insurance Scheme (NIAS) - National Agricultural Development Programme (NADP)	- Incentives for solar energy, drip and sprinkler irrigation and organic agriculture. In Karnataka, drip irrigation for sugarcane farmers was recently made compulsory as a water saving, income enhancing mechanism[23]. - Millet Cultivation using the System of Rice Intensification Method in semi-arid regions of Karnataka(Mandal, 2014) - Using temperature tolerant rice cultivars and green manures/biofertilisers for economising water (Geethalaxmi et al. 2011)
Water	- Participatory watershed management through Drought Prone Area Programme (DPAP) - Integrated Wasteland Development Programme (IWDP) - Integrated Watershed Management Programme (IWMP) - National Watershed Development Project for Rainfed Areas (NWDPRA)	- Tamil Nadu: World Bank assisted dam rehabilitation and improvement project (DRIP) - Tamil Nadu Irrigated Agriculture Modernisation and Water Bodies Restoration and Management Project (TN IAMWARM) - Comprehensive Watershed Development Program (COWDEP) and Jal Sandharan in Maharashtra
Livestock	- National Livestock Mission (NLM) National Programme for Bovine Breeding and Dairy (NPBBD) - Livestock Health and Disease Control	
Health	- National Environmental Policy (2006) - National Health Mission (National Rural Health Mission, 2013; National Urban Mission, 2013) - National Health Policy (2002) - Rashtriya Swasthya Bima Yojana (2002) - Community-Based Health Insurance Scheme	- Karnataka: Yeshasvini Co-operative Farmer Health Care Scheme (2003), AYUSH Grama Yojane - The Integrated Child Development Scheme (ICDS) and the Tamil Nadu Integrated Nutrition Project (TINP) aims to provide nutrition for vulnerable children and pregnant and lactating mothers. - Maharashtra: Navsanjivani Yojana for rural areas

[23] http://www.thehindu.com/news/national/karnataka/drip-irrigation-to-be-mandatory-for-sugarcane-cultivation-from-february/article6633757.ece Date accessed: 10.01.2015

Urban	- National Urban Renewal Mission or Jawaharlal Nehru National Urban Renewal Mission (JNNURM, 2005), addresses infrastructure deficits in cities, provide for avenues that reduces urban poverty and improves urban governance - National Urban Transport Policy (NUTP)	- Karnataka Municipal Water Energy Efficiency Project - North Karnataka Urban Sector Investment Program - The Bangalore Water Supply and Sewerage Act (2009) which has made rainwater-harvesting mandatory in the Bangalore agglomeration - Sherwood Institute, a US-based NGO, is collaborating with Bangalore Development Authority (BDA) to revive lakes and watersheds in the city[24].
Socio-economic	- Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) - National Rural Livelihood Mission	- In Maharashtra, Employment Guarantee Scheme (EGS) - In TN, Mahalir Thittam is a socio economic empowerment programme for women based on a Self-Help Group (SHG) approach and is implemented in partnership with NGO's and community based organisations.

[24] The first watershed proposed to be revived under this scheme is the Bellandur watershed. Its catchment area, spread across 140 km^2, includes Bellandur, Madiwala, Agara, Devarabeesanahalli, Kaikondrahalli and Doddanekundi lakes. Sherwood Institute and Carollo Engineers, a US-based water engineering firm, have proposed working with Invicus Engineering, a Bangalore-based firm and the BDA to rejuvenate the watershed.

Climate and biophysical impact modelling suggests a range of adaptation strategies that may be viable in India (summarised in Table 5.3) but lacks sufficient evidence for mainstreaming.

Table 5.3 Adaptation options suggested for different sectors (from modelling studies)

SECTOR	ADAPTATION OPTIONS	KEY IMPACTS	STUDY
Water	• Adaption options should be no different from present day stresses. • Application of Integrated Water Resource Development at different levels (from households to catchments) • The best adaptation option may be artificial restoration of hydrological system by enhancing water storage and infiltration	Decreased water availability in many of the semi-arid basins	Gosain et al. 2006
	Do not prescribe specific adaptation options, rather sub-basin level model outputs for the whole country and users are urged to draw adaptation inferences at local levels (**http://gisserver.civil.iitd.ac.in/natcom)**	Decreased water yield in many river basins in SARs	Gosain et al. 2011
	The increase in surface run-off may be unevenly distributed across the seasons, there is a need to create storage to smooth out the peaks in water availability throughout the year, otherwise greater run-off volumes may induce flooding.	Increased water availability in Ganga basin	Fung et al. 2011
Agriculture	New wheat cultivars are needed to adapt the crop to changing environments	High yielding wheat area loss	Ortiz et al. 2008
	The impact of two low-cost adaptation options were tested: a) change in variety and b) change in sowing date. Adaptation strategies yield positive results as these are projected to reduce the climate change impacts in both the monsoon and winter sorghum	Decreased yields of Sorghum under climate change scenarios	Naresh Kumar et al. 2013
	Suggested adaptation strategies were: • system of rice intensification, • using temperature tolerant cultivars • using green manure/biofertilisers to reduce water use	Rice yield loss	Geethalaxmi et al. 2011
Forestry	Inclusion of climate change concerns in long term forest policy planning	Forest type shifts	Ravindranath et al. 2006
	Need to reduce forest fragmentation and need for anticipatory planting to cope with future climatic changes	Forest type shifts	Chaturvedi et al. 2011
	Bala et al. (2013) suggest that conservation efforts such as large scale afforestation, reforestation and forest conservation in India may have led to NPP increase in Indian forests over 1982-2006.	NPP increase	Bala et al. 2013

5.2.3 Rural Risk Management

In rural India, risk management occurs at various scales and through different actors. Variations in risk management mechanisms across SARs in India are a function of geographical variability; physical, social, and natural capacity; gender; and institutional supportive structures (ADB, 2009).

At the household level, risk management strategies are undertaken singly or concurrently, *ex-ante* or *ex-post*[25], and encompass a variety of context-dependent activities. Current adaptation initiatives are directed towards anticipating and responding to climatic variability by adjusting agricultural practices such as using drought and flood tolerant seeds, pest and disease resistant varieties of crops, ICT based agro-advisories and weather-based insurance. People also undertake opportunistic adaptation depending on options available. Policy thrusts on poultry farming and fisheries to diversify livelihoods have helped people expand their livelihood options. Since poultry is consumed in urban centres, such opportunities are more viable in peri-urban areas, showing that adaptation options can be spatially differentiated. Although several papers allude to gender being a mediator of adaptive capacity and irisk management behaviour, gender mainstreaming in adaptation planning and implementation is still inadequate (Box 5.6).

Diversification is a key risk management strategy in rural rainfed systems. This can be crop diversification, such as inclusion of trees in the farming system to conserve moisture and nutrients or diversifying agricultural activities by farmers in Wardha, Maharashtra who are shifting away from cotton and soybean to less water-intensive crops, such as sorghum and pulses, in combination with fruit trees (Pande and Akermann, 2008). Kale and D'Souza, 2014 report how farmers in Kumbharwadi village, Sangamner, Maharashtra used to grow two main crops pearl millet (*kharif*) and sorghum (*rabi*), with a little of moth bean, green gram, horse gram and sugarcane for fodder over 325.5 hectares. After the implementation of the Indo-German Watershed Development programme which began in 1996, farmers started cultivating cash crops, like wheat, tomato and onion. Adaptations by small-scale livestock farmers include strategies such as changing herd size and composition, change in grazing and feeding patterns, or diversifying livelihoods, along with the use of new varieties of fodder crops suited to changing rainfall conditions (Salema et al., 2010).

Migration (seasonal or permanent), is a risk management strategy that traverses the rural-urban continuum. It helps people cope with temporary, season-based risks but can erode present and future capacities (e.g. migrants have lower access to social safety nets and public services) as well as exacerbate existing vulnerabilities (women, children and elders left behind often are increasingly vulnerable) (Hazra 2012). Empirical research in Byalal, Karnataka showed that almost 60 per cent of the population engaged seasonal migration for

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[25] *Ex-ante* risk management strategies or risk-reducing strategies are taken before a climatic event and are based on expectations (the probability of bad or good events occurring). *Ex-post* strategies are undertaken after an event and are reactive in nature. *Ex-ante* strategies are also called "income smoothing mechanisms", and *ex-post* mechanisms "consumption smoothing mechanisms".

six months per year to urban centres. This was an undesirable but necessary risk management strategy (Wilson et al., 2014).

Adaptive responses need not always be new and can include farm level practices such as change of planting dates, altered water conservation practices, change to early maturing varieties to mitigate shortened growing season, change to drought tolerant crop varieties, and change to high yielding crop varieties to take advantage of unusually favourable weather (Krishnan et al., 2009).

Box 5.6

Climate Change and Women – Aspects of Risk Management

Although India spends 2.5% of its GDP on CCA (MoEF 2012), it is not clear how much of this explicitly addresses the gendered impacts of climate change (Alternative Futures 2014).

In India, 20 per cent households still do not have access to adequate water for domestic use (MoEF 2012). To meet household water demands, women spend significant time and effort in collecting water (Krishnan et al., 2004). This burden of carrying water often falls on young girls, resulting in relatively school attendance (Aggarwal et al., 2012). With climate change projected to reduce per capita water availability further, (5177m^3/capita/year in 1951 to 1654 m^3/capita/year in 2007 and 1140 m^3/year by 2050) time and effort spent in water collection is expected to increase drastically, with implications on drudgery for women.

- Studies from mountainous landscapes of northwest India find that while drinking water supply interventions reduce the distance women walk to reach water sources and the drudgery of negotiating steep mountain slopes, they result in an increase in volume of water women are expected to carry (Narain 2014).
- A study in Rajasthan found that relatively lesser participation in community decision-making, lower access to vital social networks within and beyond the community, and limited access to information channels such as extension officers and mobile phones, affect women's perceptions of climate variability and their ability to respond to climatic and non-climatic stressors (Singh 2014). In addition, exclusion from male kinship relations, patriarchal land inheritance norms and poorer education and health status of women result in multiple vulnerabilities.
- A state-level index-based study exploring climate vulnerability in 2025, found that wherever there were projected improvement in social and economic indicators of women well-being, such as literacy rate, life expectancy, incomes; it invariably led to vulnerability reduction to climatic stresses (partly due to their increased ability to lobby) (MoEF 2012).

At the community level, groups of people may come together and undertake risk management activities through forestry management, infrastructure development, resource management, information gathering, and disaster preparation (Agrawal 2010). Such activities fall under the broad framework of Community-based Adaptation or CbA (Wright et al., 2014). With the growing realisation that CbA is successful, especially in agriculture (ibid.), it is increasingly being funded and facilitated by national and state governments, multilateral organisations, international development organisations and large NGOs. Communities also manage risk through community insurance (informal credit) as well as mechanisms of informal insurance such as patronage, kinship, and accessing communal resources (Ramaswami et al., 2003).

Currently, **NGO interventions** typically use government or international funding to build local adaptive capacity from a livelihoods perspective. For example, Watershed Organisation Trust (WOTR) supports communities and local self-governments to use locale-specific climate forecasts and agricultural information for decision-making (Centre for Science and Environment (CSE), 2014). Agro-met services facilitate flexible, weather-based agriculture planning and immediate response using forecasts and crop-calendars, and thus enable local communities to adapt to risks from seasonal variability[26]. NGO initiatives also mainstream gender issues in their interventions through focus on income diversification of women and supporting microfinance through women's savings and credit groups [27].

International and national Research for Development (R4D) organisations such as the Consultative Group for International Agricultural Research (CGIAR) institutions are also playing a crucial role in trying to understand and build local adaptive capacity, especially in the agriculture sector. Of notable mention is the Research Program on Climate Change, Agriculture and Food Security (CCAFS) that uses climate change scenarios, participatory planning and agromet advisories to facilitate community adaptation planning (Mandal, 2014).

Private sector actors play a role in local adaptation by activities under the umbrella of Corporate Social Responsibility (CSR). They do this through engagement in risk transfer strategies such as crop- or weather-based insurance (Fischer and Surminski, 2012), improving information access (for example, Indian Tobacco Company or ITC provides farmers with market and weather information through their *e-choupal* initiative), and finally, through Public-Private partnerships or PPP (Box 5.7).

[26] http://www.wotr.org/sites/default/files/AGROMET-6.9.13.pdf
[27] For examples, see SEWA: http://sewabharat.org/program-themes/microfinance/

Box 5.7

Public-Private partnerships (PPP) to meet adaptation and development goals[28]

Indian Tobacco Company (ITC) and integrated watershed development: ITC's Mission Sunehra Kal (Mission for a Golden Tomorrow) uses a community-centric approach to build rural capacity for natural resource management, livelihood diversification, women empowerment, and education. ITC's Integrated Watershed Development Programme covers 1,35,000 households across eight states (Andhra Pradesh, Telangana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Odisha and Tamil Nadu). The projects are implemented in partnership with National Bank for Agriculture and Rural Development (NABARD) and various state governments with help from local NGOs.

Hindustan Unilever (HUL) and sustainable sourcing of tomatoes: HUL follows a PPP model with the Government of Maharashtra to incentivise farmers to grow tomatoes using sustainable agriculture practices such as drip irrigation and optimal seed selection. HUL buys back these tomatoes from the farmer through Varun Agro, a food processing company, thus providing a reliable market. By doing so, HUL incentivises tomato production and therefore agriculture incomes, strengthens the tomato supply chain, and builds capacity (with the Department of Horticulture).

5.2.4 Urban Risk Management

In urban areas, development issues revolve around sectors such as infrastructure and services, transport, water, and housing. Due to rapid urbanisation, India's policy focus is shifting from rural areas to address development deficits in urban spaces. Adaptation in the urban areas is mostly private sector and individual led, especially in the face of intensive risks like flooding. There is very little or no reliance on local and state-led adaptation interventions (Patankar, 2010). However, private adaptation is driven by personal or financial motivations and hence may not be addressing issues of equity (who wins/losses) and sustainability.

Our project review found that **risk management in Bangalore is dealt through techno-centric, infrastructure-based and large-scale interventions.** Risk management has also been conceptualised at the metropolitan level. Risk management interventions tend to be **reactive rather than proactive** and CCA and DRM are poorly integrated (Varma et al. 2014). The current risk management approach is inspired by development deficits and pressures on infrastructure and services the city is facing.

The city has not been targeted by major internationally funded programs (such as the ACCCRN, Box 5.3), which has targeted Indian cities facing similar challenges. Despite this, international agencies play an important role in funding. Interestingly, what seems partly

[28] Further reading: Unilever: http://www.hul.co.in/sustainable-living-2014/casestudies/Casecategory/Tomato-Sourcing.aspx and ITC: http://www.itcportal.com/sustainability/investing-in-social-development.aspx

guiding adaptation is the **presence of both local and international companies, which are affected by climatic hazards**. For instance, the Bellandur watershed was chosen as a pilot project because of the presence of corporate firms around it, who are concerned about it (Khanna, 2013)[29]. Similarly, JICA noted how the Bangalore Water Supply and Sewerage Project would also benefit many Japanese companies operating in the Bangalore metropolitan area[30]. In addition to this, adaptation in Bangalore seems to be substantially **private-led.** As mentioned above, engineering consulting companies are proactively seeking involvement in the restoration of lakes. There are also innovative private efforts to green the city, although limited to private lands and real estates[31]. Within the context outlined above, there is **little or no consideration for ecosystem-based adaptation (EbA)** and **community-based adaptation approaches (CbA).** Some possible EbA options for Bangalore are discussed in Table 5.4.

Table 5.4 Ecosystem-based adaptation options in Bangalore

INTERVENTION	RISKS ADDRESSED	ECOSYSTEM-BASED ADAPTATION APPROACH
Storm water management	Flooding	Combining traditional storm water drain interventions with Sustainable Drainage Systems (SUDS)
Lake and wetland restoration	Flooding (improved drainage system); livelihoods; heat stress; quantity and quality of groundwater (groundwater recharge);	Ecological restoration which goes beyond mere engineering options (such as desiltation and cementing); protection of groundwater dependent ecosystems (wetlands); turning lakes into drinking reservoirs
Groundwater management	Water scarcity	Water harvesting and groundwater recharge through wetland restoration and green infrastructure.
Waste water treatment and reuse	Water scarcity and water quality	Neighbourhood-scale treatment and reuse, with lakes acting as water storage structures
Green infrastructure and UPA	Heat stress, flooding; livelihoods; ground water recharge	Urban afforestation and tree conservation with a focus on tree density, large canopy trees and other species that maximise ecosystem services.

Source: Ansems et al. 2014; Ramachandra and Mujumdar, 2009; Jamwal et al., 2014; Khanna (2013); Ramachandra and Kumar, 2010; Nagendra and Gopal (2010, 2011)

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29 http://bangalore.citizenmatters.in/articles/us-ngo-engineering-firms-want-to-revive-bellandur-lake?

30 http://www.jica.go.jp/english/news/jbic_archive/autocontents/english/news/2005/000024/attach.html

31 http://www.thebetterindia.com/12212/forest-backyard-sustainable-environment-afforestt/

5.3 Implications of Risk Management

5.3.1 Is Enhanced Risk Management Building Adaptive Capacity?

The evidence from adaptation projects suggests that risk management strategies at various scales and initiated by various actors, is helping build local adaptive capacity but this is not uniform across regions, sectors or scales. A study looking at urban vulnerability to flooding (Patankar, et al., 2010) found that risk management in Indian cities is still an individual or community level activity in the absence or deficit of planned adaptation. India's rural systems have seen relatively higher and longer investment in adaptation projects through direct CCA projects, as well as those that have adaptation co-benefits such as interventions for livelihood diversification, biodiversity conservation, sustainable agriculture, or natural resource management (CSE, 2014). Given the large development deficits and vulnerabilities of the rural poor, coping strategies to manage risk are more common than adaptive action (Singh, 2014). Examples of risk management strategies building adaptive capacity are discussed in Table 5.5.

Table 5.5 Examples of how risk management through watershed development builds adaptive capacity through better resource management, increased agricultural productivity, and livelihood diversification

RISK MANAGEMENT STRATEGY	IMPLICATIONS FOR ADAPTIVE CAPACITY	SOURCE
Watershed development in Shekta Watershed, Ahmednagar District, a rain shadow region of Sahyadris in Maharashtra	Impact assessment showed that watershed development was economically beneficial with a benefit cost ratio (BCR) of 1.5 and internal rate of return (IRR) of 16 per cent. Diversified farming systems with high-value crops and livelihood sources such as livestock rearing and micro-enterprise, benefited people in terms of increased crop yields, income, improved livelihoods, and reduced seasonal migration by 60 per cent.	Sreedevi et al. (2008)
Mandhwan in village of Ahmednagar district	Watershed development programme there is increase in net sown area, gross cropped area, area under irrigation, yield and ground water level among others.	Varat (2013)
Bahirwadi Watershed in Ahmednagar district of Maharashtra	The project was economically viable since the BCR is more than unity with an IRR of 3. Total income accrued per hectare from both crop production and livestock activities has shown an increase of 101 per cent with an overall B:C ratio of 1.59. Increased irrigation facilities and number of milch animals have enhanced annual employment of	Tilekar et al., 2009

	male and female workers by 43.19 per cent and 51.73 per cent, respectively.	
Participatory integrated watershed management programme approach in Sundarwadi Watershed, Paithan, Aurangabad district, Maharashtra	Development was not confined to agricultural lands, but started from the highest point of the area (ridgeline) to the outlet of the natural stream (ridge to valley). This involved implementation of ameliorative measures on barren hill slopes, marginal lands and privately owned farms. These activities resulted in increased livestock population, agricultural productivity, per capita income and drinking and irrigation water availability. It also helped in reduction in debt, workload of women, migration, and runoff.	Aher and Pawar (2013)
WOTR-implemented project in the Kumbharwadi watershed	Net Present Value (NPV) of the watershed development project in Kumbharwadi ranged from $5.07 to $7.43 million, which equates to benefits of $5,573 to $8,172 per hectare treated or $29,650 to $43,479 for each of Kumbharwadi's 171 households. The benefit-cost ratio ranged from 2.28 to 3.76.	Gray and Srinidhi (2013)
Impact of watershed management projects in semi-arid tropics within India	Watershed development activities have had a significant impact upon ground water recharge and access resulting in the expansion of irrigated area.	Palanisami, et al., 2011
National Mission on Micro Irrigation in Tamil Nadu which incentivised installation of sprinkler irrigation	During 2012-13 there was an increase of 30-50 per cent in productivity, due to adoption of high yielding/hybrid seeds, micro irrigation and fertilisation in vegetables, turmeric, banana	MoEF 2005

In urban areas, the national urban renewal program has focussed attention on provision of Basic Services to the Urban Poor (BSUP), which includes enabling security of tenure at affordable prices, improved housing, water supply, sanitation, and reliable service delivery through convergence of existing universal services for education, health and social security. The implications of these interventions on adaptive capacity and future adaptation are still understudied and remain to be examined.

5.3.2 Are Some Strategies Potentially Maladaptive?

In recent times, mainstreaming CCA into development efforts (by the state, civil society, and international development organisations) is increasing because of enhanced awareness of climate change impacts across regions and sectors; global policy and research focus on addressing climate change; as well as enhanced financial support for understanding and addressing current and future climate change. In India, this mainstreaming is witnessed in a) national-level policy planning and narratives (Section 5.1.2), b) multi-scale (but predominantly local) risk management practice through international actors who undertake multi-sectoral projects (Section 5.3.4 and 5.3.5 and c) individual and collective risk management strategies. It remains to be seen whether CCA mainstreaming this is better done as a bottom-up process through which successful community-based strategies are scaled up, or as a top-down process through national-level planning (Wright et al., 2014).

Identifying certain pathways and strategies as maladaptive is tricky because of temporal issues (the impacts of certain decisions may not be apparent immediately), spatial issues (trade-offs between catchments within a larger river basin) and data insufficiencies (accurate trade-off analysis of interventions is missing/unclear). A potential maladaptive strategy at the **individual scale** is indiscriminate use of groundwater for irrigation, which is driving resource scarcity, pushing up agriculture input costs, locking people into an energy-intensive, diesel-dependent pathway, thus becoming unsustainable in the long run (Shah, 2009). The incentivising of farm ponds by the government is also potentially maladaptive (Box 5.8).

Box 5.8

Subsidised construction of farm ponds as a potentially maladaptive strategy in Maharashtra

Farm ponds are traditional water harvesting structures located on farmland fed by surface run-off from its catchment. Water from farm ponds is drawn through a gravity outlet/pump, depending on its location. Benefits of the farm ponds include improvement in land productivity, supplemental irrigation to crops and embankment plantation, reduced water logging in high rainfall terrains, harvests good quality water to irrigate crops on salt affected coastal area and fish culture when sufficient water is available. The Maharashtra Government through MGNREGA and the National Horticulture Mission has been promoting the farm ponds and targeted to achieve 70,400 FPs during 2009-2010.

The traditional design of the farm pond is to harvest rain water, with an inlet and outlet to allow runoff to ingress in the pond and outlet to let excess water flow. In practice, farmers pump groundwater to fill the structures and then irrigate farms either by gravity flow or by pumps. The farm ponds are thus converted into storage tanks. This has become popular among many large farmers who can afford to invest their part of the contribution. The dimensions of the tanks have also started increasing depending on the farmer’s affordability, leading to a possibility that water losses might have increased due to surface evaporation and reduced ground water availability for the adjacent land owners. These water losses and transfers are poorly understood but present a situation of a policy intervention possibly incentivising maladaptive behaviour.

At a **watershed scale**, rainwater harvesting upstream may have negative repercussions downstream (Bouma et al. 2011). At an **SES scale**, an increasingly input-dependent agricultural system that favours cash crops over local, hardy crops such as millets is inherently unsustainable and maladaptive in the long run since it increases the system's sensitivity to disease incidence, climatic stresses, extreme events, and market fluctuations (Singh, 2014; O'Brien et al., 2004). In Maharashtra, increased access to irrigation facilities (wells and canals) in Ahmednagar district has increased acreage under commercial crops. Thus, the traditional subsistence agricultural structure is transforming into a market oriented, semi-commercialised farming system (Rede et al., 2013).

At a **national scale**, India has an ambitious river linking project designed to transfer water from the potentially water surplus rivers to water scarce Western and Peninsular river basins (Amarasinghe, 2012). Given that this inter-basin transfer of water can potentially alleviate water inequalities, it has been severely criticised for 1) not addressing rehabilitation issues lead to displacement of about 5.5 million people, most of them tribal and farmers, 2) environmental damage (change in hydrology and ecological conditions and submergence of land), and 3) causing structural alterations that could alter traditional coping mechanisms (Nigam, 2014).

In urban centres such as Bangalore, potentially maladaptive processes include:

- **Unplanned urbanisation:** While indiscriminate construction on lake beds has ostensibly led to more housing, it has caused declining ecosystems services such as water storage and recycling provided by erstwhile lakes (CDKN, 2014).
- **Location of infrastructure:** The development of Bangalore's airport far from the main city is leading to the development of a growth corridor to the airport but since the area is water stressed, it has resulted in unsustainable groundwater extraction.
- **Poor water provisioning:** Bangalore's informal water tanker market operates prevalently in the newly added villages and 'revenue layouts' along its periphery that lack Bangalore Water Supply and Sewage Board (BWSSB) supply network. Such self-supply and private supplies are exacerbating groundwater depletion which is a maladaptive trajectory[32].

While mainstreaming climate risk management into existing development programmes is critical, evidence shows that it may not be sufficient to reduce vulnerability (Wright et al., 2014). Reflecting on mainstreaming adaptation in agriculture, Wright et al. (2014) suggest moving beyond 'climate-proofing' agricultural development towards addressingf poverty and vulnerability drivers holistically.

[32] http://cseindia.org/userfiles/bangaluru_portrait.pdf

5.4 Barriers and Enablers of Adaptation

To map the different barriers and enablers of adaptation in SARs in India, a systematic literature review of peer-reviewed articles was conducted. Examples of best practices from grey literature such as NGO reports were also reviewed. Adaptation projects relevant to the study areas were analysed and inputs from WOTR's field experiences were used to enrich this section. A list of the papers reviewed can be found in Annex 5.6.

Multiple factors constrain adaptation planning and implementation (IPCC, 2014a). These barriers may limit the range of available adaptation options and the nature of climate change itself can make some barriers more persistent, accentuate other barriers, and trigger the emergence of new barriers (Biesbroek et al., 2013). General impediments to adaptation relate to physical, biological, economic and financing, socio-cultural, governance and institutional, knowledge-awareness and technological, and cognitive barriers (Adger et al., 2007; IPCC, 2014a). The following sections discuss these barriers.

5.4.1 Physical and Biological Constraints

- **Transformations and regime shifts:** Climate change may lead to transformations of the physical environment, which may consequently constrain adaptation (Adger et al., 2007). For example, climate change will lead to land degradation and acute water stress conditions in arid region of India (GoI, 2004). This in turn will influence crop yields and livelihoods of smallholder farmers.
- **Present adaptation choices affect future options:** Future adaptation options and their costs of implementation can be constrained due to past decisions on the built environment and its need for continual maintenance. The effectiveness of adaptation can be constrained due to the loss of local knowledge around thresholds in ecological systems (Folke et al., 2005). For example, eroding local knowledge on managing drought risk through traditional farming or food practices can reduce the number of contextual and highly localised options available in the future.
- **Resource availability and access:** Population growth and economic development can constrain adaptation in regions where livelihoods are closely linked to ecosystem goods and services (IPCC, 2014a). The intensification of groundwater use for agriculture in arid regions of India will lead to resource depletion, secondary salinisation and depleted quality of groundwater (Shah, 2009) influencing the stability of farming livelihoods in the face of hydro-climatic variability and hence their capacity to adapt. Soil degradation and desertification reduce crop yields and resilience of agricultural and pastoral livelihoods to deal with future change (Lal, 2011).

5.4.2 Economic and Financial Constraints

- **Restricted access to financial capital** can challenge the implementation of specific adaptation strategies and options (IPCC, 2014a). For example, the utility of insurance as a risk transfer mechanism can be constrained due to reduced accessibility and/or increased costs of insurance.

- **Economic development and urbanisation** may increase vulnerabilities by increasing pressure on natural resources and ecosystems (Titus *et al.*, 2009). Certain economic enterprises may be economically profitable but could constrain adaptation and aggravate vulnerabilities (Adger et al., 2007). For example, although sugarcane farming in Karnataka is economically profitable it is water intensive, which aggravates vulnerability.

- **Lack of adequate resources** limits the ability of low-income groups to afford proposed adaptation mechanisms like climate-risk insurance. Farmers are often unable to benefit from adaptation measures, which involve significant investment such as irrigation systems, improved or new crop varieties, and diversification of farm operations (Adger, 2007; Patnaik, 2010). In India, microfinance as a risk management mechanism is led by profit-driven commercial firms (Humle and Maitrot, 2014) which charge usurious interest rates (Ventures, 2011). While index insurance is valuable to business entities and local governments, they might not be effective for individual farmers (Ramaswami, 2010).

5.4.3 Social and Cultural Constraints

These arise due to different perceptions of risk, values, and normative behaviour (Jones, 2010). Social discrimination can restrict adaptation action (Box 5.9). Studies from Nepal and India report that adaptation decisions involving women can be constrained by cultural and institutional pressures that favour male land ownership (Jones and Boyd, 2011) and limit access to hazard information (Ahmed and Fajber, 2009).

Box 5.9

Social and cultural constraints to adaptation in South Asia

Traditional and existing cultural norms and practices along lines of caste and gender may exclude certain people thereby exacerbating existing vulnerabilities:

Caste as a barrier: Studying local adaptation in semi-arid Rajasthan, Singh (2014) found that farmers are constrained by socio-cognitive barriers. Due to a history of socio-economic and political isolation, tribal farmers perceived themselves as more vulnerable than upper caste, educated farmers.

Gender as a barrier: In South Asia, cultural norms, increase female vulnerability to flooding, resulting in a disproportionate amount of female deaths (Chowdhury et al., 1993).

5.4.4 Governance and Institutional Constraints

Governance in much of South Asia and India is fragmented, making coordination across different agencies and scales challenging. Cities in particular accumulate and generate new risks through unplanned development and deepening inequality, are vulnerable to food, energy and water fragility and consequent social and political unrest. Planning, including for risk management, often takes place at higher levels of government, while the role of local bodies, civil society and communities tends to be that of implementation with little room for innovation. These challenges undermine their potential to foster inclusive and climate resilient development.

- **Multiplicity and redundancy**: Multi-scale governance networks that include multiple actors and institutions challenge adaptation planning and implementation through lack of policy guidance, limited coordination between levels, and lack of available governmental resources (Biesbroek, 2013). For example, disaster risk management for drought in India displays a lack of coordination in government departments (Prabhakar and Shaw, 2008). In cities, traditional institutional mechanisms are ineffective in governing a diverse range of actors. Municipal authorities lack the jurisdiction needed to tackle environmental challenges. Decision-making is often overlapping and fragmented. There is also an absence of effective mechanisms for citizen involvement in decision-making (CDKN, 2014).
- **Fragmented governance:** Fragmented governance where different actors have different objectives, jurisdictional authority, and levels of power or resources make reducing risk challenging (CDKN, 2014). Local governments and administrations often consist of different sectoral and professional silos with their own internal norms, values and priorities. The institutional rigidity of existing administrative and political sectors creates compartmentalisation where CCA is seen as the isolated task of a singular sector which may hinder the mainstreaming and horizontal coordination across sectors and departments (IPCC, 2014a; Dubash and Jogesh, 2014; GoI, 2013).

- **Top-down approaches:** Local bottom-up initiatives on adaptation are constrained and vulnerabilities are masked by government driven, top-down approaches. Since planning often takes place at higher levels of government, local bodies, civil society, and communities tend to play a role in implementation with little room for innovation. Studying urban flooding in Mumbai, Patankar et al., (2010) found that moving from the national to state to city level, there is devolution of functional aspects without a simultaneous financial decentralisation. Therefore, local municipalities have the power but not the money to undertake adaptation action. This lack of proper municipality-led adaptation drove private/individual adaptation.
- **Institutional rigidity:** Climate adaptation efforts are often embedded in existing policies, and thus not framed as climate adaptation actions (Berrang-Ford *et al*., 2011; Dubash and Jogesh, 2014). Institutional rigidity also takes the form of path dependency where past policies, decisions, habits and traditions, constrain the extent to which systems can learn or adapt to climate change (IPCC, 2014a). In India, this was seen in the formulation of State Action Plans on Climate Change where new goals (adaptation to climate change) are being undertaken by the existing state-level bureaucracy using existing governance and development planning processes. Since the local political and bureaucratic actors drive this planning process, the SAPCC process potentially excluded participation from multiple and less empowered actors (Dubash and Jogesh, 2014).
- **Low capacity to deal with unprecedented changes:** Existing institutional arrangements may not be sufficiently equipped to handle new shocks such as within and across-country migration in India resulting from sea-level rise (Byravan and Chella Rajan, 2009).
- **Absence of certain actors and sectors:** Ganguly and Panda (2010) note that sectors such as food security, rural and urban housing for the poor, and health and education infrastructure have received inadequate attention in policy development. They also find that regional priorities and needs are sometimes subverted which increases inequities. The lack of knowledge exchange between think tanks and grassroots organisations in India results in weak representation of such actors and their opinions in policymaking (Mandal, 2014).

Governance as a barrier is peculiar since it acts as a constraint on its own as well as a barrier that can diffuse into and exacerbate other barriers.

5.4.5 Knowledge, Awareness, and Technology Constraints

Technological adaptation solutions may not be economically practical or culturally acceptable options (Adger et al., 2007), are sector specific (IPCC, 2014a) and contextual. Knowledge deficits may arise due to the challenges regarding decision-making under uncertainty about the future. Information on climate change (causes, impacts and potential solutions) does not essentially translate into adaptation solutions and barriers include availability of usable information and using information for decision-making (Adger, 2007). Specific barriers within the Indian context include:

- **Lack of locally downscaled climate information** (Kumar et al., 2010), and poor data on state-level climate vulnerability and sectoral impact assessments (Patra, 2014). For example, the Government of Andhra Pradesh highlighted knowledge constraints in its State Action Plan on Climate Change as lack of awareness on climate change issues and its impacts among rural and urban populations (GoI, 2012).
- **Limited knowledge of adaptation costs and benefits** (Agrawala and Frankhauser, 2008). There is even less evidence of the actual costs of ecosystem based adaptation (Kumar et al., 2010)
- **Lack of information about government schemes or policy provisions** can affect benefit or access to subsidies (Chatterjee et al., 2005).
- **Lock-in pathways:** Green revolution technologies have locked-in Indian agricultural systems into a trajectory of input-intensive farming, which has repercussions on future adaptation options (Singh, 2014, Thompson et al., 2007).

5.4.6 Examples from Sub-regions

5.4.6.1 Barriers and Enablers of Adaptation in Tamil Nadu

Studies indicate that adaptation to climate change is already occurring in Tamil Nadu but on a limited basis. Planned adaptation strategies are often coupled with or carved out of existing development strategies. Studies conducted in and around the Tamil Nadu sub-region indicated that major impediments to adaptation include governance and political factors including power relations and access to resources (CSTEP, 2014).

- **Sustainable, climate-smart agriculture:** There are various government interventions aimed towards climate change adaptation particularly in the agricultural sector such as crop insurance schemes, precision farming projects, System of Rice Intensification (SRI) promotion, and input supplies (Palinasamy, 2009). Most of these programs had a low level of success due to a range of impediments including low awareness of adaptation methods, lack of government support, limited presence of cooperating formal institutions including farmers associations and societies and lack of inter- and intra-community knowledge sharing (Climadapt, 2013; Palinasamy,2009; Geethalaxmi et al. 2011).
- **Social learning:** Emphasis on social learning is essential for successful implementation of adaptation strategies. Government policies play a crucial role in the success and uptake of adaptation strategies. Governance issues around water resource strategies such as effective resource management and conflict resolution institutions are a major impediment of farmer uptake of adaptive water-saving techniques (Senthilkumar et al., 2008).

Box 5.10

Case study of successful adaptation in the Moyar-Bhavani Transect: Adaptive water resource management in the lower Bhavani Basin

The Lower Bhavani Project (LBP) diverts water from the Bhavani river. It was the first major irrigation project implemented in India after Independence in 1947 and was fully operational in 1956. Since the implementation of the LBP farmers and authorities in the area have adapted to the available water resources relative to the size of the area and the environmental conditions of the command area. An example of this was the establishment of wells in the command area for conjunctive use to increase the reliability in timing of water supply, and balance seasonal and annual water scarcity. The water allocation and cropping systems established in 1964 was an effective mechanism to adjust to the limits and seasonality of nature in the area. These strategies along with capacity building and social learning have ensured improved resilience of the area to the effects of climate change. The LBP case study is a positive example of water management. The importance of social learning and understanding of complex adaptive systems was a crucial factor in the success of the lower Bhavani Basin Water Resource Management project, in spite of contending with an imperfect irrigation system design and intense competition for water resources. Water resource managers and farmers are able to adapt and continue to reap benefits from a productive agricultural system (Lannerstad and Molden (2009).

5.4.6.2 Examples of Adaptation in Sangamner

- **Changing agricultural practices:** Many researchers suggested that crop diversification could certainly be thought of as a possible adaptation to climatic variability and change. Improved agricultural practices such as System of Crop Intensification (SCI) could help in tackling water scarce situation (WOTR, 2014). SCI is an adaptation of the SRI method to other crops where the rationale of crop specific spacing is used to enhance crop productivity. Along with crop spacing, systematic soil preparation and application of locally prepared organic inputs and micronutrient foliar sprays increase productivity. WOTR has been making efforts to orient and build capacities of the farmers towards SCI approach. According to Gangwar and Singh (2011), the yield gaps in *kharif* and *rabi* sorghum were to the extent of 5 to 10 q/ha while in onion crop the bridgeable gap is about 64 q/ha. The recommended alternative cropping system for this region was to adopt soybean-onion, soybean-wheat and pearl millet-chickpea cropping sequences with two to three protective irrigations at sensitive growth stages of the crop. Even though these are recommended, the farmer's preferences are guided by market factors.

- **Integrated water management:** Gray and Srinidhi (2013) describe watershed development programs aim to restore degraded watersheds in rainfed regions to increase their capacity to capture and store rainwater, reduce soil erosion, and improve soil nutrient and carbon content so they can produce greater agricultural yields and other benefits. Therefore, the watershed development approach inherently improves the resilience of the local ecosystems and production systems, which in turn sustain the rural livelihoods. Interventions in Kumbalgarh, Maharashtra demonstrate how watershed development can help crop diversification by improving water availability, and increase incomes through improved productivity (WOTR, 2013; 2014). Micro-irrigation method includes irrigation through drip method and sprinkler method. The conveyance and distribution losses are reduced completely which result in higher water use efficiency under micro-irrigation (Narayanamoorthy, 2007). Drip irrigation has a significant impact on resources saving, cost of cultivation, yield of crops, and farm profitability (Kumar and Palanisami, 2010). Improving water use efficiency through micro-irrigation methods would greatly enhance water productivity as compared to the flood irrigation method.

- **Knowledge and information sharing:** Information and Communication Technologies (ICT) help in disseminating key messages related to weather parameters, production related extension support and market information to the farmers. Such agro- advisories contribute to reducing risks to the farmers by enhancing preparedness and taking pre-emptive measures in the event of prolonged dry spells, advent of pests and diseases or even general good management practices to increase yields. Examples of such initiatives include weather-based crop advisories by Indian Council of Agriculture Research (ICAR), mobile phone-based agri-information service providers such as IKSL (Indian Farmers Fertiliser Cooperative Kisan Sanchar Limited in partnership with Bharti Airtel, Reuters Market Light (RML), and fisher friend program by Qualcomm and Tata Teleservices, in partnership with the MS Swaminathan Research Foundation and WOTR. More details on WOTR experiences in the transect area can be referred to in Chapter 5.

5.4.6.3 Examples of Adaptation in Bangalore

Bangalore demonstrates increasing mainstreaming of adaptation in development planning. The recent Revised Master Plan for Bangalore 2035[33] aims to do an assessment of physical, social, economic and environmental vulnerabilities; leading to an integrated risk multi-hazard risk assessment and an identification of hazard hot-spots in the city. Some barriers especially related to governance and capacity remain (Box 5.11).

Box 5.11

The role of the private sector, academia, and civil society in overcoming local government constraints: a case study of state CCA planning in Bangalore

Interconnected environmental risks in growing cities will require them to coordinate diverse range of actors (intergovernmental organisations, development agencies, multinational companies, public or private sector institutions, state authorities). Traditional institutional structures have proven ineffective at governing this diverse range of actors. Many cities have demonstrated how creative partnerships (public, private, and third sectors) play an important role in responding to environmental challenges. Bangalore exhibits how effective the private sector and civil society prove to be when the authority and capacity of local governments is limited.

The Bangalore Development Authority (BDA) is understaffed with limited political support and financial resources. This has constrained the government's ability to deal with risks such as urban sprawl and tackling the escalating intensity of energy use, which in recent times is being attempted to resolve by a number of private initiatives. Illustrative examples of which are innovative shifts to green design, and emergence of a number of city level actors (Karnataka State Council for Science and Technology and Centre for the Study of Science, Technology and Policy) engaging in city level interventions such as energy efficiency, rainwater harvesting (limited space), train farmers and help link them to policymakers (CDKN, 2014).

5.4.7 Overcoming these Barriers

Adaptation barriers can be overcome avoided or reduced by individual or collective action with concerted effort, innovative management, changed ways of thinking, political will, and reprioritisation of resources, land uses, and institutions (Eisenack et al., 2014). A few examples of overcoming barriers include understanding and addressing the underlying causes of these barriers better through capacity building, collaborative projects through informal partnerships and formal interagency working groups (Pelling et al., 2008; Rouillard et al., 2012), clear assignment of responsibilities in adaptation decision making (Runhaar et al., 2012; Mukheibir et al., 2013), interaction between actors at all levels, and policies promoting and incentivising adaptation measures.

[33] http://www.bdabangalore.org/tpm-rmp_2035_qcbs_300512.pdf

5.5 Key emerging research and information gaps

Through an intense literature review process and insights from key informant interviews, major gaps in research and information have been identified. These gaps are listed below:

1. There is limited evidence on adaptation planning, particularly in the Indian context, that coherently addresses multiple challenges as well as recognises local, regional and national dynamics. These challenges range from identifying multiple stressors and their determinants to recognizing a huge flux in development transitions, especially in the rural-urban corridors.
2. There is insufficient understanding on how different actors address adaptation planning at different levels (at the levels of individual, household, community). Further understanding on interactions at each level, such as the interlinkages of national and regional priorities, sectoral linkages between agriculture, water and livelihoods, is needed.
3. There is a lack of adaptation planning that addresses contiguous landscapes. In the Moyar-Bhavani sub-region, for instance, the semi-arid landscape is surrounded by sub-humid and humid landscapes and the climatic impacts are differentially experienced. Experts have suggested that landscapes of such contiguous variety should be studied together rather than in isolation so as to understand the social dimensions of impacts. Unfortunately, adaptive responses are usually corrective and local in nature and lack longer term perspective and therefore, adaptation planning needs to choose a larger spatial reference for effectivness and impact assessment. For instance, there is an urgent need to study the wider processes underlying conservation planning around biodiversity, land-use management and associated incentive mechanisms, which are financial and otherwise.
4. There is insufficient understanding how people and their livelihoods can be secured through measures such as sustainable crop management practices. These management practices do not involve large-scale technological changes, but focusing primarily on local effective farming practices, controlling the sowing dates, soil management, among others.
5. There is limited understanding on how local adaptation strategies can be scaled up. Most adaptation initiatives are localised and have the potential for widespread implementation. For e.g., some rural areas have effectively implemented effective resilient agricultural practices with adequate market linkages. These efforts may have succeeded in some locations but its replication in other contexts might require certain changes in the technical and legislative response of regional governments. It is these barriers and enablers that need to be identified to develop adaptation strategies for widespread use.
6. There is a need to understand the utility of creating tailored climate-messages that are sufficient to create adaptive responses, while also maintaining a balance between immediate and long-term strategies, including modifying current adaptation practices (such as the use of agromet advisories) to enable large scale

uptake and scale. The medium to long-term climate information available for decision making, along with identification of appropriate institutional linkages, lacks evidence and is insufficiently tested in the Indian context.

7. There is a need to create more evidence on how institutional innovations (such as the role of communities in developing and participating in informal pooled insurance or formal weather insurance services) and associated risk sharing and transfer mechanisms (formal or informal) can foster effective, widespread and sustained adaptation response.
8. There is a need to create an evidence-based understanding on how trade-offs between diverse adaptation practises are determined and appraised, in order to enable adaptation mainstreaming. These trade-offs refer to the burden of negative and positive impacts on participants, mostly economic in nature (mostly studied in the agriculture sector). Further, the trade-offs have to be simultaneously understood in the context of disturbing the existing socio-ecological system (in the case of Bangalore sub-region, for instance; large scale development in primarily rural peri-urban areas have disturbed the local ecological systems and thereby have impacted the hydrological capacity of the sub-region) and its impacts. There is also insufficient evidence in highlighting certain solutions within the existing socio-ecological systems, which might create certain trade-offs for all. For e.g., the trade-offs between understanding hydrological disorders through a human intervention in the upstream of a river-basin and the corresponding hydrological impacts downstream.
9. With specific reference to the agriculture sector, there are key research gaps. These include the effectiveness of waste land and soil management, the impact of planting new crop varieties and effects of crop diversification, effectiveness of value addition to farm produce, impacts of introducing post-harvesting techniques such as grading for better sale, impact of introducing unique market linkages, the role of institutions in adaptation effectiveness, the usefulness of small processing implements at village scale and effectiveness of linked livelihood diversification strategies such as poultry farming and other non-farm service activities.
10. Weather-based insurance, including a more holistic farm income-based insurance mechanism, has emerged as a key risk mitigation strategy in recent times. Increasingly, farm-income based insurance mechanisms are gaining prominence, lending to the need for robust evidence for its mainstreaming as an effective adaptation strategy.
11. There is a lack of robust evidence on adaptation strategies that are locally embedded and relies on traditional practices, local perceptions, willingness and ability. This is especially relevant in the context of agricultural and water management practices.
12. The lack of access to appropriate technology (including its identification) as a mediating variable for effective adaptation is considered to be a major barrier to

widespread adaptation. There is insufficient understanding within the local context of the technology-adaptation nexus.

5.6 Conclusion

The sub-region peculiarities and characteristics in the ASSAR project offers an opportunity to research on multiple contextual and interactive aspects, rooted in the nuanced understanding of sub-regional dynamics. While risk management in the rural setting is predominantly natural resource dependent and focussed on enhancing and diversifying livelihoods, the urban setting is complex, critical, and enmeshed within the continuum dynamics of rural to urban areas. Risk management, including the evolution of adaptation and conjoint adaptation-mitigation perspective, lacks evidence and is plagued with corrective short-term solutions without taking stock of how risks are managed (including the incidence of costs and benefits), amidst the interplay between the objectives of economic growth, environmental sustainability and social welfare. There is a severe lack of evidence on effective risk management practices in rural and urban areas; particularly in the context of ensuring scale, with lock-ins in inflexible institutional architectures.

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CHAPTER 6

Conclusion

Conclusion

As highlighted in the Introduction to this report, the RRP phase aims to help develop implementable plans of action to address key risks, impacts and vulnerabilities in the sub-regions of this research project. In doing so, it is recognised that three major developmental transformation options ('transformative adaptation') exist in India – to increase productivity of existing biophysical and socio-economic systems, or to create new sustainable livelihood forms and/or, shift population from fragile ecosystems to resilient ecosystems. In doing so, the developmental pathways should be able to sustain existing ecosystems (to some extent), respect embedded socio-cultural dynamics, innovate around governance and institutional structures, and respond to current and projected non-climatic and climate-induced risks. The RRP phase will therefore respond to the challenges highlighted above and focus on research that helps understand the barriers and enablers for effective medium-term adaptation better.

It is imperative that the RRP phase researches multidimensional vulnerability to stresses, explores shocks on human well-being (to ensure food, water and livelihood security, resolve resource conflicts and mitigate health risks), moves beyond narrow adaptation, and explores innovative transformative scenarios/solutions.

To summarize the findings in the RDS report, India's economic growth has been impressive, notably in the last two decades, but this has not translated into effective poverty reduction and balanced progress on other human development indicators. Environmental degradation, stagnant agricultural growth, rising regional and sub-regional inequality, poor quality and quantity of employment, and inadequate access to public services for the poor are some of the major national concerns. It is also noteworthy to highlight that the agriculture sector still remains the dominant livelihood source in India. Being primarily rain-fed, it is highly vulnerable to the changing climatic regime.

In the Bangalore sub-region, the local economy is based on the services sector and manufacturing, but over the last two decades, the informal economy and inequality has also equally flourished. Simultaneously, rapid population explosion mainly due to in-migration and increase in the built up area (particularly in the last two decades) has led to a substantial decline in environmental quality. The last decade has also observed serious conflicts between land use transformations and environmental conservation, with the city extending its spatial contours to neighbouring agrarian lands. Urban floods remain a common occurrence leading to loss of livelihoods and health hazards like malaria, dengue and fragile ecology of the city further endangers its economic sustainability.

The Sangamner sub-region is characterised by some of the lowest levels of agricultural productivity in SARs and rainfall here is below the national average. Traditional coarse cereals like pearl millet and sorghum, and fodder crops, are being replaced by cash crops such as soybean and cotton, thereby threatening regional food security. Water management is a key concern. Any additional water available through conservation efforts has been diverted to the production of water-intensive commercial crops, such as sugarcane. The regional government is experimenting with various participatory watershed management approaches for drought-proofing and these efforts have helped address farmer livelihood vulnerability. Dairy and livestock constitute a major part of the total agricultural output in the sub-region, but these are extremely vulnerable to climatic variability.

The Moyar-Bhavani sub-region in the state of Tamil Nadu is mainly a tribal belt (housing marginal communities) and agro-forestry and fisheries remain the main sources of livelihood. The sub-region often witnesses human-animal conflicts and the habitats are at risk due to relocation because of forest conservation efforts. The sub-region has also witnessed large-scale adoption of agricultural improvement programmes (with considerable success) such as System of Rice Intensification (SRI), Sustainable Sugarcane Initiatives (SSI), precision farming, the Millets Mission, System of Pulses Intensification (SPI). However, aggressive agricultural intensification is potentially projected to have diverse biophysical impacts and thereby lead to erosion of traditional methods of agriculture which might have been more resilient.

5.1 Regional Research Programme – Emerging Issues and Themes

5.1.1 Climate Trends in the Sub-region

The Indian monsoon has weakened in recent decades along with an increase in the frequency of intense precipitation events in some areas. Increasing trends in temperature and significant declines in precipitation were observed in Bangalore and Moyar-Bhavani ASSAR sub-regions, but temperature trends were more uncertain in the Sangamner sub-region. Precipitation in the Sangamner sub-region was observed to be highly variable and has increased modestly since the 1990s. High variability has been recorded in the contribution of sparse rain and moderate rain events in the Sangamner sub-region envelope while these events decreased in the Moyar-Bhavani and Bangalore-sub-region envelopes.

Despite intense analytical efforts at the sub-region level, researchers acknowledge that the production of reliable downscaled data may not be available with current models. Additionally, the spatial scale of currently available downscaled climate products (Regional Climate Models) may preclude its use in local decision-making. Further, regions neighbouring our research sites are located in sub-humid and humid areas, confounding the attribution of observed changes. In order to enhance the granularity of our analysis, we intend to explore statistical downscaling of climate projections during the Regional Research Programme (RRP) phase. Most studies that consider the impacts of climate on the biophysical environment are at large spatial scales and lack granular detail. This detracts from their use at smaller scales that are more relevant to local stakeholders. Additionally, understanding northeast monsoon behaviour (especially in certain ASSAR sub-regions) is a major gap that needs focused research. Studies on climate change impacts are impaired by lack of regional data.

5.1.2 Risk, Impacts and Vulnerability

We note that biophysical impact studies are also often limited in scope and restricted to the water sector and major agricultural crops (e.g., rice, wheat). Additional research is needed to understand climatic impacts on other natural and agro-ecosystems, relevant to the sub-region. Often, locally significant drivers such as land use-land cover change overwhelm the influence of climatic drivers. Research needs to assess trends in the response of coupled socio-ecological systems (social and climatic) to climate-induced perturbations at global and local scales. The risks to the sub-regions varies with geography and institutional, societal and governance norms. Since majorly dependent on natural resource-based systems are directly impacted by rainfall and temperature variability, climatic and non-climatic risks in the sub-regions are further exacerbated by the lack of institutional support and unplanned development.

In urban areas, climate risks include flooding, water scarcity (with impacts on food and water systems, infrastructure, health, natural ecosystem and biodiversity) are major areas to be studied in detail. Non-climatic risks in the form of poverty, inequality, inequitable access to resources, and a large dependence on the informal sector for livelihoods are some of the key emerging research themes. The major climatic risk in the Bangalore sub-region is occurrence of floods (outcome of intense precipitation) and lack of water availability, impacting households living in squatter settlements and employed in the informal sector (plagued with poor adaptive capacities). Climatic and non-climatic risks need to be studied in a holistic and inter-dependent frame of analysis, particularly in the urban context and in conjunction with the changes occurring in the larger rural-urban continuum.

In the sub-regions of Sangamner and Moyar-Bhavani, farmers with small land holdings, subsistence agriculturalists and indigenous communities with limited access to state-sponsored subsidies and welfare schemes are directly affected through reduction in crop productivity and risk to livestock. In the Sangamner sub-region, which is susceptible to drought, pastoral livelihoods are at risk. In the Moyar-Bhavani sub-region, pastoralist and tribal communities are devoid of access to basic amenities, lack availability of adequate health infrastructure, suffer from poor nutritional intake and inadequate financial resources, and are consequently at greatest risk. Women are much more vulnerable because socio-cultural inequalities translate into unequal pay, higher drudgery, and poor access, control, and ownership of land. In rural areas, crop failure usually affects women the hardest; increasing their workloads and reducing nutritional values, which has severe detrimental effects on their health and wellbeing. Building a comprehensive understanding on the determinants and drivers of key vulnerabilities – both in rural and urban areas of the sub-regions will be the major research theme in the RRP phase. By understanding some of the elements identified above, we expect to help identify key entry points for effective and widespread adaptation, particularly in the medium-term frame of reference.

5.1.3 Adaptation-Development Spectrum

Risk management strategies in the sub-regions and in semi-arid areas of India traverse a response continuum from short-term coping, to long-term adapting and finally, at a larger spatial and temporal transformation. However, addressing climate change vulnerability in India has been largely mainstreamed into the developmental agenda. Economic development and poverty alleviation are seen as major drivers for reducing vulnerability. Governance responses to critical vulnerabilities are fragmented, making coordination across different agencies and scales challenging. Planning often takes place at higher levels of government, with the role of local bodies, civil society and communities circumscribed to implementation with little room for innovation. The fiscal regime has also not been uniformly supportive in achieving large-scale vulnerability reduction.

There is limited evidence on adaptation planning, particularly in the Indian context, that coherently addresses multiple challenges as well as recognises local, regional and national dynamics. These challenges range from identifying multiple stressors and their determinants to recognizing a huge flux in development transitions, especially in the rural-urban corridors. Further, there is insufficient understanding on how different actors address adaptation planning at different levels and negotiate interactions at each level. Examples of these interactions are interlinkages between national and regional priorities and sectoral linkages between agriculture, water and livelihoods. There is also a need to understand the utility of creating tailored climate-messages that inform adaptive responses, while also maintaining a balance between immediate and long-term strategies. Medium to long-term climate information available for decision making, along with identification of appropriate institutional linkages, lacks evidence and is insufficiently tested in the Indian context.

There is also a need to create an evidence-based understanding on how trade-offs between diverse adaptation practises are determined and appraised, in order to enable adaptation mainstreaming. These trade-offs refer to the burden of negative and positive impacts on participants, mostly economic in nature (mostly studied in the agriculture sector). Further, the trade-offs have to be simultaneously understood in the context of disturbing the existing socio-ecological system (in the case of Bangalore sub-region, for instance; large-scale development in primarily rural peri-urban areas have disturbed local ecological systems and impacted the hydrological capacity of the sub-region).

With specific reference to the agriculture sector, there are key research gaps in evidence of the role of risk management practices in building adaptive capacity. These include the effectiveness of waste land and soil management, the impact of planting new crop varieties and effects of crop diversification, effectiveness of value addition to farm produce, impacts of introducing post-harvesting techniques such as grading for better sale, impact of introducing unique market linkages, the usefulness of small processing implements at village scale, and effectiveness of livelihood diversification strategies such as poultry farming. Weather-based insurance, including a more holistic farm income-based insurance mechanism, has emerged as a key risk mitigation strategy in recent times. Increasingly, farm-income based insurance mechanisms are gaining prominence, leading to the need for robust evidence for its mainstreaming as an effective adaptation strategy. There is a lack of evidence on adaptation strategies that are locally embedded and rely on traditional practices, local perceptions, willingness and ability. This is especially relevant in the context of agricultural and water management practices.

The RRP phase also aims to understand the forms of planned intervention and spontaneous innovation that have been effective, and which of these could potentially be deepened and/or scaled and in what potential sequence. The RRP phase also aims to understand the strategic institutional, technological and policy gaps which could be pragmatically filled so as to achieve meaningful transformation and simultaneously delineate the role and kind of principal agencies and processes that could take forward the (transformation) development agenda.

CHAPTER 7

Annexes

Annex 1.1. Map depicting semi-arid regions in India and the three transects

Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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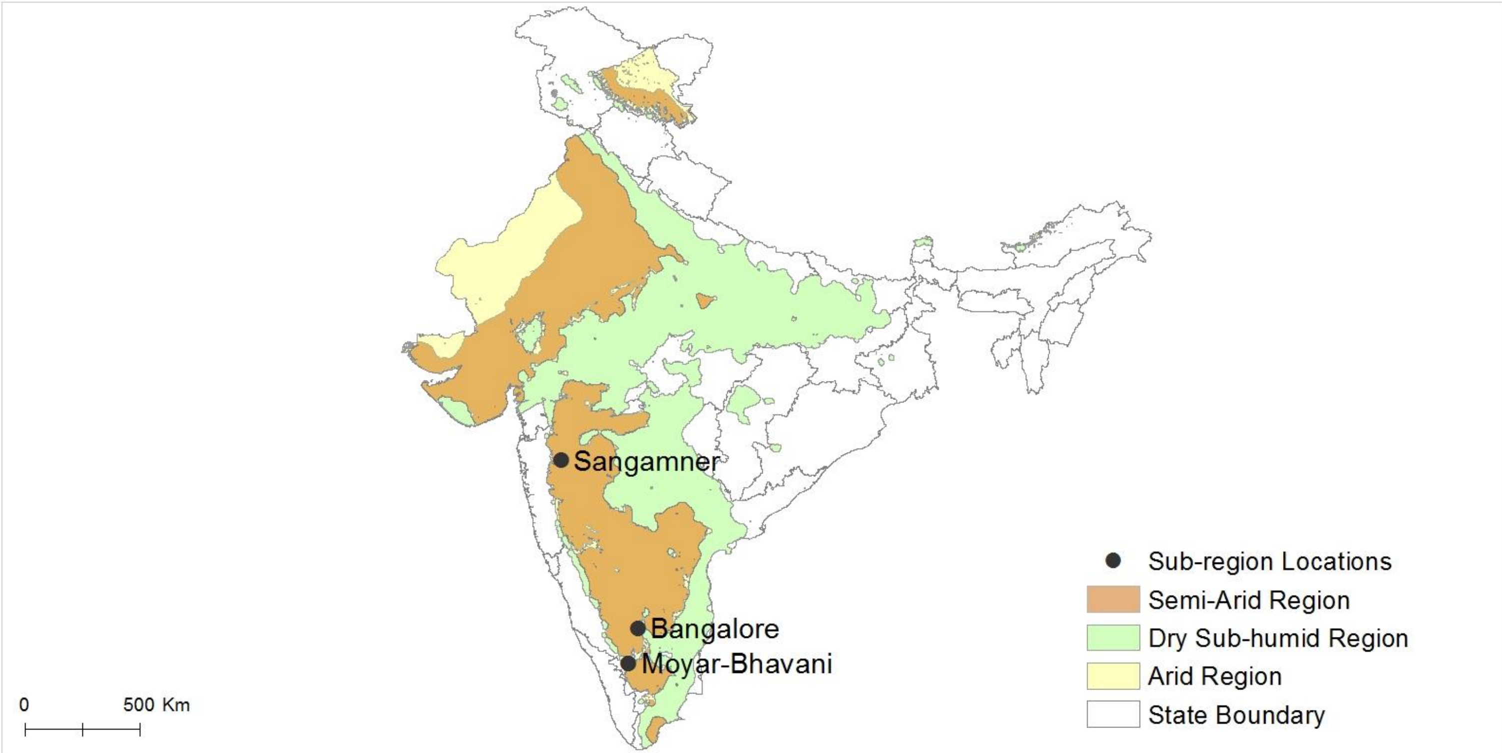
Arid, Semi-Arid and Dry Sub-humid Regions of India

Location of Sangamner, Bangalore and Moyar-Bhavani Sub-regions



Data Used, Year: Semi-Arid, Dry Sub-humid and Arid Regions - CGIAR Global Aridity Index; State Boundary and Sub-region Locations - IIHS GeoLibrary, 2015

Image used: NIL | Coordinate System: GCS WGS 1984 | MAP ID: CAR060315NLC04 | Date: 06-03-2015

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Annex 1.2 Details of Key-informant interviews carried out by IIHS

Name	Designation and Affiliation	Date of Interview
Dr. Sharachchandra Lele	Senior Fellow, ATREE (Ashoka Trust for Research in Ecology and the Environment)	5-Dec-2014
Dr. Veena Srinivasan	Fellow, ATREE (Ashoka Trust for Research in Ecology and the Environment)	5-Dec-2014
Dr. Jagdish Krishnaswamy	Senior Fellow, ATREE (Ashoka Trust for Research in Ecology and the Environment)	5-Dec-2014
Dr. Kirit Parikh	Chairman, IRADe (Integrated Research and Action for Development)	08-Dec-2014
Dr. Ulka Kelkar	TERI (The Energy and Resources Institute) Bangalore	16-Dec-2014
Dr. Arivudai Nambi Appadurai	Strategy Head, WRI (World Resource Institute)	17-Dec-2014
Dr. Shrinivas Badiger	Fellow and Programme leader, ATREE (Ashoka Trust for Research in Ecology and the Environment)	23-Dec-2014
Dr. Chandrashekhar S	*5.1.4 Associate professor, IGIDR (Indira Gandhi Institute of Development Research)*	5-Jan-2015
Prof. Sripad Motiram	Professor, IGIDR (Indira Gandhi Institute of Development Research)	5-Jan-2015
Prof. NH Ravindranath	Professor, IISc (Indian Institute of Science)	16-Jan-2015
Prof. Himanshu Pathak	Professor, NICRA (National Initiative on Climate Resilient Agriculture)	21-Jan-2015
Dr. Soora Naresh Kumar	Principal Scientist, NICRA (National Initiative on Climate Resilient Agriculture)	21-Jan-2015
Prof. AK Gosain	Professor, IIT- D (Indian Institute of Technology- Delhi)	21-Jan-2015
Dr. Jyoti Parikh	Executive Director, IRADe (Integrated Research and Action for Development)	22-Jan-2015
Mohan Rao	Principal Designer, INDE' (Integrated Design)	29-Jan-2015
Prof. A Damodaran	Professor, IIM-B (Indian Institute of Management-Bangalore)	2-Feb-2015
Prof. Raman Sukumar	Professor, Centre for Ecological Sciences, IISc (Indian Institute of Science)	03-Feb-2015
Dr. Vimal Mishra	Assistant Professor, IIT- G (Indian Institute of Technology- Gandhinagar)	12-Feb-2015

Annex 1.3 Map of Sangamner Sub-region, Maharashtra

Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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Sub-regions

Sangamner Sub-region | Area: 5255.8 sq. km

Data Used, Year: Sub-region Boundary - WOTR; Pravara Catchment - CGIAR Global Aridity Index; State Boundary, City Location, Sub-region and River - IIHS GeoLibrary, 2015

Image used: DigitalGlobe, GeoEye, Earthstar Geographics, USGS | Coordinate System: GCS WGS 1984 | MAP ID: CAR050315NLC03 | Date: 05-03-2015

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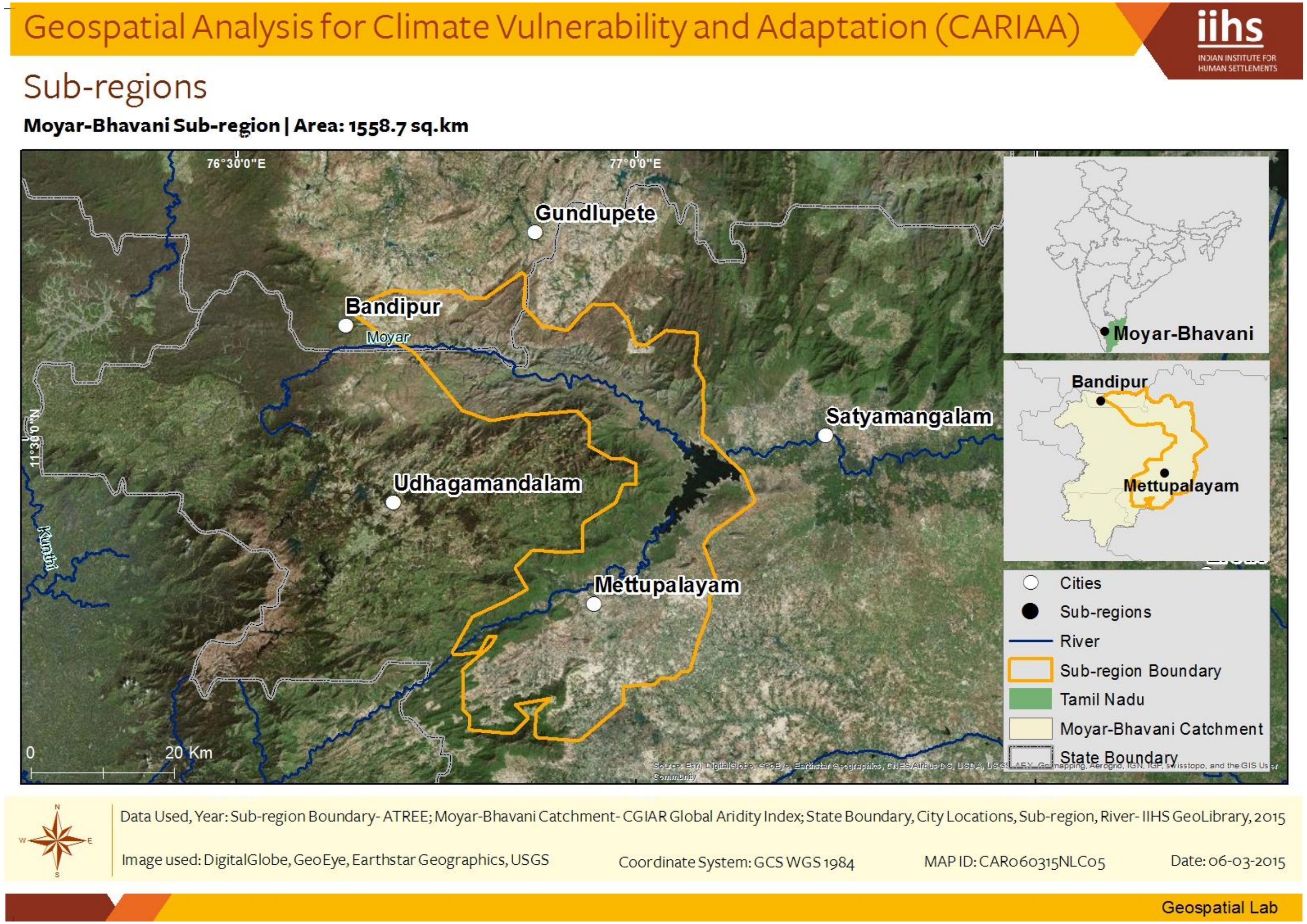
Annex 1.4 Map showing Moyar-Bhavani Sub-region, Tamil Nadu



Annex 1.5 Map of Bangalore Sub-region, Karnataka

Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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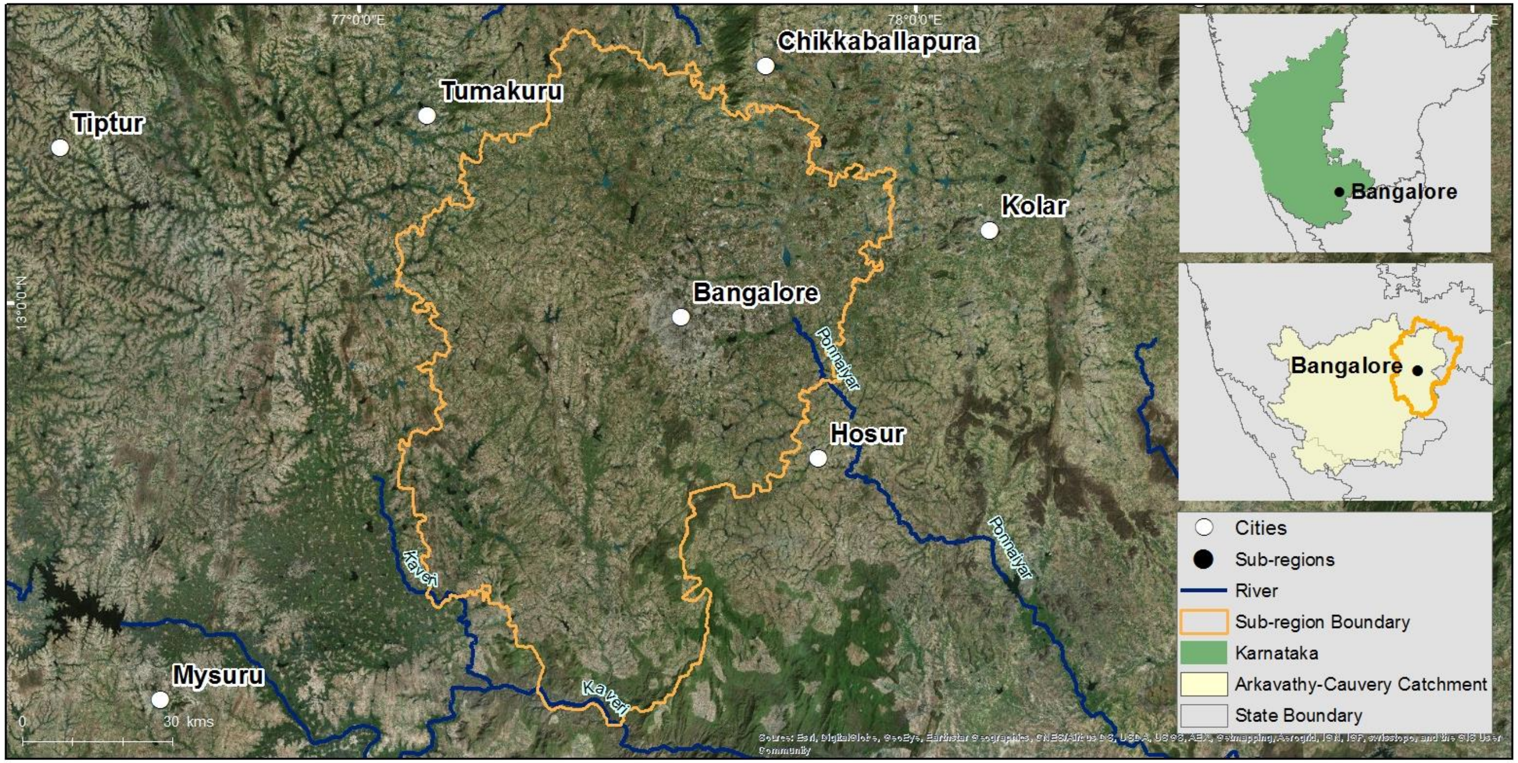
Sub-regions

Bangalore Sub-region | Area: 8017.2 sq. km



Data Used, Year: Arkavathy-Cauvery Catchment - CGIAR Global Aridity Index; State Boundary, Sub-region Boundary, City Location, Sub-regions & River - IIHS GeoLibrary, 2015

Image used: DigitalGlobe, GeoEye, Earthstar Geographics, USGS | Coordinate System: GCS WGS 1984 | MAP ID: CAR050315NLC01 | Date: 05-03-2015

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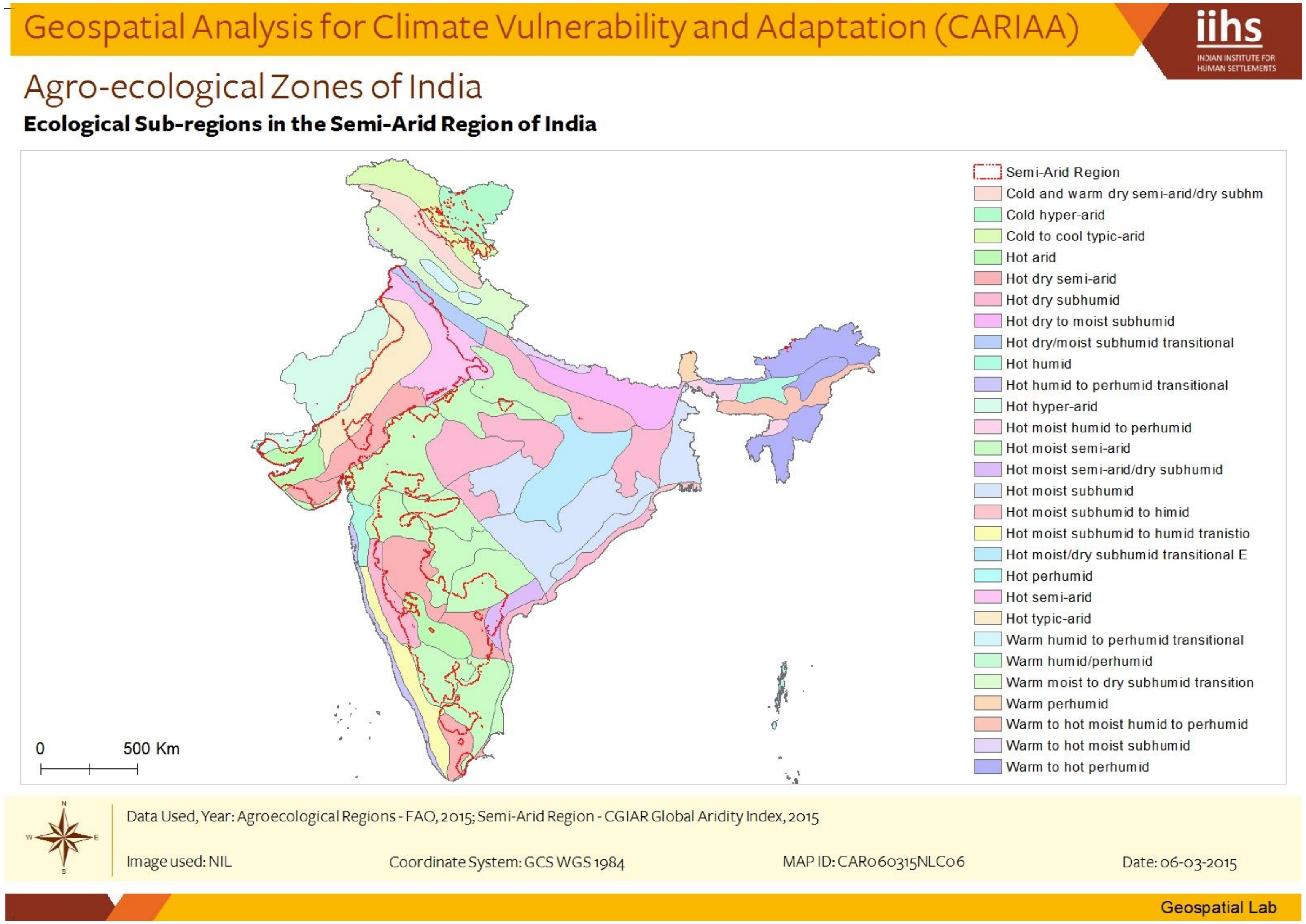
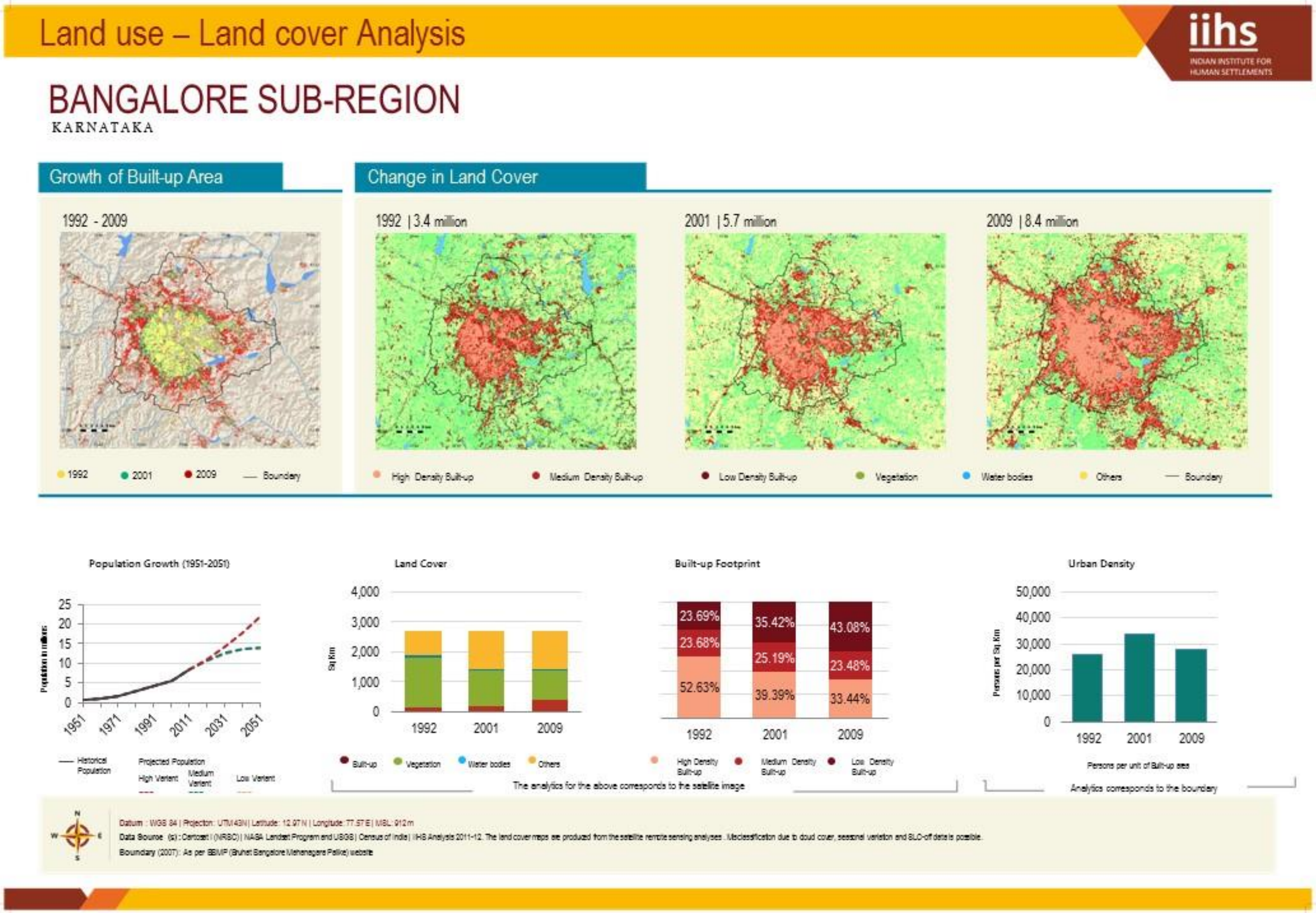
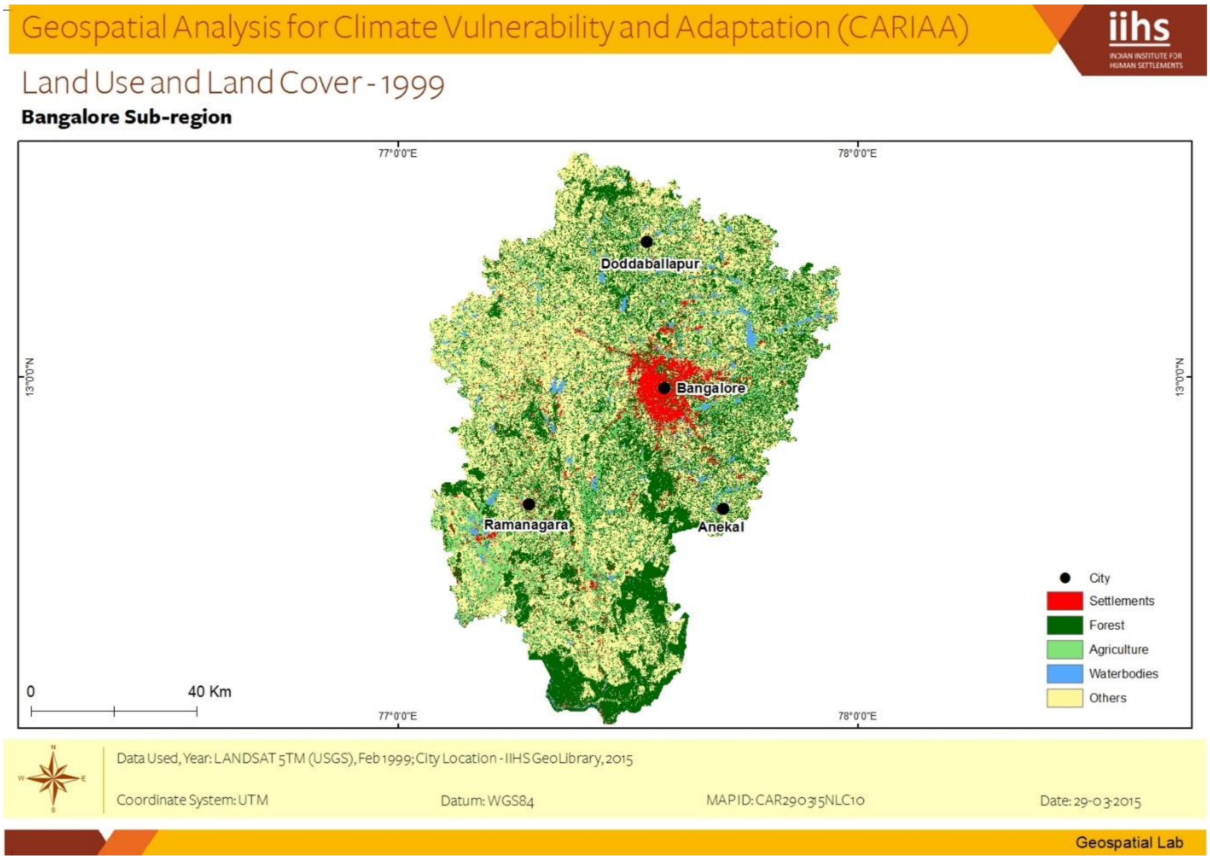
Annex 1.6 Agro-ecological zones of the semi-arid region in India

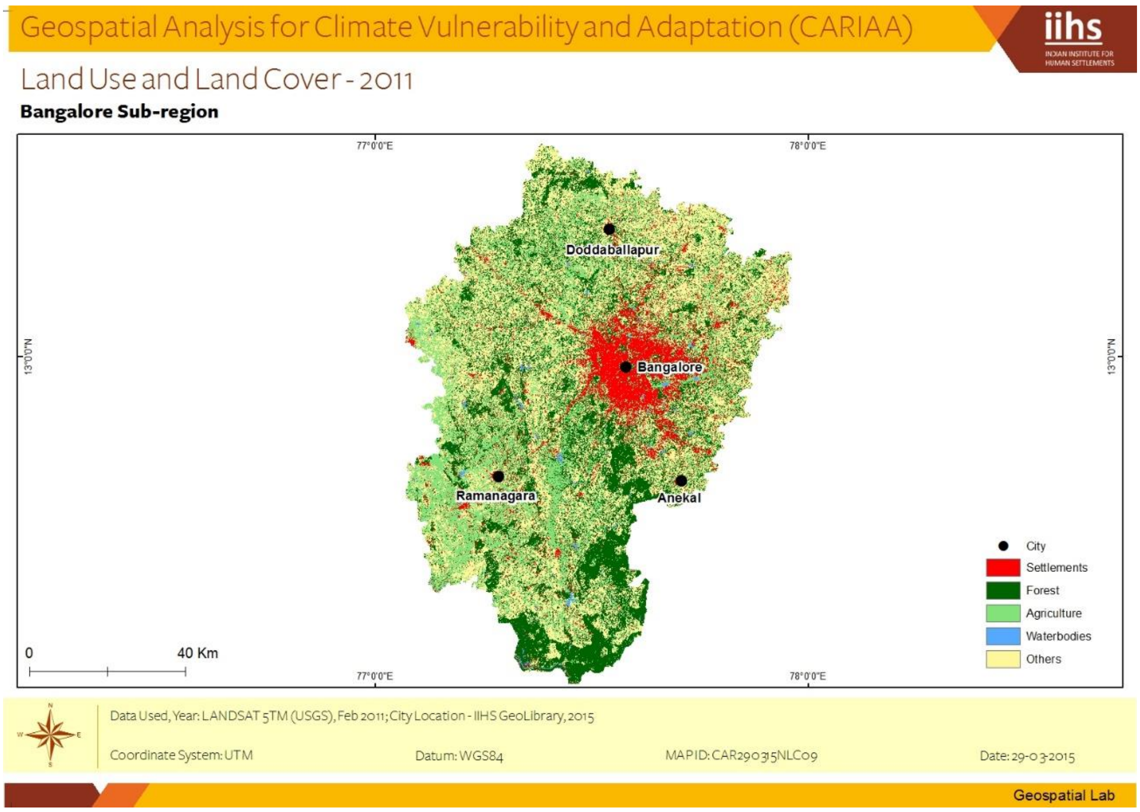


Annex 2.1 Characterizing the Bangalore Sub-region



Annex 2.2a Changes in the biophysical state in Bangalore, Sangamner, and Bhavani-Moyar sub-regions (1999-2011)





Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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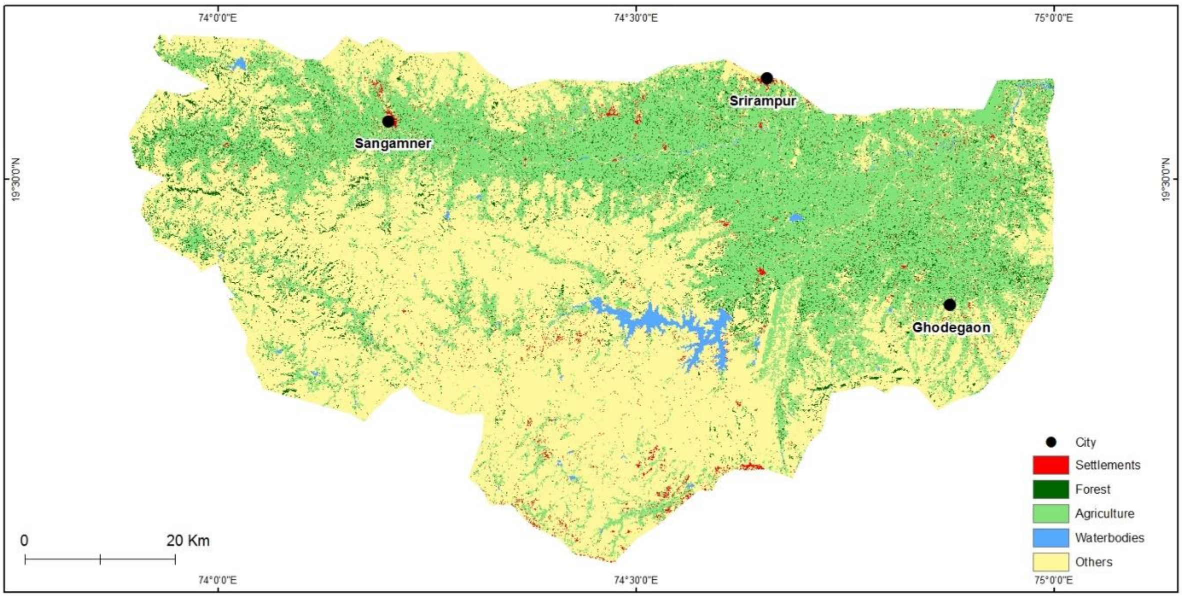
Land Use and Land Cover - 1999

Sangamner Sub-region



Data Used, Year: LANDSAT 5TM (USGS), Jan 1999; City Location - IIHS GeoLibrary, 2015

Coordinate System: UTM | Datum: WGS84 | MAPID: CAR290315NLC13 | Date: 29-03-2015

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Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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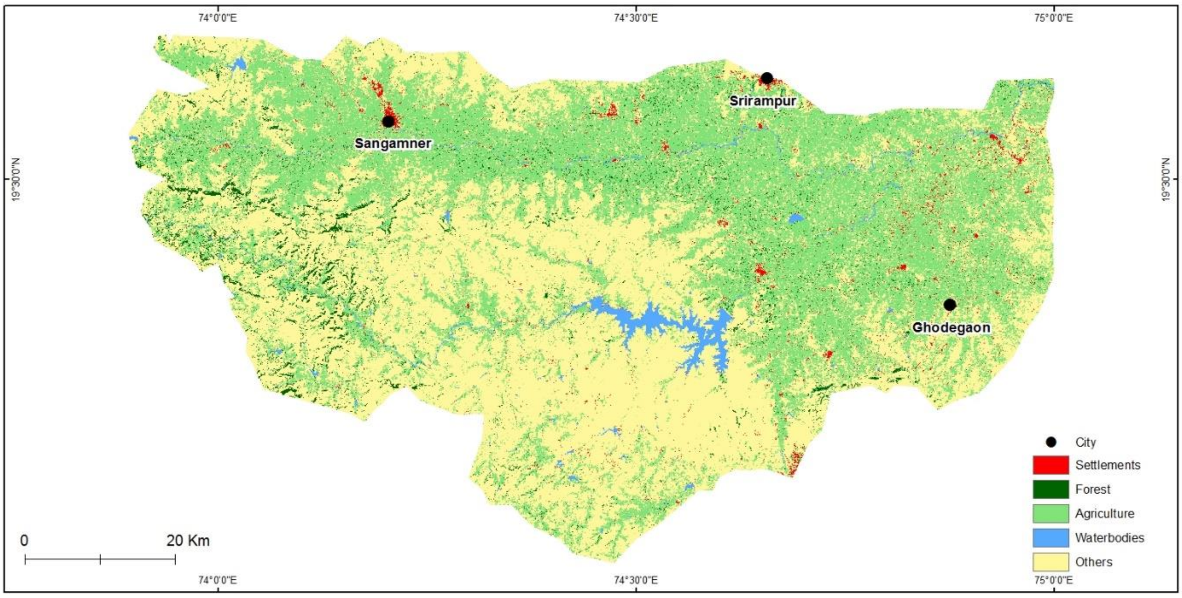
Land Use and Land Cover - 2011

Sangamner Sub-region



Data Used, Year: LANDSAT 5TM (USGS), Feb 2011; City Location - IIHS GeoLibrary, 2015

Coordinate System: UTM | Datum: WGS84 | MAPID: CAR290315NLC14 | Date: 29-03-2015

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Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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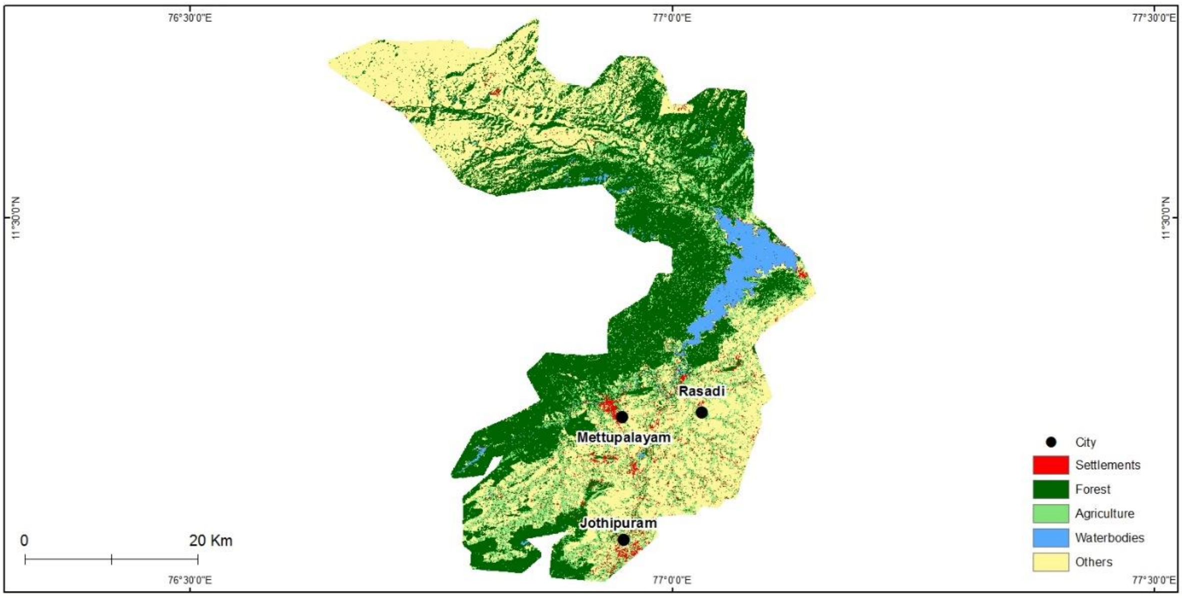
Land Use and Land Cover - 1999

Moyar-Bhavani Sub-region



Data Used, Year: LANDSAT 5TM (USGS), Feb 1999; City Location - IIHS GeoLibrary, 2015

Coordinate System: UTM | Datum: WGS84 | MAPID: CAR290315NLC11 | Date: 29-03-2015

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Geospatial Analysis for Climate Vulnerability and Adaptation (CARIAA)

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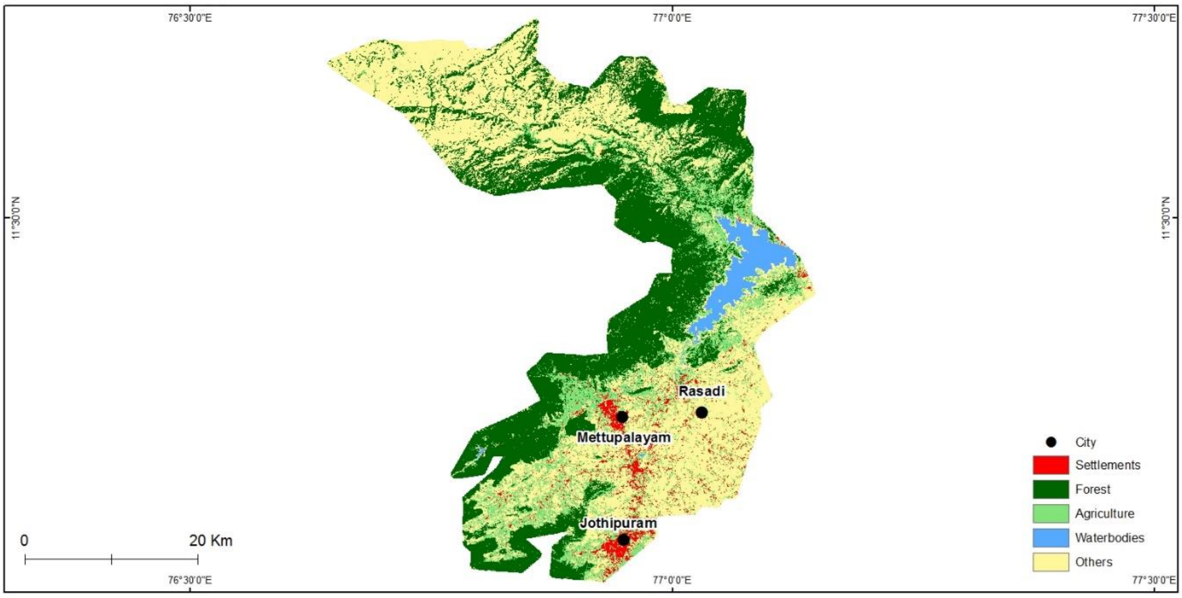
Land Use and Land Cover - 2011

Moyar-Bhavani Sub-region



Data Used, Year: LANDSAT 5TM (USGS), Feb 2011; City Location - IIHS GeoLibrary, 2015

Coordinate System: UTM | Datum: WGS84 | MAPID: CAR290315NLC12 | Date: 29-03-2015

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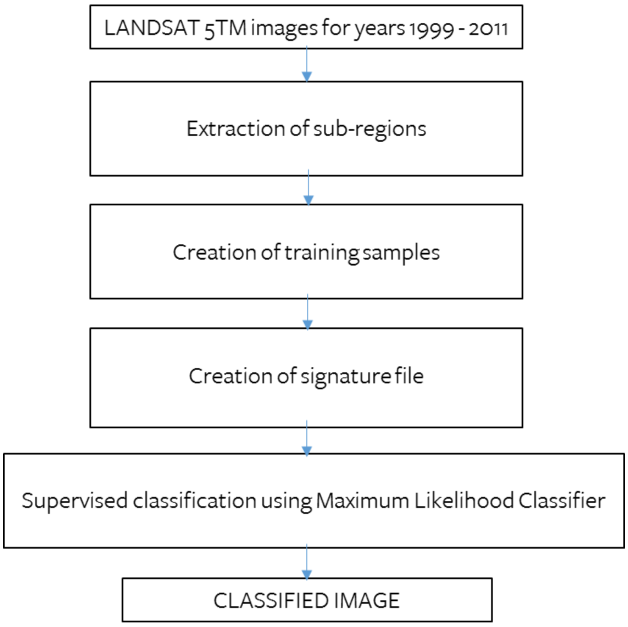
Annex 2.3 Methodology for Land use Land cover classification

To identify the land cover classes for the three sub-regions, satellite images (Landsat 5TM) for the years 1999 and 2011 (January and February) were processed using Image classification software. Supervised classification based on spectral signatures obtained from training samples was used to identify the land cover classes. The methodology adopted is explained below through a flow chart.



The LANDSAT 5TM images used have a spatial resolution of 30m. The sub-regions were extracted from the satellite images for performing land use and land cover (LULC) classification. These images were then classified under five LULC classes, namely, Settlements, Agriculture, Forest, Water bodies and Others (includes open lands, barren lands and agriculturally fallow lands). A minimum of ten training samples were created for every class which were further used to create a spectral signature file. This signature file created was the main input for supervised classification. Maximum Likelihood Classifier, which is a statistical classifier based on probability theory, was used.

Signature Name	Color	Red	Green	Blue
Forest		0.781	0.607	0.683
Water		0.385	0.573	0.709
Agriculture		0.858	0.664	0.738
Built-up		0.767	1.000	0.970
Others		0.796	0.934	0.861

Figure: Spectral signature of the LULC classes for Moyar-Bhavani sub-region 2011

The final output is a classified image having the formerly mentioned five land cover classes. These classified images were used to make area calculations and also to create maps. For calculating area the number of pixels in each LULC class was considered. Following this an excel sheet was created for every sub-region and percentage cover of each class with respect to the entire sub-region area was calculated, the values of which have been represented through bar diagrams.

There are several noticeable changes in the land use and land cover of all three sub-regions from 1999 to 2011.

Changes in Settlements: The most remarkable change that is easily identifiable in the three sub-regions is the expansion of the settlement areas. In case of Bangalore sub-region settlement growth (98.45%) is more as compared to Moyar-Bhavani (49.47%) and Sangamner (13.44%) sub-regions. This is mainly because of the expansion of the Bangalore City. In Moyar-Bhavani sub-region major settlements are concentrated mainly towards the south. In Sangamner sub-region, settlements are seen only in northern and eastern part of the sub-region.

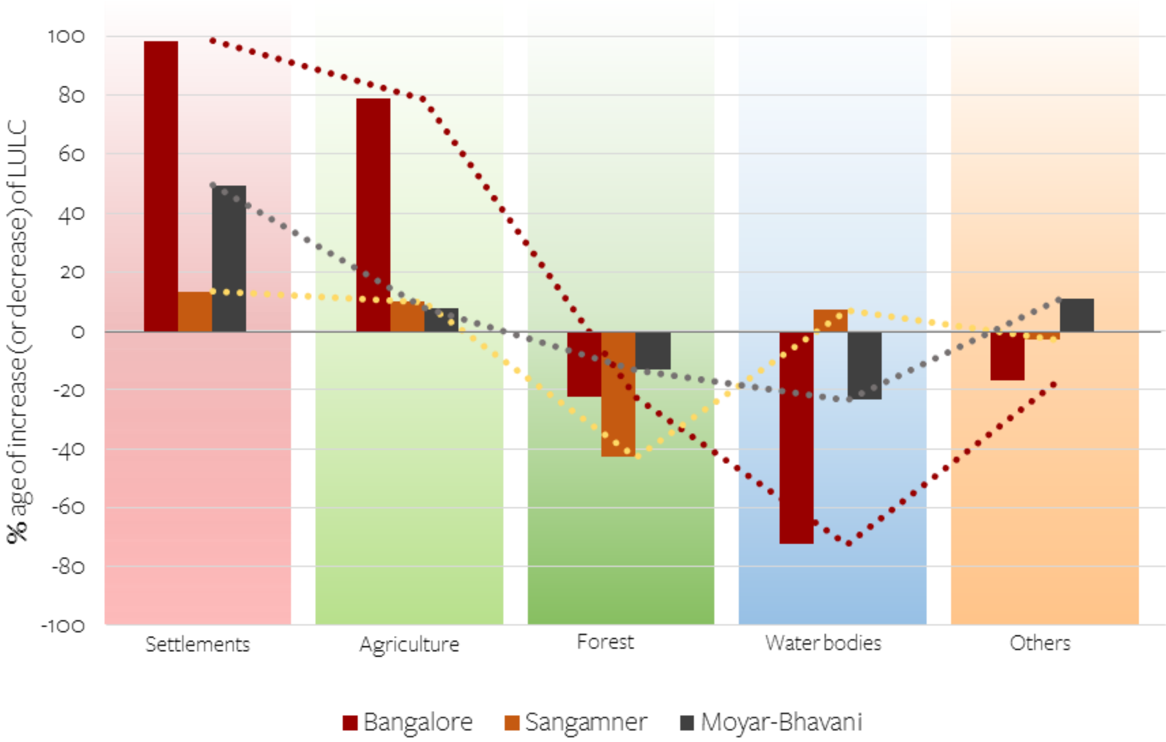


Figure: Percentage of increase (or decrease) of area for LULC classes for the three sub-regions from 1999 to 2011

Changes in Agriculture, Forest and Others: The three sub-regions have undergone an increase in agricultural land over the years. For Bangalore sub-region there has been a 78.75% growth, whereas, for Moyar-Bhavani and Sangamner sub-regions there has been an increase of

7.90% and 9.99% respectively. The increase in agriculture that has been cited is mainly because of reduction of forest areas and cultivation in plots of land that were fallow previously. Forest areas in Bangalore sub-region have decreased by 22.5%. In Moyar-Bhavani and Sangamner sub-region the decrease has been by 13.12% and 42.87% respectively. In case of Sangamner and Bangalore sub-region there has been a decrease in the open lands, barren lands and agriculturally fallow lands by 3.14% and 16.66% respectively. As mentioned earlier, this decrease has majorly contributed to an increase of agricultural lands and also to settlement expansion.

Changes in Water bodies: Water bodies have also reduced over the years. In Bangalore sub-region, an entire water body (Hoskote Lake) towards the north-western part of Bangalore city have been replaced entirely by open lands and some vegetative cover as well. The total decrease in water bodies for Bangalore sub-region from 1999 to 2011 is by 16.66%.

Annex 3.1: Trends in temperature across India during 1901-2007.

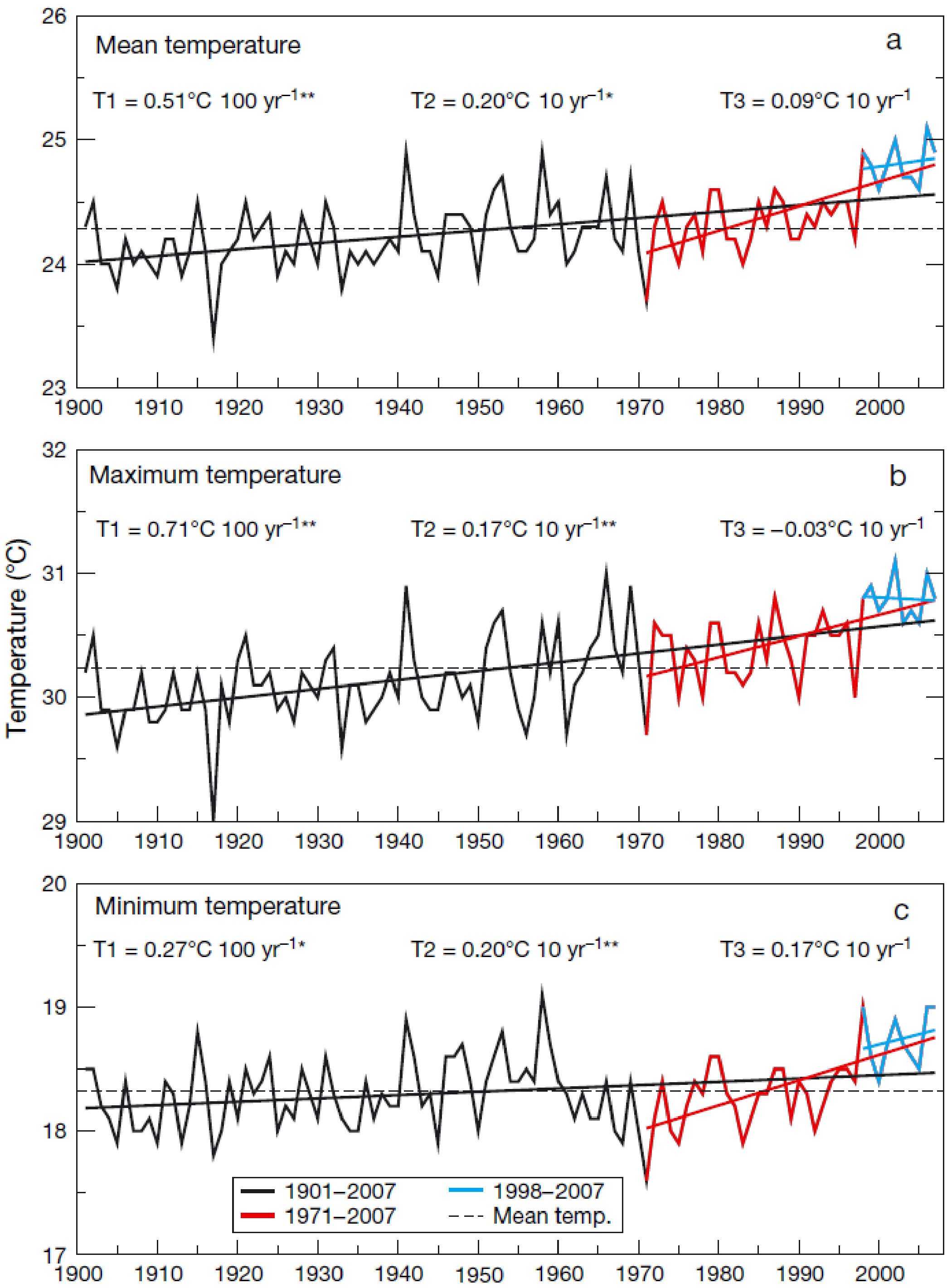
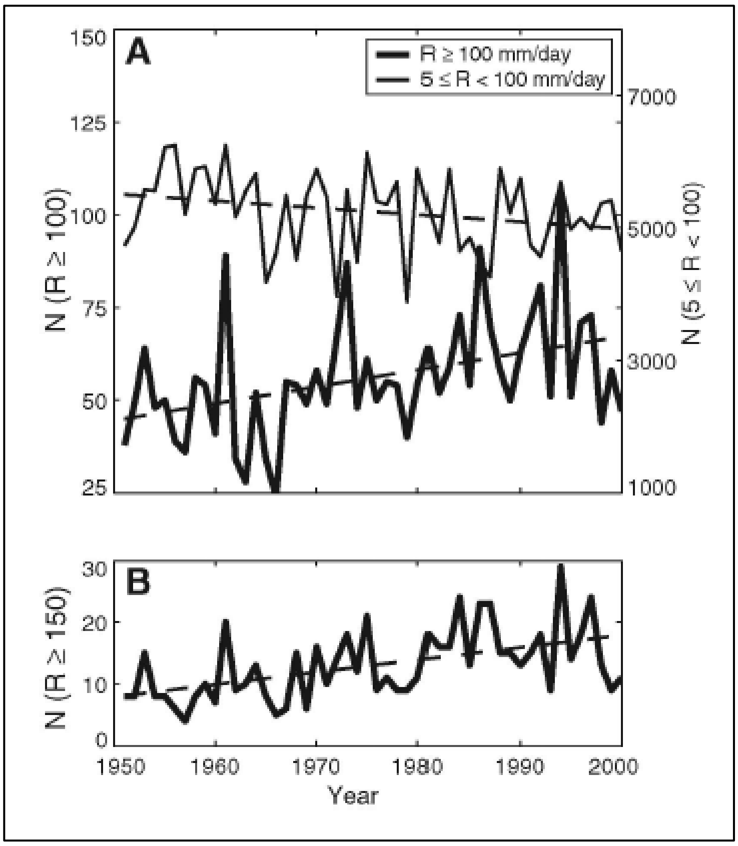


Fig. 2. Indian annual temperature variations during trend periods 1901–2007 (T1), 1971–2007 (T2) and 1998–2007 (T3). *$p < 0.05$; **$p < 0.01$

Source: Kothwale et al. 2010, http://dx.doi.org/10.3354/cr00857

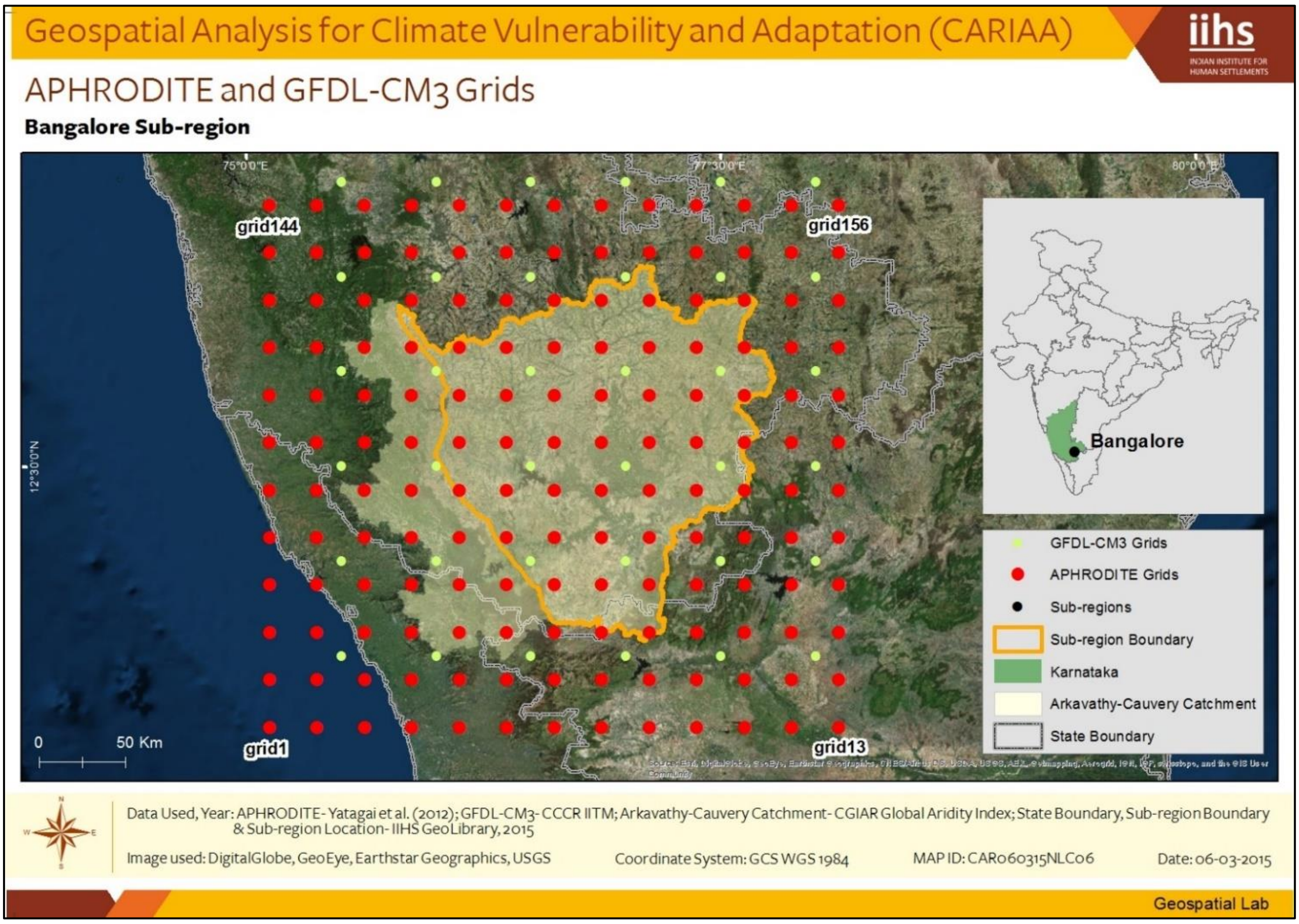
Annex 3.2: Temporal variation (1951-2000) in the number (N) of (A) heavy (R ≥ 100 mm/day, bold line) and moderate (5 ≤ R ≤ 100 mm/day, thin line) daily rain events and (B) very heavy events (R ≥

150 mm/day) during the summer monsoon season over CI. The dashed lines indicate the statistical significance of the trends.



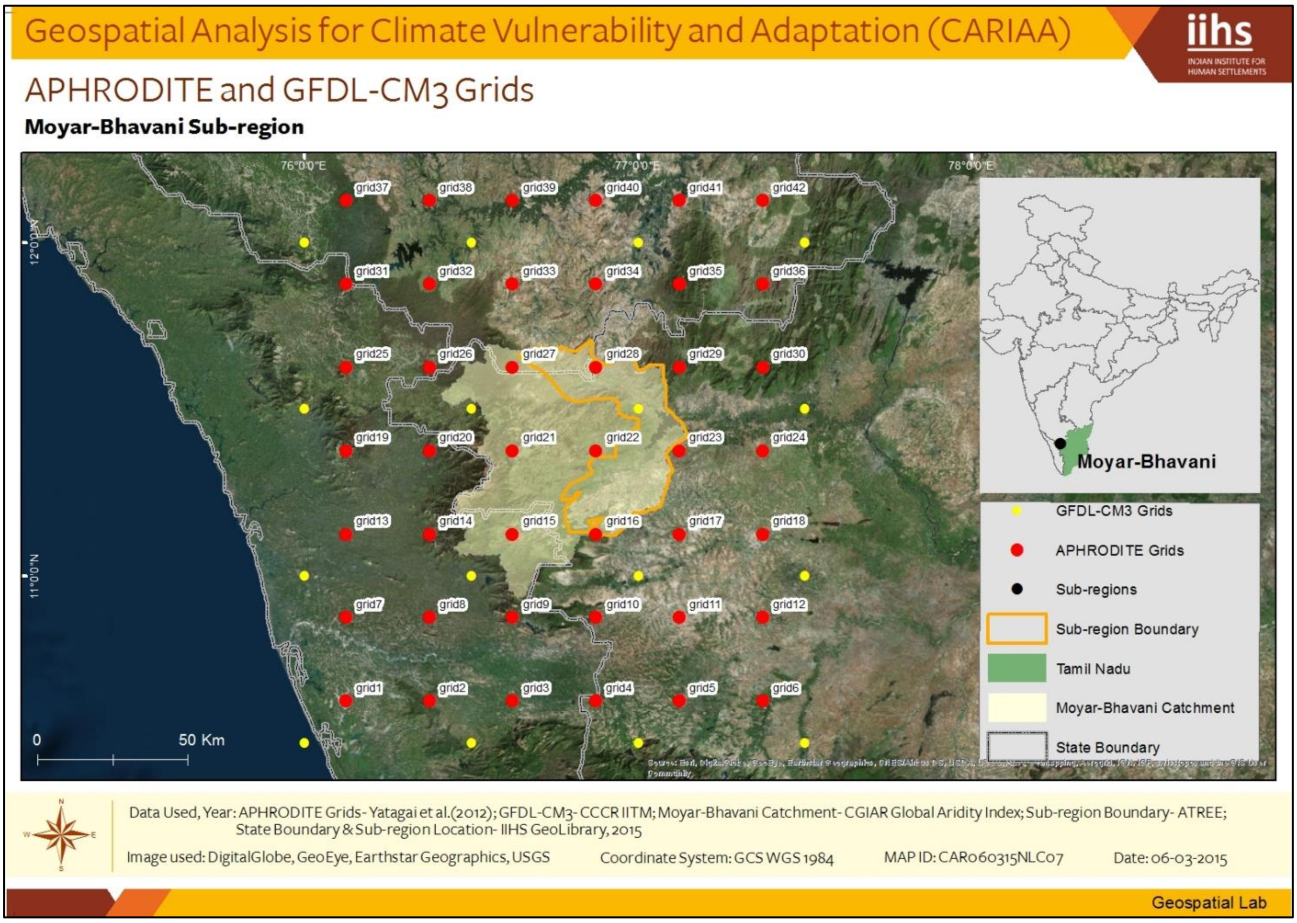
Source: Goswami et al. 2006; DOI: 10.1126/science.1132027

Annex 3.3: APHRODITE pixel corners (grids) used in the assessment of historical (1951-2007) precipitation trends in the Bangalore sub-region envelope. The watershed (WS), semi-arid region (SAR) and pixel corners of the CSIRO-GFDL CM3 climate model[34] have been shown for illustrative purposes. Pixel corners located offshore were not included in this assessment.

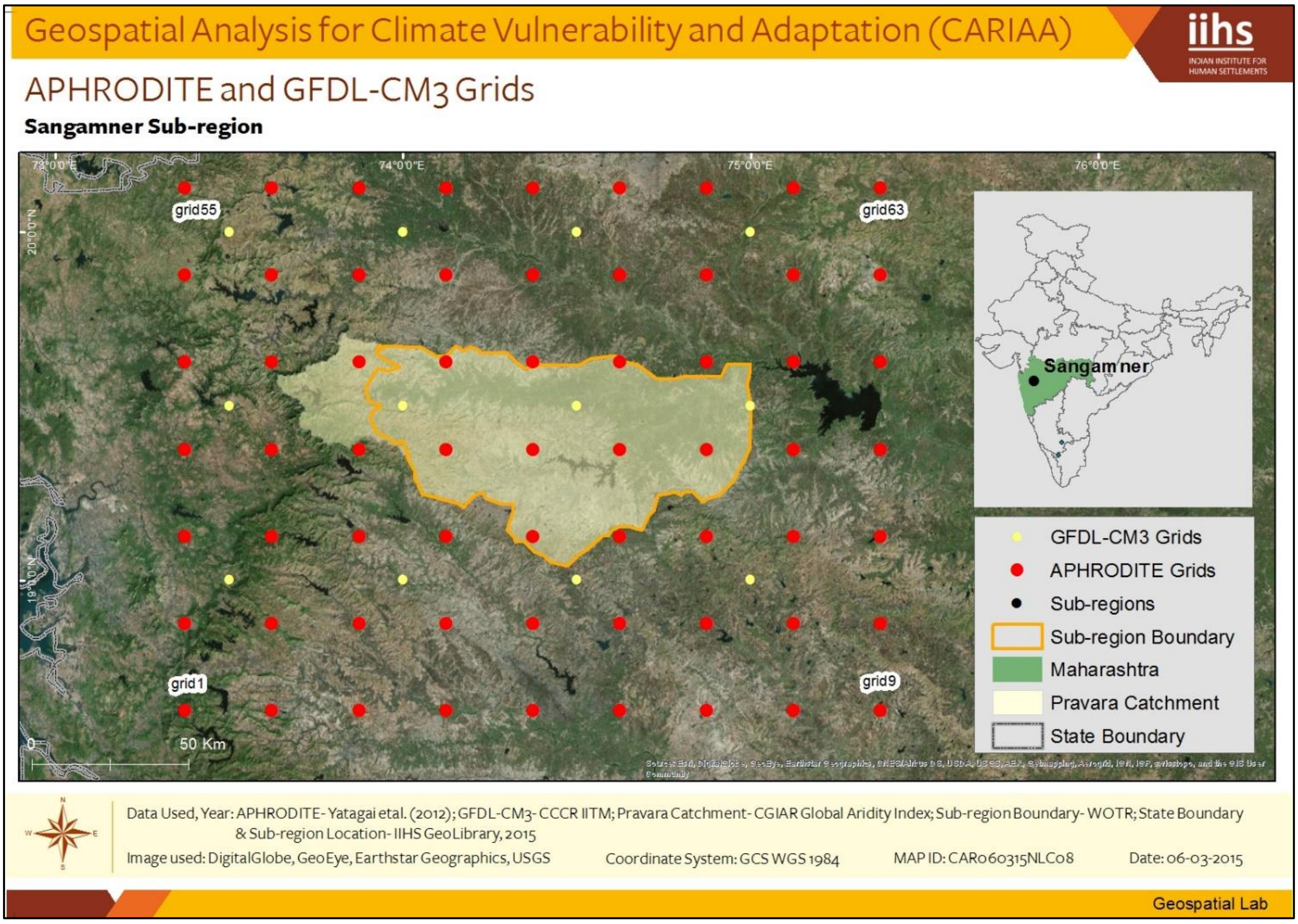


[34] The CSIRO GFDL-CM3 is a global coupled model developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as a component of the Coupled Model Intercomparison Project-Phase 5 (CMIP5). For more detail please see: http://cmip-pcmdi.llnl.gov/cmip5/availability.html

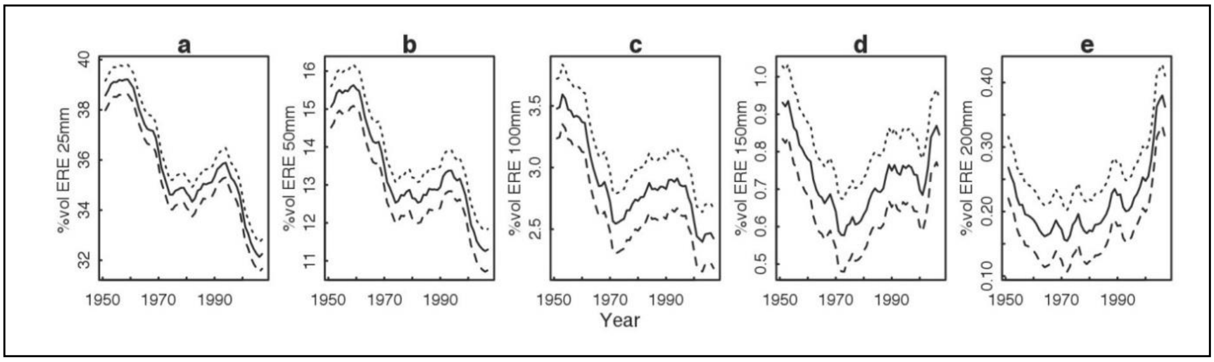
Annex 3.4: APHRODITE pixel corners (grids) used in the assessment of historical (1951-2007) precipitation trends in the Moyar-Bhavani sub-region envelope. The watershed (WS), semi-arid region (SAR) and pixel corners of the CSIRO-GFDL CM3 climate model (see footnote on previous page) have been shown for illustrative purposes.



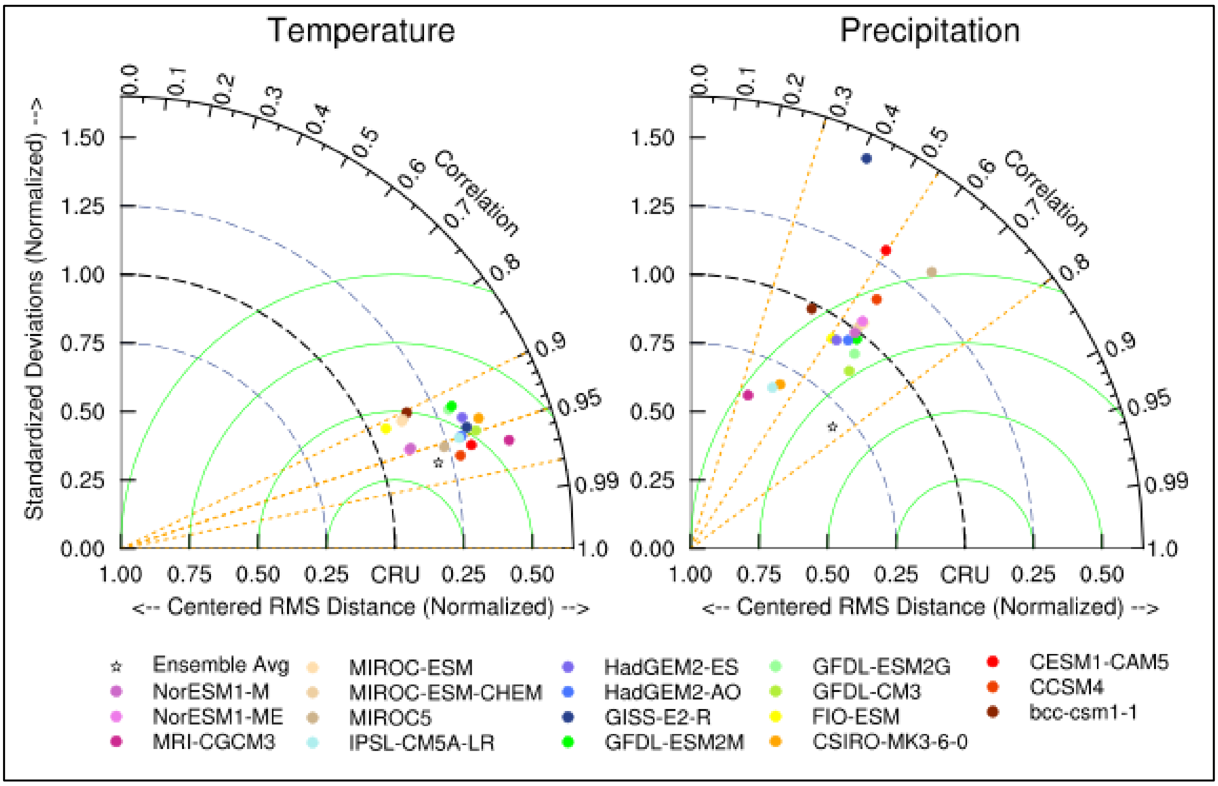
Annex 3.5: APHRODITE pixel corners (grids) used in the assessment of historical (1951-2007) precipitation trends in the Sangamner sub-region envelope. The watershed (WS), semi-arid region (SAR) and pixel corners of the CSIRO-GFDL CM3 climate model have been shown for illustrative purposes.



Annex 3.6: Trends in percentage volume of rainfall (Jun-Nov) contributed by (a) 25 mm, (b) 50 mm, (c) 100mm, (d) 150mm and (e) 200mm extreme rain events (ERE) to the Indian monsoons (Krishnaswamy and Vaidyanathan unpublished).



Annex 3.7: Performance of individual CMIP5 (solid circles) and ensemble (solid star) models for temperature and precipitation. The green circles centred at the reference point represent loci of constant root mean square (RMS) distance and the circles centred at the origin represent loci of constant standard deviation. Correlation is represented as cosine of the angle from the X-axis. Models with as much variance as observation, high correlation and low RMS error are considered to be performing well.



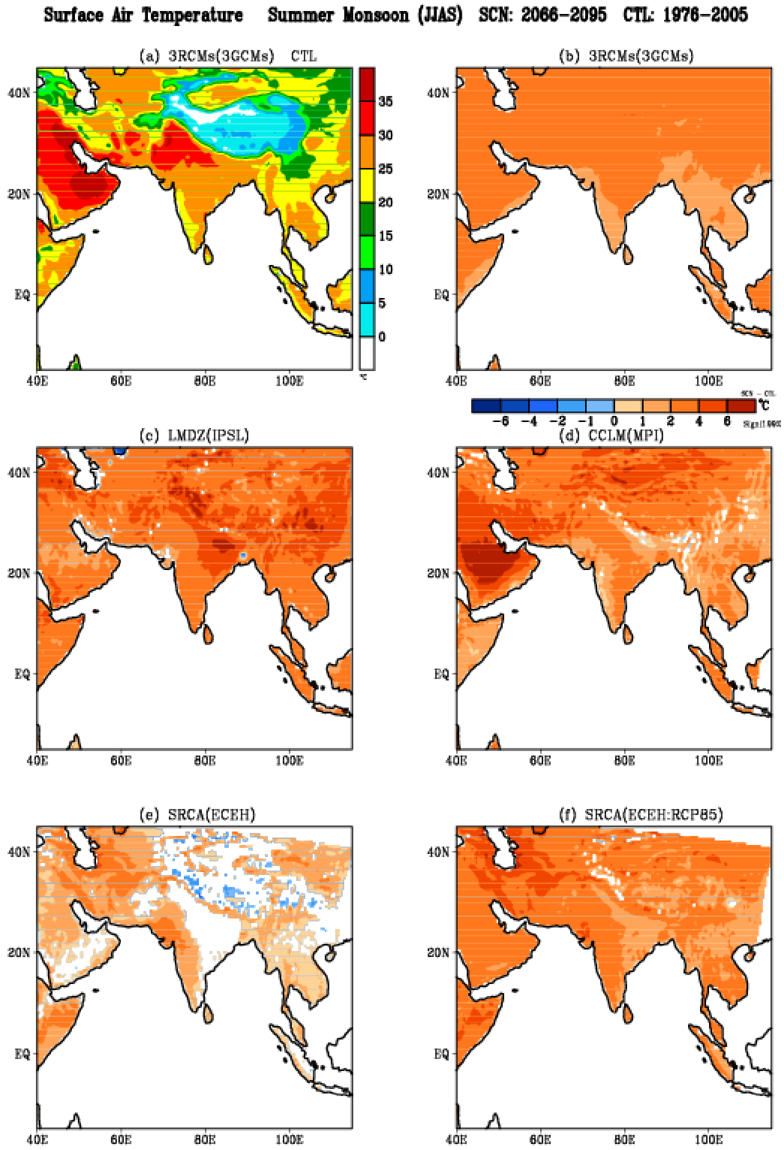
Source: Chaturvedi et al. 2012; http://eprints.iisc.ernet.in/id/eprint/45488.

Annex 3.8: A review of key climate change projections for India

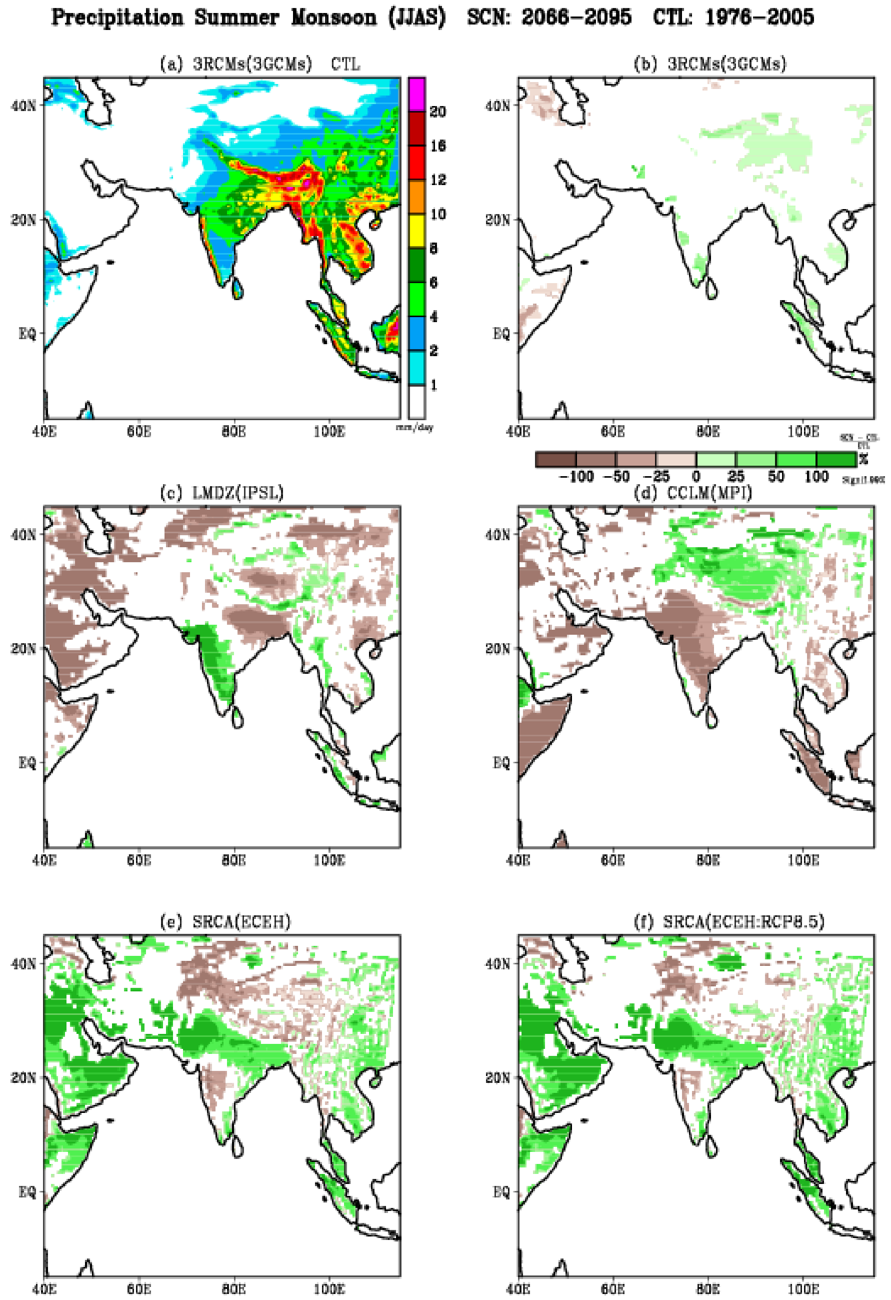
Study	GCM used	Downscaling model	Resolution	Climate scenario	Time-period	Key results	Key limitations
Rupakumar et al. 2006	HadCM3	PRECIS	0.44×0.44°	A2, B2	1960-1990; 2070-2100	All India temperature projected to increase 2.9°C (B2) and 4.1°C (A2) by 2080s relative to 1960-1990 baseline. All India precipitation projected to increase 18% (B2) and 23% (A2) by 2080s relative 1960-1990 baseline	Single GCM, only two SRES used, uncertainty in precipitation projections, lack of further downscaling
Krishnakumar et al. 2011	HadCM3 – QUMP≠	PRECIS	0.44×0.44°	A1B	1960-2098	All India temperature projected to increase 3.5°C to 4.3°C under the three Qs of A1B scenario by 2080s relative to 1960-1990 baseline. All India precipitation projected to increase 12% to 15% under the three Qs of A1B scenario by 2080s relative 1960-1990 baseline	Single GCM, single SRES scenario, uncertainty in precipitation projections, lack of further downscaling
Geethalaxmi et al. 2011	EH5OM GCM	RegCM3	0.5×0.5°	A1B	129 years (1971-2099)	For Tamil Nadu, while PRECIS projected a maximum temperature increase of 3.7°C, the RegCM3 projected a rise of 3.1°C. The increase in minimum temperature in PRECIS was 4.2°C and in RegCM3 it was 3.7°C during the same period. The increase in minimum temperatures was higher than that in maximum temperatures in both models.	Used only two RCMs
Pankaj Kumar et al. 2013	ECHAM5-MPIOM and	The Regional Model (REMO)	0.25×0.25°	A1B	1900-2100	For India the annual spatial warming is estimated between 2.5 °C to 5.5 °C with a	Use of SRES

	HadCM3	HadRM3 CCLM (COSMO model in Climate Mode)				maximum over Himalaya, north, central and west India. The summer monsoon season has regionally different precipitation projections like robust significant increase over peninsula (20%–40%) and Western Ghats and NE (10%–20%) by the end of the 21st century.	
Chaturvedi et al. 2012	18 GCMs	None	0.9-3°	RCP2859.6, RCP4.5, RCP6.0, RCP8.5	2006-2100	Chaturvedi et al (2012) projected a warming of 3.3°C to 4.6°C (relative to pre-industrial) for the Indian region under the business as usual scenario by 2080s and suggest that temperatures may rise to 2°C by as early as 2030s All-India annual precipitation under the business-as-usual scenario is projected to increase from 4% to 5% by 2030s and from 6% to 14% towards the end of the century (2080s) compared to the 1961–1990 baseline	Coarse resolution, uncertainty in precipitation projections; high uncertainty in extreme precipitation events

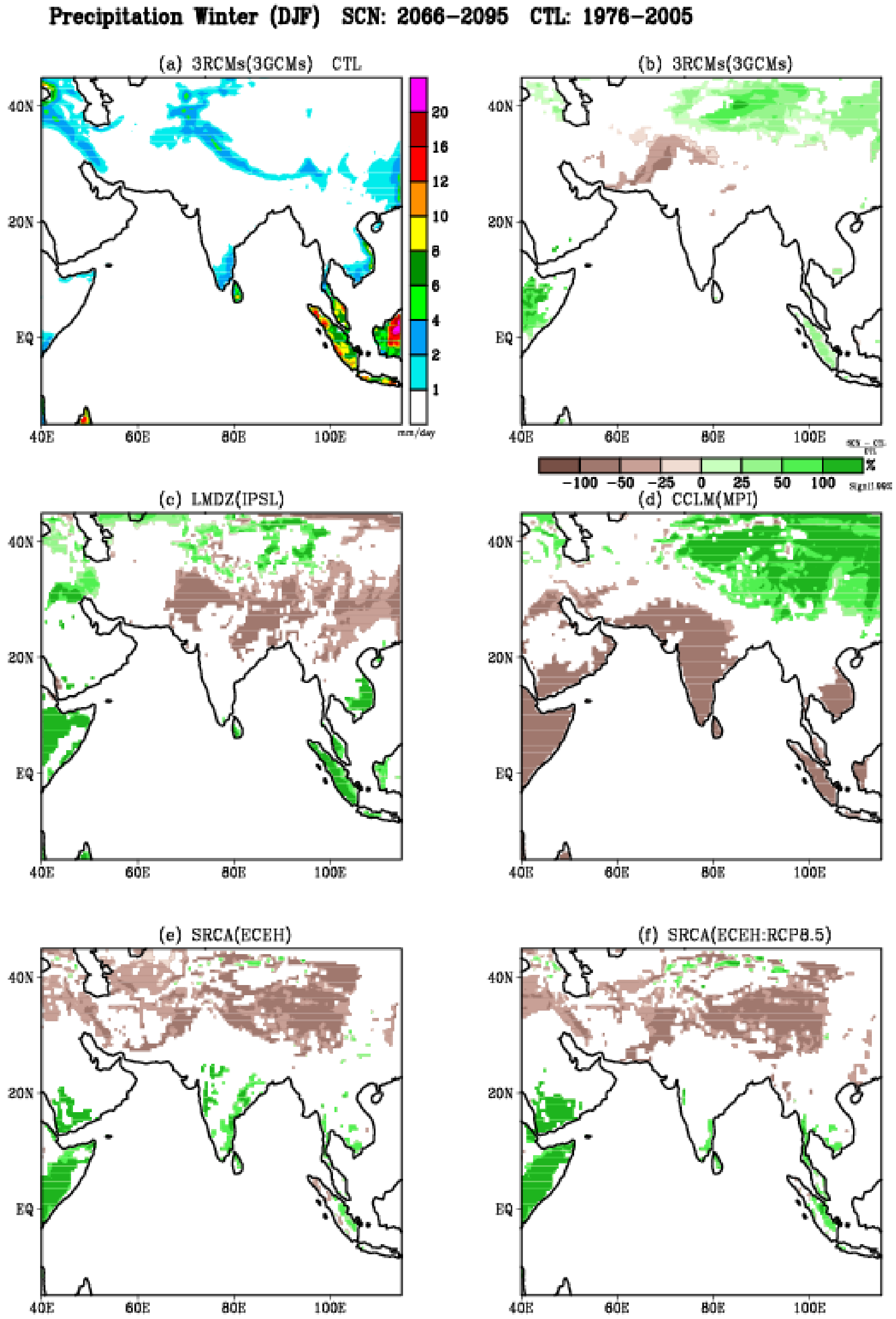
Annex 3.9 (a) The CORDEX South Asia multi-model ensemble mean of summer monsoon (JJAS) season mean 2-m air temperature (◦ C) for 1976-2005 and the changes of 2-m air temperature in 2066-2095 relative to 1976-2005 for the CORDEX South Asia simulations driven by CMIP5 AOGCM RCP4.5 scenario experiments: (b) multi-model ensemble mean and (c-e) three different RCMs listed in Table 3A.2. (f) same as (e) except for the RCP8.5 scenario experiment with SRCA RCM. Only 2-m air temperature differences significant at the 5% significance level are shown



Annex 3.10 (a) The CORDEX South Asia multi-model ensemble mean of summer monsoon (JJAS) season mean precipitation (mm day^{1}) for 1976-2005 and the changes of precipitation (%) in 2066-2095 relative to 1976-2005 for the CORDEX South Asia simulations driven by CMIP5 AOGCM RCP4.5 scenario experiments: (b) multi-model ensemble mean and (c-e) three different RCMs listed in Table 1. (f) same as (e) except for the RCP8.5 scenario experiment with SRCA RCM. Only precipitation differences significant at the 5% significance level are shown.



Annex 3.11 (a) The CORDEX South Asia multi-model ensemble mean of winter (DJF) season mean precipitation (mm day-1) for 1976-2005 and the changes of precipitation (%) in 2066-2095 relative to 1976-2005 for the CORDEX South Asia simulations driven by CMIP5 AOGCM RCP4.5 scenario experiments: (b) multi-model ensemble mean and (c-e) three different RCMs listed in Table 1. (f) same as (e) except for the RCP8.5 scenario experiment with SRCA RCM. Only precipitation differences significant at the 5% significance level are shown.



Annex 3.12 CORDEX-South Asia Regional Climate Model (RCM) experiments used to simulate climate for 1976-2100.

Experiment Name	RCM Description	Driving GCM	Contributing Institute
CCLM(MPI)	COnsortium for Small-scale MOdelling (COSMO) model in CLimate Mode version 4.8 (CCLM; Dobler and Ahrens, 2008)	Max Planck Institute for Meteorology, Germany, Earth System Model (MPI-ESM-LR; Giorgetta et al 2013)	Institute for Atmospheric and Environmental Sciences (IAES), Goethe University, Frankfurt am Main (GUF), Germany
SRCA(ECEH)	Rossby Centre regional atmospheric model version 4 (RCA4; Samuelsson et al., 2011)	Irish Centre for High-End Computing (ICHEC), European Consortium ESM (EC-EARTH; Hazeleger et al. 2012)	Rosssy Centre, Swedish Meteorological and Hydrological Institute (SMHI), Sweden
LMDZ(IPSL)	Institut Pierre-Simon Laplace (IPSL) Laboratoire de Me´te´orologie Dynamique Zoomed version 4 (LMDZ4) atmospheric general circulation model (Sabin et al., 2013)	IPSL Coupled Model version 5 (IPSL-CM5-LR; Dufresne et al. 2013)	Centre for Climate Change Research (CCCR), Indian Institute of Tropical Meteorology (IITM), India

Annex 4.1 Hazards, key vulnerabilities, key risks, and emergent risks illustrative of the three ASSAR transects in India. Climatic hazards interact with social, institutional, economic, or environmental dynamics and vulnerabilities. Emergent risks arise from system-level interactions. [Developed based on IPCC Technical Summary 2014]

Hazard	*Key vulnerabilities*	*Key risks*	*Emergent risks*
Extreme precipitation (higher frequency of extreme rain events) and inland flooding	**URBAN** - **Environmental:** Exposure flood events in urban areas, especially in low-income informal settlements (e.g. slums in Bangalore - **Infrastructural and institutional:** Ageing, poorly maintained, badly managed and inadequate drainage infrastructure. Inadequate governmental attention to disaster risk reduction - **Social, economics:** Limited coping capacity due to poverty, socio-political marginalization, poor social capital (if recently moved to the city) and culturally imposed gender roles	- Death, injury, and disruption of human security, especially among children, elderly, and disabled persons - Loss of personal belongings, house	- Increasing frequency of extreme precipitation events - Urbanization in dried lake beds and low lying areas - Inadequate expansion, cleaning of drainage networks - Negligible insurance (especially in low and middle income groups) - Burden of risk management shifted from the state to those at risk leading to greater inequality - Creation of high risk/high poverty spatial traps through gated communities (islands of prosperity among sea of poverty) – e.g. Electronics City
	RURAL - Exposure of crops to isolated high intensity rainfall events in rural areas - Sensitivity of households to damage due to heavy rainfall	- Soil erosion, waterlogging, crop loss leading to reduced income flow and food production - Mud huts in villages may get damaged or washed away	- Limited weather insurance which exacerbates existing vulnerabilities - Increasing monoculture leading to dependence on one crop type - Deforestation which may lead to further soil erosion
Novel hazards yielding systemic risks	- Lack of historical experience with novel hazards leading to unexpected (unplanned for) vulnerability - Poor adaptive capacity in systems that have low livelihoods diversity (e.g. dependence on one crop may increase sensitivity to particular hazard) - Poor forecasting ability	- Failure of coupled systems (e.g. groundwater extraction in Maharashtra and Bangalore's IT sector relies on power availability which may be disrupted in a novel hazard) - Collapse of health and emergency services in extreme events	- Magnification of impacts of extreme events with potential ripple effects across scale - Erosion of trust in disaster management institutions leading to lowered preparedness - Loss of traditional knowledge which may have helped cope with some novel hazards
Drought	**URBAN** - Water shortages and irregular supply for	- Insufficient water supply for people and industry - Food insecurity driving risk of	- Increasing urbanization, groundwater depletion put strain on already strained resources

	domestic and industrial purposes - Groundwater depletion and drying tanks leading to increasing water transfers and increasing rural–urban (e.g. Bangalore is drawing water from neighbouring watersheds)	malnutrition, stunted growth and weaker labour force	- Interactions of climate changes, - Reduced productivity, population growth, and ongoing food insecurity have implications on adaptive capacity and system resilience.
	RURAL - Resulting food insecurity (especially smallholder farmers and low income groups in urban areas) - Impacts on biodiversity and natural ecosystems leading to loss of ecosystem services - Insufficient and uncertain access to drinking and irrigation water	- Loss of agricultural productivity and/or income of rural people - Erosion of livelihoods depending on water intensive agriculture - Risk of food insecurity	- Interactions across human vulnerabilities: deteriorating livelihoods, poverty traps, heightened food insecurity, decreased land productivity, rural outmigration, and increase in new urban poor in developing countries - Increased conflict over depleting natural resources - Potential tipping point in rainfed farming systems such as in Ahmednagar - Burden on already overburdened social networks
Rising temperatures, changes in frequency and intensity of extreme heat	**URBAN** - Urban heat island effect - Health issues (especially to vulnerable sections like slum dwellers, elderly, expectant mothers) - Inability of local organizations that provide health, emergency, and social services to adapt to new risk levels	- Losses of important ecosystem services - Increased mortality and morbidity during periods of extreme heat	- Interaction of demographic shifts with changes in regional temperature extremes, local heat island, and air pollution - Overloading of health and emergency services - Higher mortality, morbidity, and productivity loss among manual workers
	RURAL susceptibility to - higher disease incidence, - increased evapotranspiration (leading to more water requirements) - loss of provision of food, livestock	- Losses of important ecosystem services - Risk of loss of endemic species and locally adapted crop varieties - Resulting loss in agricultural livelihoods and potential migration	- Shift in livelihood pattern of the region (from agriculture to non-farm) - Migration leading to increased population stress in urban centres - Loss of ecosystem services leading to transformation of farming SES

Annex 4.2 Multi-dimensional vulnerability at different scales.

		Scale			
		Household	***Community***	***State***	***National***
Dimensions of vulnerability	**Exposure**	**Climatic** - Changes in precipitation - Changes in temperature - Changes in frequency and intensity of extreme hazards - Local flooding **Non-climatic** - Natural resource degradation - Resource exploitation - Local market dynamics - Local political unrest	**Climatic** - Changes in precipitation - Changes in temperature - Changes in frequency and intensity of extreme hazards - Local flooding **Non-climatic** - Natural resource degradation - local market dynamics - Local political unrest	**Climatic** - Changes in precipitation - Changes in temperature - Changes in frequency and intensity of extreme hazards - Drought, desertification **Non-climatic risks** - Market fluctuations - New infrastructure projects	**Climatic** - Changes in precipitation - Changes in temperature - Changes in frequency and intensity of extreme hazards - Drought, desertification **Non-climatic risks** - Change in policy, institutional regime - International trade agreements
	Sensitivity	- Health (nutritional and food security, life expectancy, fertility) - Demographic composition of household (Literacy, gender, education) - Income level, no. and quality of livelihood streams	- Cohesiveness, trust - Differentiation of community over land type, livelihood type	- Population growth and distribution - Human development indicators at state level	- Population growth - Human development indicators - National GDP - Dependence on one livelihood/sector

	Adaptive capacity	- Access to natural resources - Asset ownership (e.g. pump, pipes, well for irrigation) - Access to infrastructure (road access for marketing agricultural produce) - Access to credit and insurance facilities (banks, relatives, moneylenders etc.) - Access to information (e.g. weather forecasts for decision-making) - Social capital (bridging and binding ties) and institutional support (agricultural extension to farmers)	- Social ties of the community with multiple actors (NGO workers, local government officials) - Existence of norms to access, use, share resources (e.g. forests, village ponds) - Setting up community-level infrastructure (e.g. seed banks, desilting local ponds, watershed development works on Panchayat land) - Ties within community to help others in distress (lending during local flooding/loss of life due to accident)	- Natural resource base - Infrastructure (road connectivity, electricity supply) - Governance and institutional architecture, transparency, inclusiveness - Credit facilities - Relief and social welfare programmes	- Investment in resource conservation, infrastructure, RandD - Governance (at national and international levels) - National financial health, banking facilities - National planning (DRR, social protection programmes, integration of climate resilience in development plans)

Annex 4.3 Summary of impact assessment studies for India for different sectors

Limitations/ Highlights of the study	Key impact findings	Impact model used	Study Area	CC scenarios	CC projections used*	Study	System
Findings are having large uncertainties, preliminary assessment	Projects that the "River basins of Sabarmati and Luni, which occupy about one quarter of the area of Gujarat and 60 % of the area of Rajasthan, are likely to experience acute water scarce conditions. River basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcity and shortage". Further Simulations using dynamic crop models "indicate a decrease in yield of crops as temperature increases in different parts of India". The forest modelling suggests "shifts in forest boundary, changes in species-assemblage or forest types, changes in net primary productivity, possible forest die-back in the transient phase, and potential loss or change in biodiversity"	BIOME3 - forest sector; SWAT – water;	All India	IS92a	HadRM2 (Unpublish ed)	MoEF, 2004 (NATCOM1)	Cross-sectoral (Water and Forest)
The regions covered under the in-depth study are not very relevant for the SARs	Provides an assessment of the impact of climate change in 2030s on four key sectors of the Indian economy: Agriculture, Water, Natural Ecosystems and Biodiversity and Health, in four climate sensitive regions of India: the Himalayan region, the Western Ghats, the Coastal Area and the North-East Region.	SWAT-Water; IBIS-Forests; and InfoCROP for agriculture	Four hotspots: coastal, WG, NE, Himalaya	A1B	Krishnaku mar et al 2011	INCCA, 2010	Cross-sectoral (Water, Agricultu re, Forests)
	Projected the impact of climate change on water, agriculture and forest ecosystems.	BIOME4 - forest sector; SWAT – water;	All India	A1B	Krishnaku mar et al 2011	MoEF, 2012 (NATCOM2)	Cross-sectoral
Lack of observed data on the impact of CC on water resources, Single	Study projects increased water scarcity in the semi-arid basins of Sabarmati, Luni, Krishna, Tapi and Narmada due to decreasing rainfall and increasing	SWAT	All India; Gosain et al 2006	A2 and B2	Rupakumar et al 2006	Gosain et al 2006	Water

climate model, Single Hydrological mode – hence lack of robust uncertainty assessment, Lack of climate data downscaling, Precipitation projections are highly uncertain	ET. It projects increased drought intensity in majority of the Krishna basins and		covering 12 major river basins, Gosain et al 2011 covering >18 basins, including those in the SARs region				
	Projects increased water scarcity in the semi-arid basins of Tapi, Sabarmati, Narmada, Mahi, Luni, Krishna, Indus and Godavari due to decline is water yield (see figure 13). Drought weeks during monsoon are projected to increase for the semi-arid basins	SWAT		A1B	Krishnakumar et al 2011	Gosain et al 2011	
1) GCM resolution of 3.75 and 2.5°. Lack of regional downscaling, 2) Large parts of Ganga basin is not relevant to SARs in India. 3) cautions that 'GCMs find it notoriously difficult to model the Indian monsoon, so the results for the Ganges should be treated with particular caution'	Finds that stress in the Ganges will decrease as climate change progresses. However, further cautions that 'the increase in surface run-off may be unevenly distributed across the year, and unless storage is available to smooth out the peaks in water availability throughout the year, the greater run-off volumes may present more difficulties, e.g. flooding, rather than alleviating water stress'	MaCPDM Global Hydrological model	Global, covering Ganga basin in India	+2°C and +4°C World	Ensemble* of HADCM3L GCM	Fung et al 2011	
This is a global study and it is unable to properly address many of the important sub-national issues	Conclude that "global maize and wheat production declined by 3.8 and 5.5%, respectively, relative to a counterfactual without climate trends. For India it finds the wheat yields to have declined by >5% and rice yields by about 2%		Global, covering India	Climate observation over 1980-2008		Lobell et al 2011	Agriculture
	Wassmann et al. (2009) looked at the increasing heat stress and its implication for rice production in different parts of Asia. They suggest that, in		Asia, including north and	Observation		Wassmann et al 2009	

	terms of risks of increasing heat stress, there are parts of Asia where current temperatures are already approaching critical levels during the susceptible stages of the rice plant. These places, among other areas include: North India (October) and South India (April, August)		south India				
Naresh Kumar, Srivastava papers and Geethalaxmi's paper faces the issues of Single climate model, Single Hydrological model, Lack of climate data downscaling. However Asseng Kumar et al 2014 as part of AgMIP experiment used multi-model climate projections and also used multiple impact assessment models	Climate change is projected to reduce monsoon sorghum grain yield to the tune of 14% in CZ (Central Zone) and SWZ (South Western Zone) by 2020. Yields are likely to be affected even more in 2050 and 2080 scenarios. Climate change impacts on winter crop are projected to reduce yields up to 7% by 2020, up to 11% by 2050 and up to 32% by 2080. Impacts are projected to be more in SWZ region than in SCZ and CZ. But, the yield loss due to rise in temperature is likely to be offset by projected increase in rainfall.	InfoCROP-SORGHAM	All India	A2A	HadCM3 GCM	Srivastava et al 2010	
	The study suggests that climate change is likely to reduce irrigated rice yields by ~4 % in 2020 (2010–2039), ~7 % in 2050 (2040–2069), and by ~10 % in 2080 (2070–2099) climate scenarios. On the other hand, rain-fed rice yields in India are likely to be reduced by ~6 % in the 2020 scenario, but in the 2050 and 2080 scenarios they are projected to decrease only marginally (<2.5 %)	InfoCROP - RICE	All India	A1B, A2, B1 and B2	MIROC3 GCM Rupakumar et al (2006)	Naresh kumar, 2013	
	Assessed the uncertainty in simulating wheat yields under climate change. The sensitivity analysis suggests higher decline is wheat yields at higher temperature rises	27 different wheat Crop models	World, including India	A2	16 downscaled GCMs	Asseng et al. 2014	
	Geethalakshmi et al (2011) projected a decline of 356 Kg/ha/decade, in rice yield without	DSSAT		RegCM3	EH5OM GCM	Geethalaxmi et al 2011	

	considering the CO_2 fertilization effect for the PRECIS outputs, whereas the decline was 217 kg/ha/decade for RegCM3 outputs. However, when CO_2 fertilization effect was considered, the PRECIS output showed decreasing trend at the rate of 135 kg/ha/decade, whereas RegCM3 projected a modest increase in the yield (24 kg/ha/decade).						
	Projects that under the climate change scenarios rice yield will reduce over a large part of the continent and northern part of South Asia is found to be one of the most vulnerable regions.		Asia-wide including India	A1B and A2	Multiple GCMs	Masutomi et al 2009	
	Suggests that there will be a 51% decrease in the most favourable and high yielding wheat area due to heat stress – adversely impacting about 200 million people in Indo-Gangetic plains, much of this area lying under SARs	Wheat mega-environment classification	Indo-Gangetic plains	$2XCO_2$	Worldclim CCM3 downscaled	Ortiz et al 2008	
The study is very interesting, however is not relevant for the SARs	Based on extensive field sampling and historical data estimated the vegetation shift patterns for 124 endemic species in the Eastern Himalayan state of Sikkim, over the period 1849-1850 to 2007-2010. They estimated that 87% of the 124 endemic species showed geographical range shifts in response to observed warming experiencing a mean upward displacement rate of 27.53±22.04 meters per decade	Historical data and field sampling	Sikkim Himalaya	Historical data (1849-1850 to 2007-2010)		Telwala et al 2013	Forests
Due to lack of ground estimates extensive NPP observations from India the satellite based NPP is not validated for Indian	Bala et al (2013) estimated an increasing NPP trend of 3.9% per decade over India. A multivariate linear regression analysis indicates that this increasing NPP trend is partly driven by increasing atmospheric CO2 concentration and the consequent CO2 fertilization of the ecosystems.		All India	Satellite based observation 1982-2006		Bala et al 2013	

region. Though its validated for many other regions of the world	However, human interventions such as increased irrigation and increased fertilizer use may have also played a key role in the NPP increase.						
a) Lack observed climate change impacts, b)Single Climate Model and Single Scenario, c) Climate Projections based on SRES scenarios, d) Single DGVM, e) Lack of species Level Assessment, f) Lack of integrated assessment at the landscape level, f)In sufficient representation of Nitrogen Cycle, Fire/ Pest dynamics in the DGVMs	- Projected NPP to generally rise under climate change scenarios - Projected the impact of climate change on Indian forests and conclude that about 77% and 68% of the forest grids in India are likely to experience vegetation shift under the A2 and B2 scenarios of climate change respectively by 2080s	BIOME4-Equilibrium	All India	A2 and B2	Rupakumar et al 2006	Ravindranath et al 2006	
	Used a dynamic global vegetation modeling (DGVM) approach projected that about 39% to 45% of forest grids in India may not remain optimally suitable for the current vegetation by 2080s under A2 and B2 scenarios respectively. Projected NPP to generally rise under climate change scenarios.	IBIS - Dynamic	All India	A2 and B2	Rupakumar et al 2006	Chaturvedi et al 2011	
The study finds moisture to be the key determinant of shift of Sal distribution, however GCM as well as RCMs have less confidence in rainfall projections	Looks at the possibility of shift of Sal (*Shorea robusta)* distribution to northern and eastern India under climate change. It identifies moisture as the key driver that would influence the distribution to shift towards northern and eastern India, with greater than 90% certainty.	Maxent software, version 3.3.3e	All India	A1B	Worldclim dataset	Chitale and Behera, 2012	
Single climate model,	Bhattacharya et al (2006) suggests the central and	Simple	All India	IS92a	HadRM2	Bhattacharya	Health

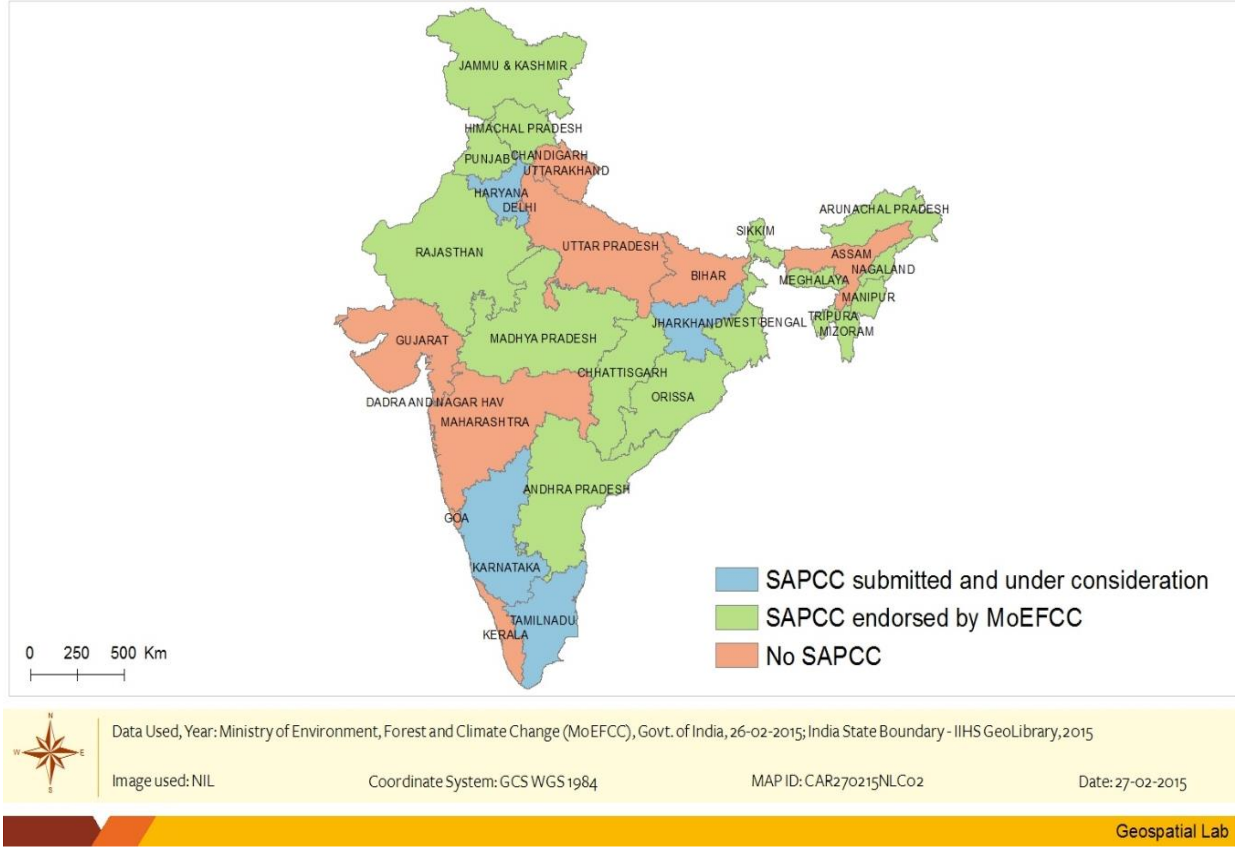
single scenario, Malaria transmission is highly complex and depends on multiple factors other than climate.	eastern Indian regions covering Madhya Pradesh, Jharkhand, Chhatisgarh, Orissa, West Bengal and Assam to be the most endemic malaria regions under the current climate and project that under the climate change projections of HadRM2 "malaria is likely to persist in Orissa, West Bengal and southern parts of Assam, bordering north of West Bengal. However, it may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka and Kerala. Also the northern states, including Himachal Pradesh and Arunachal Pradesh, Nagaland, Manipur and Mizoram in the northeast may become malaria prone. The duration of the transmission windows is likely to widen in northern and western states and shorten in the southern states."	Transmission Window method			(Unpublished)	et al 2006	
	The study projects that "some parts of Uttarakhand, Jammu and Kashmir and Arunachal Pradesh are likely to open transmission windows in new districts with increase in 4–6 months category of transmission".North-eastern states are projected to face an increase in the intensity of transmission from 7–9 months to 10–12 months. On the other hand, the eastern coastal districts see reduction in transmission months due to increased temperatures. No change is reported in Western Ghats.	Simple Transmission Window method	Western Ghats, Himalaya, Coastal regions, Northeast India	A1B	Krishnakumar et al 2011	Dhiman et al 2011	

Annexure 5.1 The National Action Plan on Climate Change (NAPCC) and the Sustainable Development Goals (SDGs)

National Mission	Objectives	Links with SDGs	Disconnects with SDGs
National Mission on Green India	- increasing tree cover and quality of forest and non-forest lands - Enhancing forests/ecosystems resilience and ecosystem services - increasing forest-based livelihood income living in and around the forests	**Goal 15** Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss **- *all targets*** **Goal 6** Ensure availability and sustainable management of water and sanitation for all **target 6.6** By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes **SDG 11** Make cities and human settlements inclusive, safe, resilient and sustainable. ***Target 11.4*** Strengthen efforts to protect and safeguard the world's cultural and natural heritage **Target 11.7** By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	- no attention paid to the issue of access to natural resources - no attention paid to the most vulnerable dwellers (in particular women and children) and vulnerable contexts (in slums and informal settlements) - no mention of the conservation of natural heritage in cities - fail to address the risks associated with lack of green spaces in cities (heat-waves, flooding).
National Water Mission	- Conservation of water; promotion water efficiency - Promotion of basin level integrated water resources management	**Goal 6** Ensure availability and sustainable management of water and sanitation for all **Target 6.1** by 2030, achieve universal and equitable access to safe and affordable drinking water **Target 6.4** by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity **Target 6.5** By 2030, implement integrated water resources management at all levels, including through trans-boundary cooperation as appropriate **Target 6.6** By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	- Lack focus on the most vulnerable people to water-related impacts

National Mission for Sustainable Agriculture	- Transform agriculture into a climate resilient production system; - Increase productivity - Ensure food security and equitable access to food resources - Enhance Livelihood Opportunities; - Contribute to Economic Stability at the National Level	**Goal 2** End hunger, achieve food security and improved nutrition and promote sustainable agriculture **Target 2.3** By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment **Target 2.4** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality **Target 2.5** By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and ensure access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed	- fail to address the needs and challenges of marginal and poor farmers - fail to address the issue of access to land and overlook the potential of non-farm employment

Annexure 5.3 State-wise status of SAPCC in India



Annexure 5.4 Terminology Associated with Risk Management and Adaptation

Coping and adjustment: Coping is a temporary, short-term response to hazards or external stressors (Smit and Wandel, 2006; Füssel, 2007) and signifies survival in the face of immediate, unusually significant stress, when resources, which may have been minimal to start with, are taxed (Wisner et al., 2004). Adjustment is more short-term than adaptation and does not alter the system in the fundamental way that adaptations do (Williams et al., 2013). Incremental adjustments may lead to adaptation, which may or may not be effective in the long-term (Moser and Ekstrom 2010).

Adaptation and adaptive capacity: Adaptive capacity is the *"ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences"* (IPCC, 2014b). It is the ability to anticipate, deal with and respond to changing climate and development pressures, while maintaining (or even improving) wellbeing. Adaptation is the end result of adaptive capacity: a system's ability to evolve to accommodate shocks and stress (Engle, 2011). Thus, when a system realises its adaptive capacity, it is said to have 'adapted' to a certain stressor (Brooks, 2003). Adaptation can occur through various actors and at multiple scales (Jones et al., 2010), and can be disaggregated by timing (anticipatory, concurrent or reactive), degree of spontaneity (autonomous or planned), scale (undertaken by individuals, households, communities or institutions) (Smit et al., 2000).

Maladaptation: Maladaptation refers to actions, or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future (IPCC, 2014b). Actions that are potentially maladaptive need not be inadvertent, nor be "taken ostensibly to avoid or reduce vulnerability to climate change" (Barnett and O'Neill, 2010:211). Thus, maladaptive decisions must be assessed in the context of the full range of climate and non-climate considerations and pressures. Adaptive and maladaptive actions can be distinguished depending on the time period over which risks are being assessed (IPCC 2012) because increasing frequency of climatic hazards may make certain decisions considered 'adaptive' at one time maladaptive in another time when circumstances and exposure to stressors has changed (Nelson et al., 2007).

Transformations are changes over a larger time scale where there is an *"altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems)"* (IPCC, 2012). They can refer to radical changes in

Annexure 5.4 Barriers and enablers of adaptation as found in literature

Source	Aim	Region	Barrier	Enabler
Kumar et al., 2010	Economics of CC in India	India	I. Knowledge, awareness and technological constraints: a.Knowledge deficit: 1. Lack of locally downscaled climate information for India. 2. Less evidence regarding actual costs of ecosystem based adaptation	1. Need climate projections at finer spatial resolutions (locally downscaled climate information). Additionally, climate scenarios need to go beyond predictions of temperature and precipitation. 2. Link adaptation costs with payments for ecosystem services, climate change adaptation can be effectively integrated with environmental management.
Patra, 2014	The article suggests ways to enhance real time and proactive linkages between vulnerability assessments and adaptation action	India	I. Knowledge, awareness and technological constraints: a.Knowledge deficit: Lack of state-level climate vulnerability data and sectoral assessments	1. Develop an integrated and iterative process of analysis of vulnerability and capacity assessments of various sectors, systems, and communities at various levels. Additionally, regular revision and updating are essential as vulnerability is a dynamic concept.
GoI, 2012	State Action Plan on CC	India	I. Knowledge, awareness and technological constraints:	1. Setting up of Climate Change knowledge center at Environment Protection Training and Research Institute (EPTRI) 2. Harness the expertise and knowledge already available in the State and the country on adapting

			a.Knowledge deficit: Lack of awareness on climate change issues and its impacts among rural and urban populations	to climate change 3. Promote awareness of CC through training and capacity building programmes
Agrawala and Frankhauser, 2008	The report provides a critical assessment of adaptation costs and benefits in key climate sensitive sectors, as well as across sectors at the sectoral, national and global levels.	Global	I. Knowledge, awareness and technological constraints: a.Knowledge deficit: Knowledge on adaptation costs and benefits at the sectoral level is unevenly distributed	1. Dissemination of knowledge through education and public information campaigns 2. Government agencies, NGOs and private companies should foster the generation and diffusion of innovations, new forms of technologies, and knowledge
Chatterjee et al., 2005	Community adaptation to drought in Rajasthan	India	I. Knowledge, awareness and technological constraints: a.Knowledge deficit: Lack of information about government schemes or policy provisions can affect benefit or access to subsidies	1. Need for proper dissemination of information to vulnerable communities, showing how such schemes can be can be accessed (the modalities, procedures, from where etc.)
Singh, 2014	NGO led watershed development project as an adaptation strategy	Rajasthan, India	I.Knowledge, awareness and technological constraints: Lock-in pathways: Green revolution technologies have locked agricultural systems in India into a trajectory of input-intensive farming, which has	Proper norms for CPR management

			repercussions on future adaptation options II. Social and cultural constraints: Caste as a barrier: Farmers in Rajasthan are constrained by socio-cognitive barriers; Due to a history of socio-economic and political isolation, tribal farmers perceived themselves as more vulnerable than upper caste, educated farmers	
Thompson et al., 2007	Prevailing approach to agricultural science and innovation often fails to provide sustainable outcomes, particularly at larger scales and for large numbers of poor people in developing countries	Global- Africa and India	I. Knowledge, awareness and technological constraints: a.Lock-in pathways: Green revolution technologies have locked agricultural systems in India into a trajectory of input-intensive farming, which has repercussions on future adaptation options	1. Need for a wider search for different socio-technological solutions and innovation pathways. 2. Need to address agricultural practice, skill and performance instead of focusing on technology. 3. Need to re-examine the governance of science, technology and innovation in the agri-food sector
Folke et al., 2005	Exploration of the social dimension that enables adaptive ecosystem-based management	Global	I.Physical and biological and knowledge constraint: The effectiveness of adaptation can be constrained due to the loss of local knowledge around thresholds in ecological systems	1. Need adequate knowledge to understand and manage: i) periods of rapid change, ii) the social sources of resilience required for reorganization following change, as well as iii) strategies for dealing with true uncertainty. Also, improved understanding of the dynamics of the whole system is essential. 2. Different knowledge systems and learning environments are being collated and combined to enhance the capacity for dealing with complex adaptive systems and uncertainty

Lal, 2011			I. Physical and biological constraint: a.Resource availability and access: Soil degradation and desertification reduce crop yields and the resilience of agricultural and pastoral livelihoods	
GoI, 2004	India's Initial National Communication to the UNFCCC	India	I.Physical and biological constraint: Climate change will lead to land degradation and acute water stress conditions in arid region of India	Water: 1. Governments (national and state) have launched various programmes to conserve and develop water resources for agricultural and domestic sectors and also reduce vulnerability to water stress (eg: Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP), National Watershed Development Programme for Rainfed Areas (NWDPRA), Soil, Water and Tree Conservation (Operation Soil Watch), Operational research projects on Integrated Watershed Management, and the Jawahar Rojgar Yojana (JRY)). 2. A prerequisite to adaptation is the application of an Integrated Water Resources Management strategy at different levels of usage from individual households to local communities, and watersheds to catchments. 3. Maintaining and strengthening structural (dams, levies and dikes) and non-structural (land zoning, forecasting systems, insurance etc.) 4. Strategies such as rainwater harvesting, enhancement of water storage and infiltration of rainfall in urban areas and in river basins (artificial restoration of hydrological systems), biotechnology (increase crop

				yields while reducing the water requirement and developing crops that are less dependent on water) Agriculture: 1. Altered agronomy of crops 2. Development of resource conserving technologies 3. Watershed management 4. Augmenting production and its sustainability 5. Improved risk management through early warning system and crop insurance 6. Increasing income from agricultural enterprises 7. Recycling waste water and solid wastes in agriculture 8. Improved land use and natural resource management policies and institutions 9. Reducing dependence on agriculture 10. Government initiatives: National Watershed Development Project for Rainfed Areas, improved access to credit for farmers (through Kisan Credit Card), creation of a Watershed Development Fund, and implementation of the National Agriculture Insurance Scheme Forest: 1. Forest policies 2. Institution and capacity building to address climate change in forest sector 3. Forestry and silvicultural practices Marine and coastal: 1. Structural interventions: dikes or seawalls or enhancing the natural setting or landscape, planting of mangroves, beach nourishment 2. Nonstructural interventions: land-use controls, information dissemination, economic incentives,

				regulation zones and insurance 3. Research and development activities for cost-effective methods for the protection
Shah, 2009	Adaptation and mitigation strategies for India	India	I. Physical and biological constraint: a.Resource availability and access: Intensification of groundwater use for agriculture in arid regions of India will lead to resource depletion, secondary salinization and depleted quality of groundwater	1. Policymakers need to evolve a strategy of proactive management of aquifer storage. This strategy needs to incorporate effective means to manage agricultural water demand as well as to enhance natural groundwater recharge through large-scale Managed Aquifer Recharge investments. 2. Demand side: Effective and practical approach of groundwater management in India- rationing of agricultural power supply 3. Supply side: key transition India needs to transition from surface-storage to aquifer storage 4. Need coordinating mechanisms to bring the agencies (public and private sector) under an umbrella framework to synergize their roles and actions 5. Need to rethink storage technology and redesigning existing structures (eg: surface systems)
Garg et al., 2009	Integrating climate change and developmental variables in articulating a framework for integrated impact assessment and adaptation responses, with malaria incidence in India	India	I.Physical and biological constraint: Deforestation, mainly for development projects and economic pressures, allows new vectors to invade the forest fringes producing epidemics in the non-tribal and non-immune people who move to these areas for jobs	1. Strategies: Awareness generation, use of mosquito nets, insecticides sprays, reclaiming land (controlling mosquito breeding) and filling drains 2. Active participation of communities and individuals in awareness generation, facilitating early diagnosis and treatment 3. Climate-based early warning systems for malaria which have on-going evaluation systems
Das 2007	Assessing the storm protection role afforded by mangroves	India	I.Physical and biological constraint:	1. Human death can be greatly reduced by having mangroves in the areas which had mangroves historically

			Mangroves have significant influence on reducing human and property losses (even compared to institutional preparedness measures such as cyclone warning and evacuation).	2. Low-lying areas will need evacuation before a cyclone whether or not mangroves are present 3. Conservation and regeneration of mangroves in coastal areas is a necessity to reduce damages from natural calamities which occur frequently in these areas
IPCC, 2012;	Special report of the IPCC on managing risks of extreme events and disasters to advance CCA	Global	I.Economic and financial constraint: Economic development and urbanization may increase human exposure to extreme weather events, leading to greater economic losses and risks to public health and safety	1. Appropriate and timely risk communication is critical for effective adaptation and disaster risk management 2. Additionally, adaptation and risk management policies and practices will be more successful if they take the dynamic nature of vulnerability and exposure into account, including the explicit characterization of uncertainty and complexity at each stage of planning and practice
Patnaik, 2010	Understand the coping mechanisms adopted by the households in the dryland areas to cope with the distress situations	India	I. Economic and financial constraint: a.Lack of adequate resources: Farmers are often unable to benefit from adaptation measures, which involve significant investment such as irrigation systems, improved or new crop varieties, and diversification of farm operations	1. Need to understand traditional response and coping strategies, level of awareness and priorities 2. Traditional societies develop strategies like loss-minimising land utilization and social arrangement
Ventures, 2011	Rural poor at risk due to damaged private sector microfinance by the Government	India	I. Economic and financial constraint:	1. Facilitate fair restructuring of loans to MFIs to allow time for recovery 2. Supersede, suspend the AP Act (Andhra Pradesh Microfinance Institutions (Regulation of Money

			a.Lack of adequate resources: Microfinance as a risk management mechanism is led by profit-driven commercial firms which have been found to charge usurious interest rates	Lending) Act, 2010 3. Consult with equity stakeholders to ensure the new regulations do no harm
Jones and Boyd, 2011	This paper highlights the role of sociocultural environment in prescribing routes of adaptation action as well as adaptive capacity	Nepal	I.Social and cultural constraints: Social discrimination can also restrict adaptation action. Studies from Nepal and India report that adaptation decisions involving women can be constrained by cultural and institutional pressures that favor male land ownership	1. Deliberative processes in planned adaptation need to understand and take into account social barriers to adaptation without reinforcing interests of some agents over others (enable local autonomous adaptations via community institutions) 2. Transformation of social institutions 3. Strategies employed by NAPA process: bottom-up social vulnerability based approaches, consultation workshops, and transect appraisal exercises for operationalizing participation
Ahmed and Fajber, 2009	The article illustrates how researchers and practitioners can collaborate to strengthen learning across communities and regions.	India	I.Social and cultural constraints: Social discrimination can also restrict adaptation action. Studies from Nepal and India report that hazard information is limited. Men have more access to information than women.	1. Need for rigorous documentation and analysis with communities on successes and challenges of engendering climate-change adaptation 2. Need to scale up gender related CCA interventions to policies and practice at state and national levels 3. Need to emphasize on ways to engender the processes and strategies for adaptation that address priorities and needs in various communities and groups 4. State actors and civil society also need to ensure gender issues are integral to their approaches and explicitly engage women and men of different social groups in priority-setting and development of interventions 5. Building gender concerns into the systems that have been identified as necessary to enhance adaptation: livelihood diversification, infrastructure,

				communication, access to skills and knowledge, and community-based disaster governance. 6. Bridge the disjunctures between disaster risk-reduction and development sectors, to ensure that strategies are both short-term to address immediate impacts, but also long-term to reduce vulnerability and risk, and enhance more climate-resilient development. 7. Strengthening the capacities of communities, sector 8. agencies, development actors, and policy makers to understand climate change and adaptation, and gendered impacts and strategies (eg: use of Vulnerability Capacity Index monitoring tool to provide baseline data about the different physical, social, and attitudinal vulnerabilities of women and men in households and communities, and to assess changes resulting from adaptation interventions)
Chowdhury et al., 1993			I. Social and cultural constraints: a.Gender as a barrier: In South Asian nations, cultural norms and institutional restrictions, increase female vulnerability to flooding, resulting in a disproportionate amount of female deaths	
Biesbroek et al., (in press)	Demonstrate theoretically and empirically that the choice of analytical lens influences how barriers to adaptation are constructed and the intervention strategies proposed.	Global	I.Governance constraints: Failures in design and execution of governance process, actors' incompetence, and faulty institutions	1.Necessary to increase analytical understanding to critically engage in theoretical debates about barriers and to empower policy practitioners in their search for successful intervention strategies to implement adaptation measures

Biesbroek, 2013	Bring some conceptual convergence in these debates by applying a systematic review method to assess the current state of knowledge on barriers to adaptation in peer-reviewed literature	Global	Specific CCA related barriers as 1) the long-term impacts of climate change versus the short-term dynamics of politics and decision-making, 2) the reliance on scientific models to identify, understand, and communicate the problem and propose solutions, 3) and the inherent uncertainties and ambiguities of climate change	1.Vital to mature scientific debates and gain insight on the nature of barriers to adaptation. Future research should go beyond asking the questions 'if' and 'which' barriers to adaptation exist and begin asking 'how' and 'why' barriers emerge
Prabhakar and Shaw, 2008	Implications of CCA on mitigating risks due to droughts	India	I.Governance and institutional constraints: a.Multiplicity and redundancy: Disaster risk management for drought in India displays a lack of coordination in government departments	1. Need a long-term strategy to build the capacities of local governments such that their dependency on the central government is reduced significantly 2. Partnership between local governments and community based organizations will help build the capacities of the both. 3. Specific standard operational procedures need to be established, in addition to the effective drought monitoring, for taking quick decisions on the requests made by the states in the wake of a drought 4. Need an integrated assessment of climate change impacts on biophysical, environmental and socioeconomic aspects by downscaling the outputs from the global and regional simulation models, which would enhance the utility of climate change prediction research for regional policy planning 5.
CDKN, 2014	Future proofing Indian cities	India	I.Governance and institutional constraints: a.Multiplicity and redundancy: 1. Fragmented governance where different actors have different objectives,	c) Cities exhibit diversity in their models of governance and many cities are demonstrating how creative partnership (public, private, and third sectors) play an important role in responding to environmental challenges. Bangalore exhibits how these issues are resolved through private initiatives. Illustrative examples of which are innovative shifts to green design, and emergence of a

			jurisdictional authority, and levels of power or resources make reducing risk challenging 2. There is an absence of effective mechanisms for citizen involvement in decision-making b. Corruption: 1. In Bangalore, it was observed that corruption and collusion between private sector and political authorities was intensifying water scarcity c. Traditional institutional structures have proven ineffective at governing diverse range of actors. The Bangalore Development Authority is understaffed with limited political support and financial resources.	number of city level actors (Karnataka State Council for Science and Technology and Centre for the Study of Science, Technology and Policy) engaging in city level interventions such as (energy efficiency) rainwater harvesting (limited space), train farmers and help link them to policymakers
Dubash and Jogesh, 2014	State Climate Change Planning in India	India	I. Governance and institutional constraints: a.Fragmented governance: Local governments and administrations often consist of different professional silos with their own internal norms, values and priorities and that the institutional rigidity of existing administrative and political sectors creates	1. Inform the plan process with a conceptual framework elaborating the links between climate resilience (adaptation and mitigation), and sustainable development in order to avoid a business as usual approach 2. Structure well-designed processes of ex ante and ex post consultation with stakeholders to generate new ideas, appropriately sequenced with plan

			unfortunate compartmentalization where climate adaptation is seen as the isolated task of a singular sector which may hinder the mainstreaming and horizontal coordination across sectors and departments b. Institutional rigidity: 1. Climate adaptation efforts are often embedded in existing policies, and thus not framed as climate adaptation actions 2. Since the local political and bureaucratic actors were plan drivers, the SAPCC process potentially excluded participation from multiple and less empowered actors	formulation 3. Allow adequate time for climate planning; truncated time frames work against creativity and reinforce a return to existing trajectories
GoI, 2013	State Action Plan on Climate Change	India	I. Governance and institutional constraints: a.Fragmented governance: Local governments and administrations often consist of different professional silos with their own internal norms, values and priorities and that the institutional rigidity of existing administrative and political sectors creates unfortunate compartmentalization where climate adaptation is seen as the isolated task of a singular sector which may hinder the	1. Need inter-departmental coordination: improved coordination between the departments in the state that implement the government programmes and the scientific/technical research and academic institutions (including both national and state level agencies) 2. Need to strengthen institutional decision-making mechanisms and processes and capacity building (including monitoring & evaluation) to ensure cross-sectoral coordination related to climate change

			mainstreaming and horizontal coordination across sectors and departments	
Patankar et al., (2010)	Analyze responses post disaster (floods) in coastal cities	Bangkok, Mumbai, Manila	I. Governance and institutional constraints: a.Top down approaches: In the context of urban flooding in Mumbai- Moving from the national to state to city level, there is devolution of functional aspects without a simultaneous financial decentralisation. Therefore, local municipalities have the power but not the money to undertake adaptation action. This lack of proper municipality-led adaptation drove private/individual adaptation	1. A Fact Finding Committee was appointed to look into the causes and to recommend activities to reduce the future risks of flooding in Mumbai. The committee recommendations include: upgradation of storm water drainage system, improving disaster management, risk zoning, early warning mechanisms, to improve the existing environment and upgrade and improve the governance and management
Byravan and Chella Rajan, 2009	Climate change leading to immigration	US	I. Governance and institutional constraints: a.Low capacity to deal with unprecedented changes: Existing institutional arrangements may not be sufficiently equipped to handle new shocks such as within and across country migration in India resulting from sea-level rise	1. Immigration as a climate policy: Formulate domestic policy to start absorbing a significant proportion of the most vulnerable climate exiles from small island states. Provide immigration rights over, say, a five-year period to up to 1,00,000 or so of the most vulnerable climate exiles currently living in low-lying atoll nations in the Pacific and Indian Oceans, without increasing its overall intake of legal immigrant

Ganguly and Panda (2010)	The study focuses on the Union Budgets of India for the fiscal years 2006-07 to 2009-10, in order to ascertain the fiscal priorities ascribed to different sectors of adaptation and provide a robust baseline on government expenditure on adaptation in India	India	I. Governance and institutional constraints: a.Absence of certain actors and sectors: 1. Sectors such as food security, rural and urban housing for the poor, and health and education infrastructure have received inadequate attention in policy response on adaptation. 2. Regional priorities and needs are sometimes subverted which drives inequities	1. Availability of additional resources should be based on vulnerability assessment of different sectors of the economy.
Mandal, 2014	Assessing the agricultural adaptation practices in South Asia	South Asia	I. Governance and institutional constraints: a.Absence of certain actors and sectors: The lack of knowledge exchange between think tanks and grassroots organisations in India results in weak representation of such actors and their opinions in policymaking	1. Promote programmes that encourage and facilitate research cooperation and knowledge sharing (eg: Knowledge and information sharing, conservation of species, India and Bangladesh)
Pelling et al., 2008	Understanding the patterns of individual and collective action within organisations that can enhance or restrict organisational adaptive capacity in the face of abrupt climate change		Overcoming barriers	A few examples of overcoming barriers include understanding and addressing underlying causes of these barriers better through capacity building, collaborative research and projects through informal partnerships and formal interagency working groups

Eisenack et al., 2014	Explaining and overcoming barriers to CCA	Global	Overcoming barriers	1. Clear assignment of responsibilities and accompanying monitoring mechanisms can overcome barriers 2. Informal partnerships, formal interagency working groups and other deliberative venues 3. Adaptation barriers can be overcome, avoided or reduced by individual or collective action with concerted effort, innovative management, changed ways of thinking, political will, and reprioritization of resources, land uses and institutions
Archer, 2014	This paper aims to offer insights into the different scales at which CBA can be mainstreamed in urban contexts, and the various ways in which this is happening		Governance and institutional barrier	1. CBA is one of multiple tools for municipal climate governance 2. Ensure top-down priorities are aligned with local-level needs 3. Seize opportunities for institutional reform to put community-based approaches on the agenda 4. Institutionalize multi-stakeholder approaches to facilitate national mainstreaming 5. Participatory research to influence local government adaptation planning
IPCC, 2014	IPCC AR5 WGII: Adaptation Opportunities, Constraints, and Limits	Global	I. Knowledge, awareness and technological constraints: a. Knowledge deficits: Arise due to the challenges regarding decision-making under uncertainty about the future. This is a common problem identified by adaptation practitioners and stakeholders in both developed and developing countries.	1. Sustainable economic development is an over-arching process that can facilitate adaptation, and represents a key opportunity to reduce adaptation constraints and limits. 2. Actions or processes that enhance the awareness of adaptation actors and relevant stakeholders and/or enhance their entitlements to resources can expand the range of adaptation options that can be implemented and help overcome constraints. 3. The development and application of tools to support assessment, planning, and implementation can aid actors in weighing different options and their costs and benefits. 4. Policies, whether formal policies of government institutions, initiatives of informal actors, or corporate

			b. Technological deficit: Technological adaptation are sector specific. II. Physical and biological constraints: a.Resource availability and access: Population growth and economic development also drive greater resource consumption and ecological degradation. This in turn can constrain adaptation in regions where livelihoods are closely linked to ecosystem goods and services. III. Economic and financial constraints: a. Restricted access to financial capital: 1.Challenges the implementation of specific adaptation strategies and options	policies and standards, can direct resources to adaptation and/or reduce vulnerability to current and future climate. 5. Finally, the ability for humans to learn from experience and to develop new practices and technologies through innovation can significantly expand adaptive capacity in the future 6. *Awareness raising:* stakeholder engagement, communication of risk and uncertainty, participatory research 7. *Capacity building:* Research, data, education, and training, Extensions services for agriculture, Resource provision, Development of human capital, Development of social capital 8. *Tools:* Risk analysis, Vulnerability assessment, Multi-criteria analysis, Cost/benefit analysis, Decision support systems, Early warning systems 9. *Policy:* Integrated resource and infrastructure Planning, Spatial planning, Design/planning standards 10. *Learnings:* Experience with climate vulnerability and disaster risk, Learning-by-doing, Monitoring and evaluation 11. *Innovation:* Technological change, Infrastructure efficiencies, Digital/mobile telecommunications

			b. International level: 1. Concerns such as effectiveness of mechanisms, lack of incentives among donors to allocate funds for adaptation and potential for allocation of funds to adapt to climate change and meet developmental goals have been identified 2. Developing a framework to ensure the equitable and effective allocation of adaptation funds is a challenge for developing countries. c. Near-term economic costs of societal adaptation may be significant, which will increase incrementally as the climate changes. Hence, higher rates or magnitudes of climate change may reduce the effectiveness of some adaptation options, and drive up adaptation costs IV. Governance and institutional constraints: a.Top-down approaches: Higher levels (state or federal governments or private companies) tend to impede local	

			adaptation efforts b. Institutional rigidity Takes the form of path dependency where past policies, decisions, habits and traditions, constrain the extent to which systems can learn or adapt to climate change c. Corruption: Corruption within institutions also challenges adaptation efforts especially within developing countries	
Adger et al., 2007	IPCC AR4: Assessment of adaptation practices, options, constraints and capacity	Global	I. Knowledge, awareness and technological constraints: a. Technological constraint: Technological adaptation solutions may not be economically practical or culturally acceptable options b. Information on climate change (causes, impacts and potential solutions) does not essentially translate into adaptation solutions	1. Policy and planning processes need to take the various constraints into account in the design and implementation of adaptation. 2. High priority should be given to increasing the capacity of countries, regions, communities and social groups to adapt to climate change in ways that are synergistic with wider societal goals of sustainable development 3. Research is needed to monitor progress on adaptation, and to assess the direct as well as ancillary effects of such measures as adaptation initiatives are very recent 4. Need for research on the synergies and trade-offs between various adaptation measures, and between adaptation and other development

			and barriers include availability of usable information and using information for decision-making II. Physical and biological constraints: a.Transformations and regime shifts: Climate change may lead to transformations of the physical environment, which may consequently constrain adaptation. b. Regime shifts in ecosystems associated with climatic changes and other drivers can constrain economic and social adaptation III. Economic and financial constraints: a.Economic development and urbanization: Certain economic enterprises may be economically profitable but could constrain adaptation and aggravate vulnerabilities.	priorities 5. Research is also required on the resilience of socioecological systems to climate change

			b. Lack of adequate resources: Farmers are often unable to benefit from adaptation measures, which involve significant investment such as irrigation systems, improved or new crop varieties, and diversification of farm operations. IV. Social and cultural constraints: Conflicting understandings and approaches can hinder adaptive actions.