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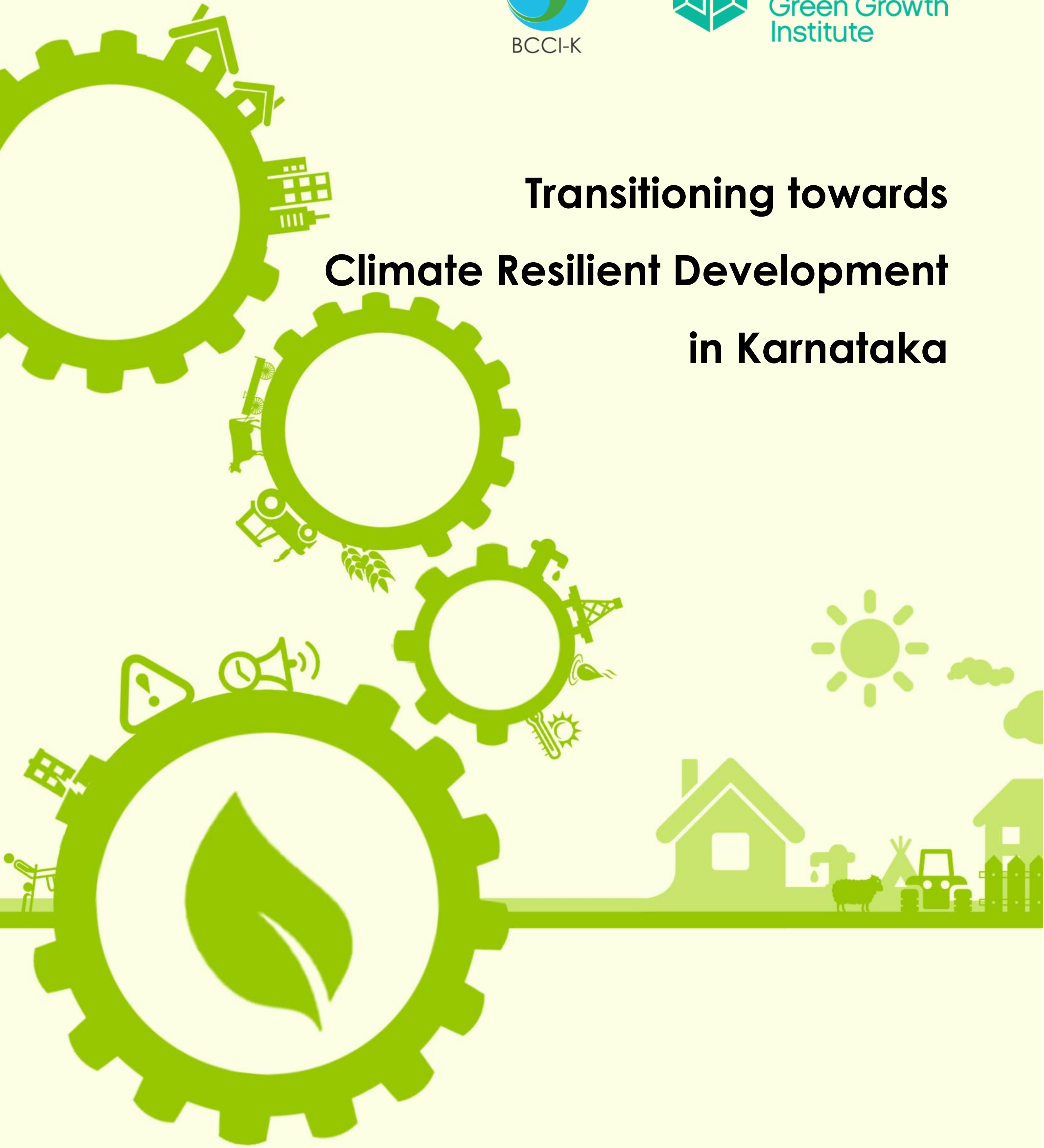
Transitioning towards Climate Resilient Development in Karnataka



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Transitioning towards Climate Resilient Development in Karnataka

Centre for Sustainable Technologies

Indian Institute of Science, Bangalore

December 2014

This report forms deliverables of the project initiated by the Global Green Growth Institute (GGGI) and the Bangalore Climate Change Initiative--Karnataka (BCCI-K) with its consortium partners: Center for Study of Science, Technology and Policy (CSTEP, Bengaluru), Indian Institute of Science (IISc, Bengaluru), University of Agricultural Sciences (UAS, Bengaluru), Institute for Social and Economic Change (ISEC, Bengaluru), Integrated Natural Resource Management (INRM, New Delhi) and the London School of Economics-India Observatory (LSE-IO, London).

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Foreword

Climate change is an emerging environmental and developmental challenge facing humanity today, and Karnataka is likely to be more vulnerable than other states. Karnataka's agriculture is rain-fed to a large extent (68% of its farmland has no irrigation, droughts are frequent, a large share of electricity is generated by hydropower, some regions face severe and perennial water shortage and so on). Further, in terms of areas prone to drought, Karnataka is next only to Rajasthan. There is adequate scientific evidence to prove that climate change is already impacting crop productivity, forest biodiversity, hydrological processes and human health. Further, the latest Intergovernmental Panel on Climate Change (IPCC) Report (2014) has concluded that climate change could be more severe, intense and take effect sooner than previously expected. The report finally concludes that it is nearly impossible to hold global warming at the globally agreed upon level of < 2° C. Thus it is imperative for states such as Karnataka to develop an understanding of the potential climate change impacts and vulnerabilities and develop coping strategies to deal with current climate variability and build resilience towards long-term climate change.

Bangalore Climate Change Initiative-Karnataka (BCCI-K), in collaboration with Global Green Growth Institute (GGGI), Seoul, South Korea, has completed an assessment of climate change projections using the latest Coupled Model Intercomparison Project Phase 5 (CMIP-5) models (IISc); assessed the impacts of climate change using the latest impact assessment models for water (INRM), agriculture (UAS), and forest sectors (IISc); developed vulnerability profiles at district (ISEC) and village levels (IISc); evaluated the current coping strategies (LSE); and developed a preliminary strategy for mainstreaming adaptation in developmental programmes, along with providing preliminary recommendations for climate-resilient development in Karnataka.

This report provides a summary of climate change projections for the short- and long-term, assessed using the latest global climate models. This is followed by an assessment of the impact of climate change on water resources, agricultural crop production and forest ecosystems. Vulnerability of communities and production systems has been assessed at the district, village and household levels to identify and rank the most vulnerable communities and districts. Currently, farmers and rural communities are exposed to inter- and intra-annual variability of the climate. In this context, the current coping strategies and their adequacy to deal with current climate variability is assessed as an indication of their vulnerability to future climate change risks. Finally, the adaptation component of developmental programmes already implemented in Karnataka is assessed, followed by a set of potential recommendations for different sectors.

There is a need to recognise the uncertainties involved in the climate change projections as well as the limitations of the impact assessment models. The science of climate change is still evolving and there is a need for continued updating of the knowledge on climate change projections, impacts and vulnerabilities. Adaptation strategies need to be urgently developed and implemented to build resilience to current climate variability, climate change risks and other environmental stresses.

Professor N.H. Ravindranath

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TRANSITIONING TOWARDS CLIMATE RESILIENT DEVELOPMENT IN KARNATAKA

Climate change is an emerging environmental and developmental challenge facing humanity today, and Karnataka is likely to be more vulnerable to climate change than other states: Karnataka's agriculture is rain-fed to a large extent (68% of its farmland is without irrigation, droughts are frequent, a large share of electricity is generated by hydropower, some regions face severe and perennial water shortage, and so on). Further, in terms of areas prone to drought, Karnataka is next only to Rajasthan; 54% of Karnataka's geographical area is drought prone, with drought affecting 88 of the state's 176 taluks and 18 of its 30 districts. There is adequate scientific evidence to show that climate change is already impacting crop productivity, forest biodiversity, hydrological processes and health. IPCC (2013) further concludes that "warming of the climate system is unequivocal, since the 1950s and many of the observed changes are unprecedented over decades to millennia. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. Continued emissions of greenhouse gases will cause further warming". While the current increase in global mean temperature since the pre-industrial period has been estimated at about 1° C, recent reports have highlighted the catastrophic impacts of increase in global mean temperature crossing 2° C. Therefore, under Cancun Agreement, there is global consensus to hold warming at 1.5° to 2° C, above the pre-industrial period, to avoid catastrophic impacts. Several studies have also shown that it is highly unlikely that the global mean warming could be stabilized below 1.5 °C to 2 °C, given the current trends in GHG emissions. Thus it is very important for states such as Karnataka to develop an understanding of the potential climate change impacts and vulnerabilities and develop coping strategies to deal with current climate variability and build resilience for long-term climate change.

Bangalore Climate Change Initiative-Karnataka (BCCI-K), in collaboration with Global Green Growth Institute (GGGI), Seoul, South Korea, has completed Phase 1 of the project aimed at promoting climate resilient development of Karnataka. Under this initiative, research institutions have completed an assessment of climate change projections using the latest Coupled Model Intercomparison Project Phase 5 (CMIP-5) models (IISc); assessed the impacts of climate change using the latest impact assessment models for water (INRM), agriculture (UAS), and forest sectors (IISc); developed vulnerability profiles at district (ISEC) and village levels (IISc); evaluated the current coping strategies (LSE); and developed a preliminary strategy for mainstreaming adaptation in the developmental programmes along with preliminary recommendations for climate-resilient development for Karnataka. Climate change projections and impacts are assessed for two scenarios, namely moderate emissions (RCP 4.5) and high emissions (RCP 8.5), while the current emission trends are even higher than those assumed in RCP 8.5.

Here we present a synthesis report of the detailed studies conducted under the collaborative project.

Climate and Bio-physical Features of Karnataka

Karnataka can be divided into four regions based on physiographic features: 1) the coastal region, 2) Malnad, or the hilly region, 3) the northern plateau, and 4) the southern plateau. The climate varies from arid to semi-arid in the plateaus and sub-humid to humid tropical in Malnad to humid tropical monsoon climate in the coastal region. Of the average annual rainfall received in the state, 80% is in the south-west monsoon period; 12%, in the post-monsoon period; 7%, in summer; and only 1% is in winter. The north-eastern monsoon, mainly between October and December[1], accounts for about 30% of the annual rainfall in the eastern part of south interior Karnataka.

Karnataka is divided into ten agro-climatic zones (Figure 1) taking into consideration the rainfall pattern; the type, texture, depth, and physio-chemical properties of soil; elevation; topography; and major crops and types of vegetation (Table 1).

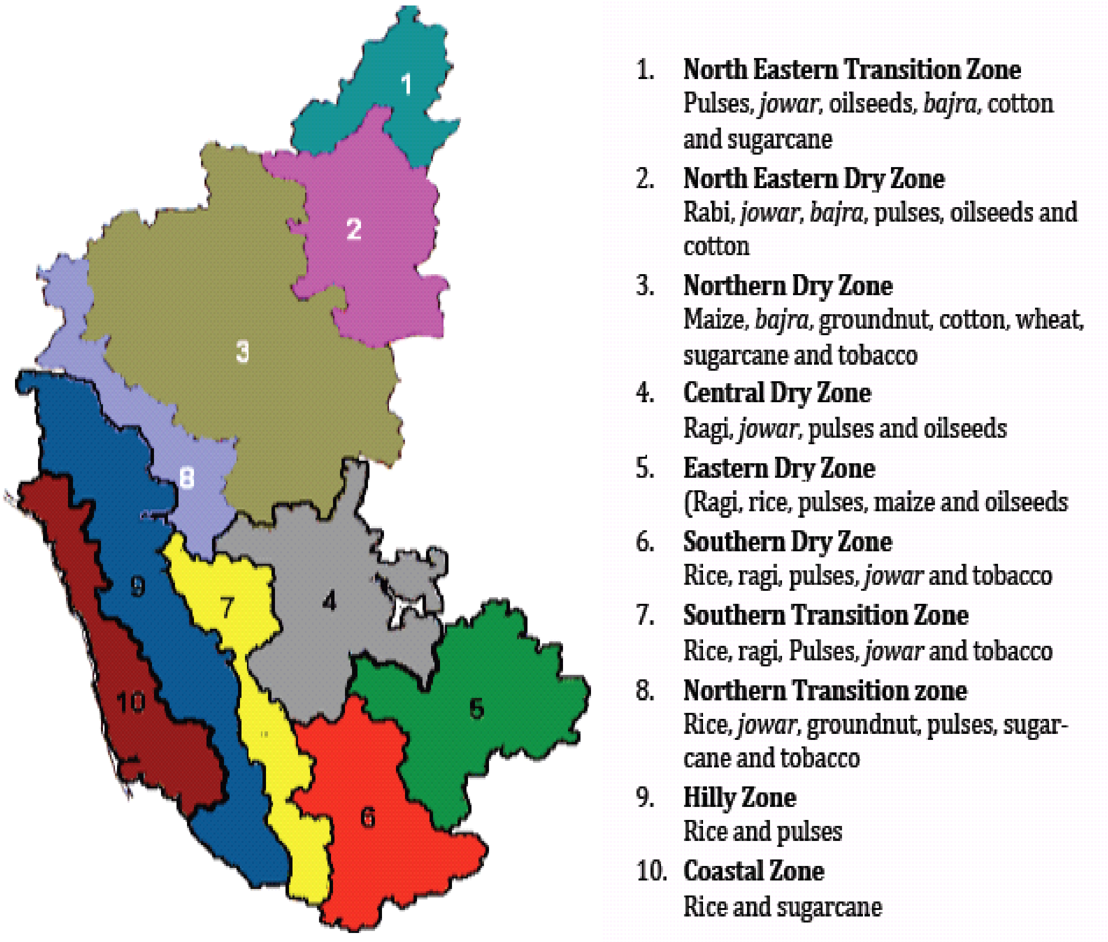

Figure 1: Agro-climatic Zones and Dominant Crops Grown

According to Census 2011, rural and urban populations accounted for respectively 61% and 39% of the total population of 61.13 million. Of the total geographical area of 19 million hectares, total cropped area is 67.7% and forest area is 19%.

[1]EMPRI & TERI (2011). *Karnataka State Action Plan on Climate Change*. Draft Report for Government of Karnataka, prepared by Environmental Management & Policy Research Institute and The Energy and Resources Institute.

Table 1: Agro-Climatic Zone and Dominant Crops

Agro-climatic zone	Area (Mha)	Rainfall range (mm)	Elevation (m)	Soil type
	0.871	830–890	800–900	Major: Shallow to medium black clay Minor: Red lateritic soils
North-Eastern Dry	1.762	633.2–806.6	300–450	Major: Deep to very deep black clay Minor: Shallow to medium black
Northern Dry	4.78	464.5–785.7	450–900	Major: Medium to deep black clay Minor: Sandy loam
Central Dry	1.943	453.5–717.7	450–900	Major: Red sandy loams Minor: Shallow to deep black clay
Eastern Dry Zone	1.808	679.1–888.9	800–900	Major: Red loamy Minor: Clay lateritic
Southern Dry	1.739	670.6–888.6	450–900	Major: Red sandy loams Minor: Black clay
Southern Transition	1.218	611.7–1053.9	800–900	Major: Red sandy loams Minor: Red loamy
Northern Transition	1.194	619.4–1303.2	450–900	Shallow to medium-black clay and red sandy loamy soils in equal proportions
Hilly (Malnad)	2.56	904.4–3695.1	800–1500	Major: Red clay loamy
Coastal	1.167	3010.9–4694.4	<300–800	Red lateritic and coastal alluvial

Karnataka has seven river systems. The two main river systems are the Krishna and its tributaries, namely the Bhima, Ghataprabha, Vedavathi, Malaprabha and Tungabhadra in the north and the Cauvery and its tributaries, namely the Hemavathi, Shimsha, Arkavati, Lakshmanathirtha, and Kabini in the south. Both these rivers flow eastward to drain into the Bay of Bengal[2] (Figure 2). Additionally, there are nine west-flowing rivers that drain into the Arabian Sea (Table 2).

[2]Gosain, A.K. et al (2013). *SWAT Hydrological Modelling of the River Basins of Karnataka*. Draft report to the Global Green Growth Institute.

Table 2: River Systems of Karnataka

River system	Tributaries	Catchment area (sq. km)	Drainage area	
			1000 sq. km	%
Krishna	Ghataprabha	8829	113.29	59.48
	Malaprabha	11,549		
	Bhima	70,614		
	Tungabhadra	47,866		
Cauvery	Harangi	717	34.27	17.99
	Hemavathi	5410		
	Kabini	7040		
	Suvarnavathy	1787		
	Lakshmanathirtha	1690		
	Shimsha	8469		
	Arkavati	4351		
West-flowing rivers	Mahadayi/Mandavi	2032	24.25	12.73
	Kali	4188		
	Gangavalli (Bedthi)	3574		
	Aghanashini (Tadri)	1330		
	Sharavathi	3592		
	Chakra Nadi	336		
	Varahi (Haladi)	759		
	Netravathy	3222		
	Barapole (Valapattanam)	1867		
North Pennar	Uttara Pinakini	6937	6.94	3.64
Godavari	Manjra	4406	4.41	2.31
South Pennar	South Pennar	4370	4.37	2.29
Palar	Palar	2813	2.97	1.56
		Total	**190.50**	**100**

In Karnataka, agriculture is predominantly rain-fed, with 24.3% of the net sown area lying in a medium rainfall region and 66.3% in low rainfall regions. Food crops occupied 75% of the net sown area as of 2008/09[3] (Table 3).

In terms of area prone to drought, Karnataka is second only to Rajasthan: 54% of Karnataka's geographical area is drought prone (Figure 3), affecting 88 out of its 176 blocks and 18 of its 30 districts. Blocks of northern drought-prone districts have, in general, more years of moderate and severe drought (absence of rainfall for more than 40 consecutive days) than blocks in southern districts.

[3]Mahesha, D. and Shivalingappa, B.N. (2012). *Changes of Cropping Pattern in Karnataka – A Geographical Study*. Golden Research Thoughts.

Table 3: Land Use and Crop Trends in Karnataka: 1995/96 to 2010/11

Land-use type	Crop type*	Crop*	Mean area (lakh ha)	CAGR (%)
Agriculture*[4]	Cereals	Rice	12.80	0.832
		Sorghum	18.02	–2.974
		Pearl millet	4.13	–1.438
		Maize	4.61	8.019
		Ragi	10.03	–1.395
	Total pulses	Red gram, black gram, green gram, chickpea	11.78	3.01
	Oilseeds	Groundnut	10.25	0.055
		Sunflower	8.28	4.040
	Commercial crops	Cotton	5.85	–2.276
		Sugarcane	3.04	4.143
Forests			30.68	0.020
Non-agricultural land			13.32	0.809
Barren and non-cultivable land			7.92	–0.095
Pastures and grazing land			9.57	–0.746
Tree crops and other groves			3.00	–0.700
Wasteland			4.24	–0.408
Current fallows			4.53	–0.258
Other fallows			14.33	–0.398

*Numbers for land use in agriculture were taken for the period 1982/83 to 2007/08.

Overall trends for various crops over the past four decades show that the area under oilseeds followed by cotton has been the most volatile, other crops like maize, sugarcane, and coconut have increased consistently whereas millets such as sorghum (jowar) and pearl millet (bajra) have declined consistently, and area under rice and ragi has shown marginal variations[5]. Kharif crops are cultivated in all agro-climatic zones, whereas rabi crops are mostly cultivated in the North-Eastern Dry and the Northern Dry zones with substantial irrigation.

Groundwater provides 45% of the irrigation in the State6. Among different districts, Shimoga has approximately 62% of its total cropped area under irrigation, and Kodagu only 2.34%. In northern Karnataka, Belgaum has 48.9% of its cropped area under irrigation and in southern Karnataka, Mandya has 57.52% of its area under irrigation, which is the second highest in the

[4]Acharya, Saraswati Poudel et al (2012). *Growth in area, production and productivity of major crops in Karnataka*. Karnataka J. Agric. Sci., 25 (4): 431-436.
[5]Purushothaman, Seema and Sham Kashyap (2010). *Trends in land use and crop acreages in Karnataka and their repercussions*. **Karnataka J. Agri. Sci.**, 23 (2): 330–333.
[6]EMPRI and TERI (2012). *Karnataka State Action Plan on Climate Change: 1st Assessment*. Prepared by Environmental Management & Policy Research Institute and The Energy and Resources Institute.

state. The existing major reservoirs in the northern regions have the potential to bring additional area under irrigation.

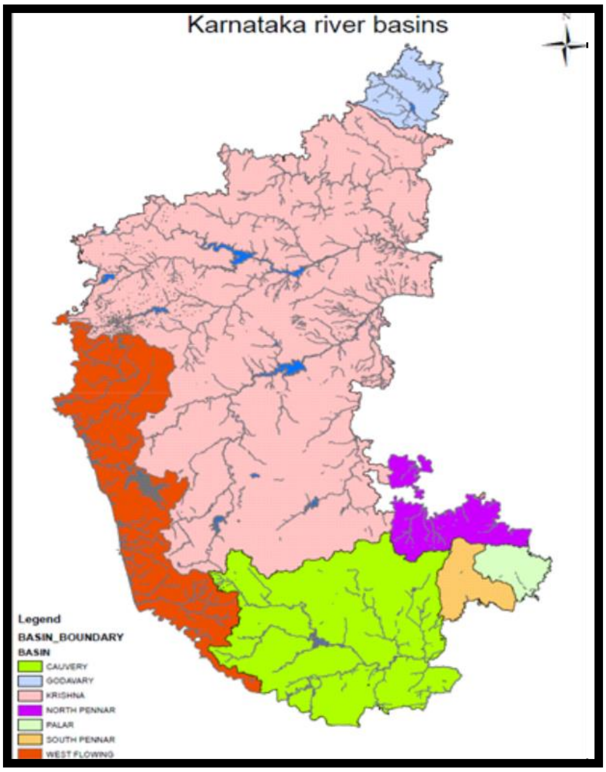

Figure 2: River Basins in Karnataka

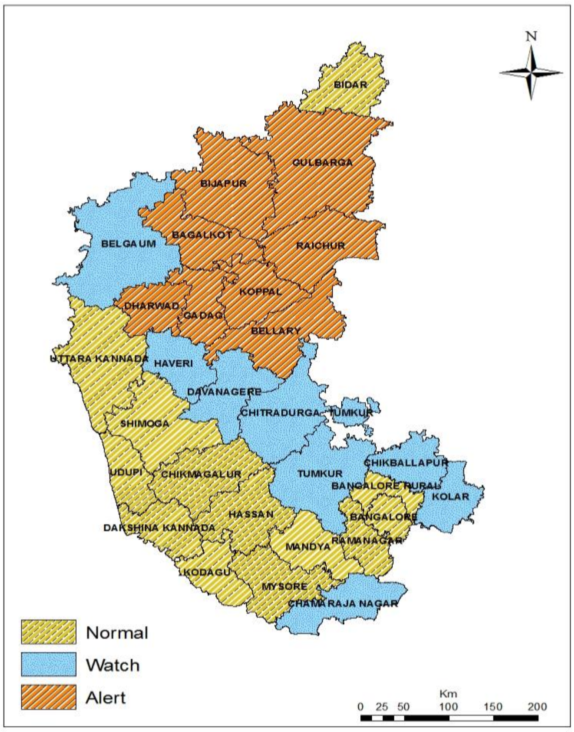

Figure 3: Agricultural Drought – July 2012

Farmers and agricultural labour account for nearly 57% of Karnataka's workforce, with horticulture contributing to 40% of the income from agriculture, and 38% of rural households have livestock and poultry, contributing significantly to their livelihood. With 320 km of coastline and 0.5 million hectares of inland water area, fishing is a major source of livelihood, engaging about 300,000 people directly or indirectly. Within the agriculture sector, the share of fisheries is increasing, while marine fish production is declining in terms of per-unit effort and return on investment.

Current Climate Variability and Future Climate Change Projections

The variability in Karnataka's climate observed over the last century, projections of climate change based on an ensemble mean of 18 Global Climate Models (GCMs), and new emission scenarios are presented below. Representative concentration pathways (RCP), which constitute new scenarios of the emissions of greenhouse gases (GHGs), represent different levels of radiative forcing leading to different levels of warming (2.6, 4.5, 6.0, and 8.5 Watts/m^2). The ensemble mean of 18 climate models is used in this report to make the projections more reliable.

Temperature trends over the last century suggest that Karnataka has warmed by about 0.4 °C (Figure 4). Minimum temperature in northern Karnataka (Bidar, Bijapur, Gulbarga, Raichur, and Yadgir districts) increased by ≥ 0.6 °C over the same period, and so did the maximum temperature in these districts (except Bidar) and all over southern Karnataka.

Rainfall trends over the last century indicate an overall decrease in annual rainfall in Karnataka by 10% (Figure 5). The decrease is more than 10% in Chikmagalur, Dakshina Kannada, Kodagu, Shimoga, Uttara Kannada, and Udupi. Rainfall has also declined significantly in northern districts such as Bidar, Bijapur, Gulbarga, and Yadgir.

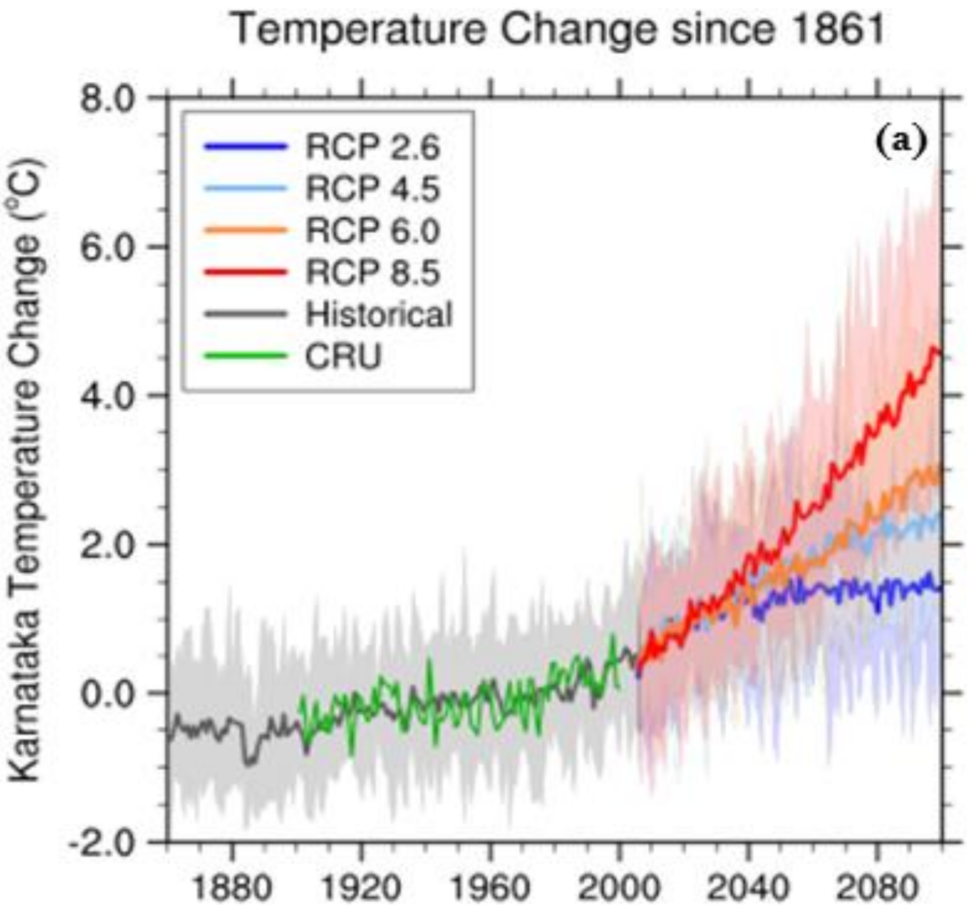

Figure 4: CMIP5-Model-based Time Series of Temperature Anomalies for Karnataka (1861 to 2099)

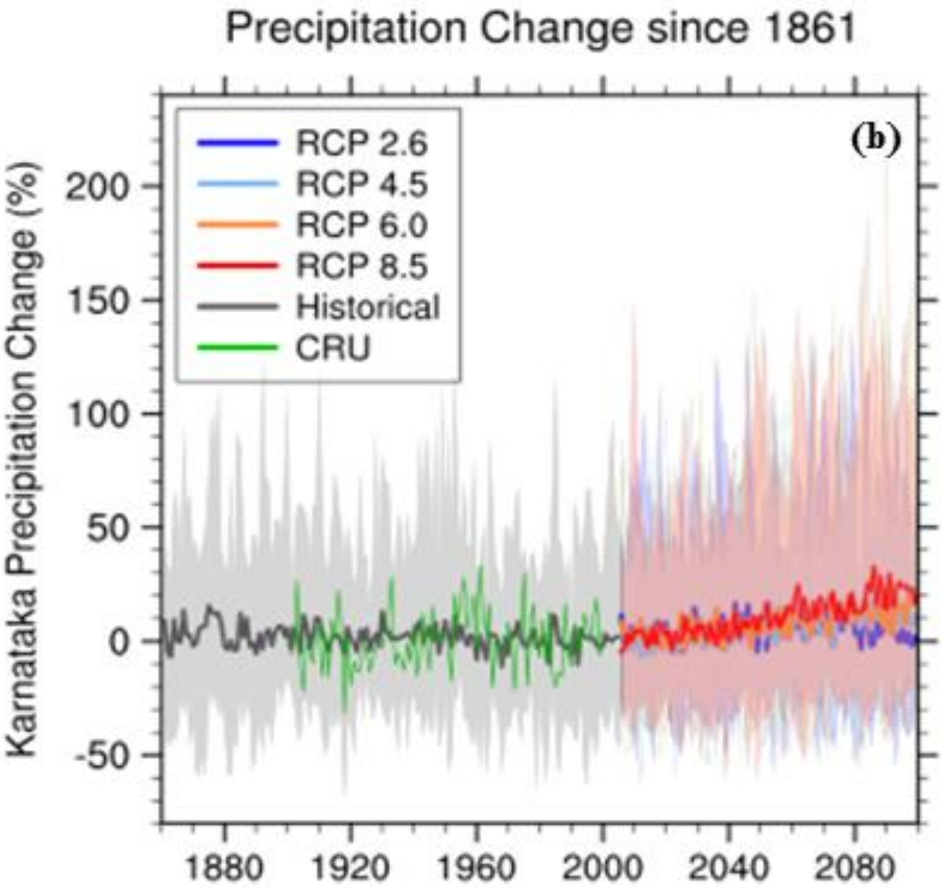

Figure 5: CMIP5-Model-based Time Series of Precipitation Anomalies for Karnataka (1861 to 2099)

For Karnataka, the projected mean warming relative to that in the pre-industrial period could be in the range of 1.0–3.0 °C by the 2030s (Figures 4 and 6). In the short term (2030s), temperature is projected to increase by about 1.7 °C relative to that in pre-industrial period (1880s) according to the moderate-emissions scenario (RCP 4.5). Chitradurga, Koppal, Raichur, and Tumkur are projected to experience the highest warming (2.0 °C and above) even by the 2030s under RCP 8.5 (Figure 6).

In the long term (2080s), the mean temperature increase for Karnataka could be as high as 5.0 °C by the end of the century under the high-emissions scenario (RCP 8.5) relative to that in the pre-industrial period (Figures 4 and 6). Most districts other than the coastal districts show a higher warming of above 4.0 °C by the 2080s. The annual mean temperature is projected to increase by 2.0–3.0 °C according to the moderate-emissions scenario (RCP 4.5). Most parts of the state are projected to experience a warming of 3.0–5.0 °C according to the higher-emissions scenario (RCP 8.5) (Figure 6).

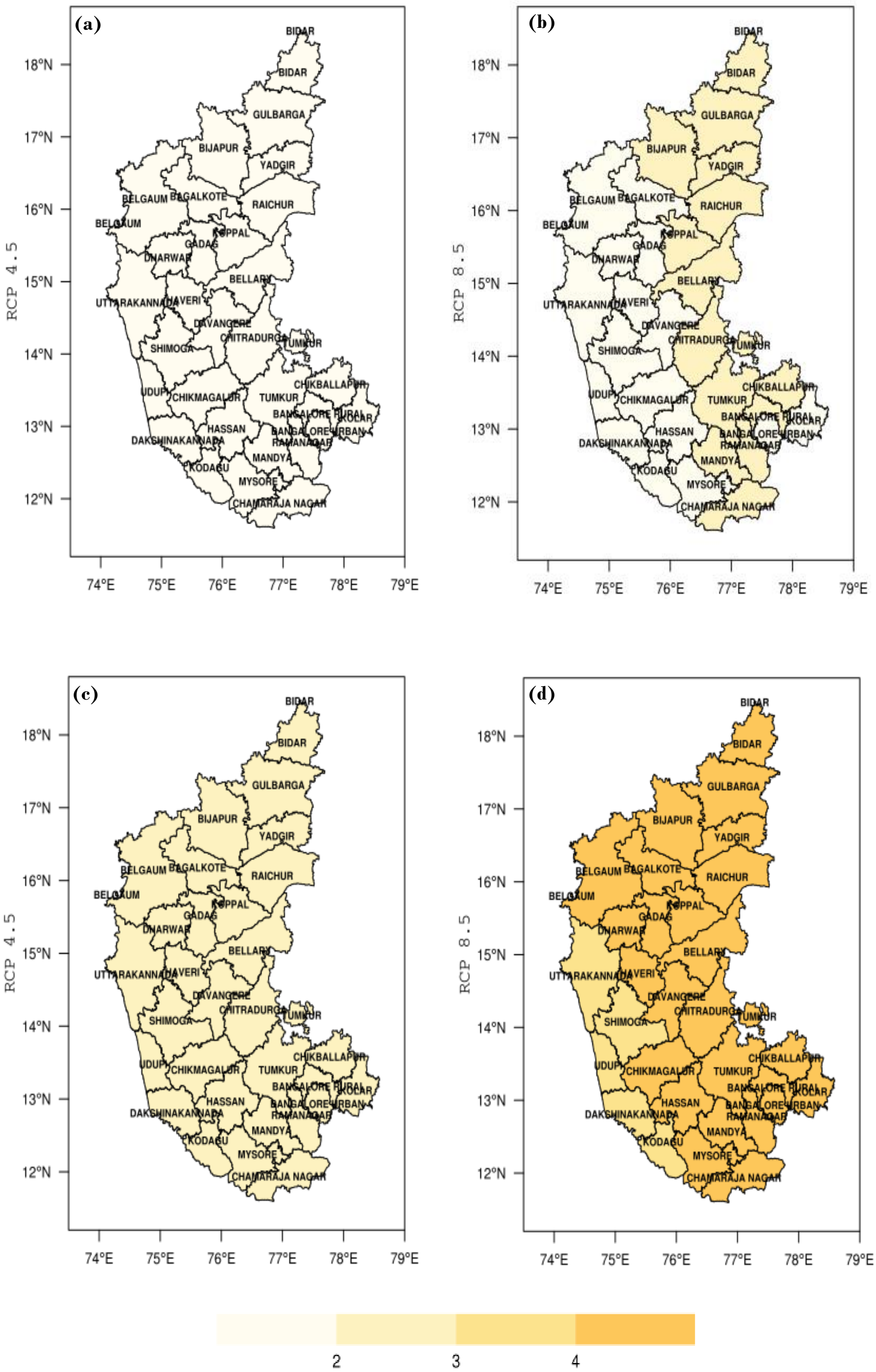

Figure 6: District-wise Projected Annual Temperature Change

Note: (C) for 2030s (top panel) and 2080s (bottom panels) relative to the pre-industrial period (1880s) for RCPs 4.5 (left panels) and 8.5 (right panels) scenario.

Models-based projections for rainfall show a wide range in percentage change for Karnataka (Figures 5 and 7). In the short term (2030s), rainfall is likely to be marginally higher (4%–8%) in Bidar, Bijapur, Gulbarga, Kolar, and Yadgir districts even under the moderate-emissions scenario (RCP 4.5) relative to that in the pre-industrial period (1880s). A similar increase in rainfall is likely in northern districts such as Bagalkote, Belgaum, Bellary, Bidar, Bijapur, Dharwad, Gadag, Gulbarga, Koppal, Raichur, and Yadgir by the 2030s under RCP 8.5 (Figure 7).

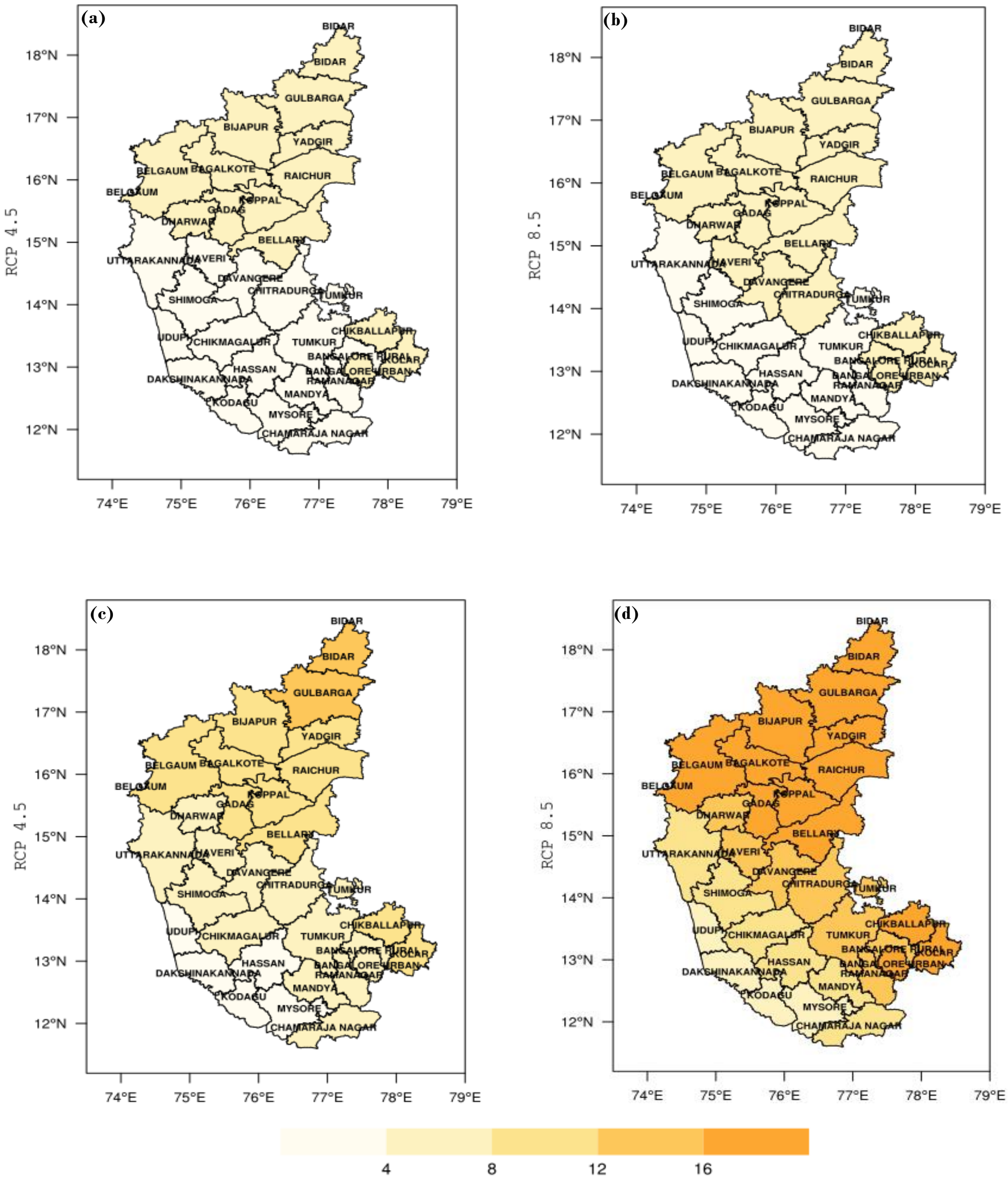

Figure 7: District-wise June to September Change in Rainfall (%)

Note: Projected for 2030s (top panels) and 2080s (bottom panels) relative to pre-industrial period (1880s) for RCPs 4.5 and 8.5 (right panels) scenarios.

In the long term (2080s), a moderate increase (8%–12%) is likely in almost all the northern districts under the moderate-emissions scenario (RCP 4.5) relative to that in the pre-industrial period (1880s). Northern districts such as Bagalkote, Belgaum, Bidar, Bijapur, Dharwad, Gadag, Gulbarga, Koppal, Raichur, and Yadgir and south-eastern districts such as Bangalore, Chikballapur, and Kolar are projected to experience a higher than 16% increase in rainfall under the high-emissions scenario RCP 8.5 (Figure 7).

Global Climate Models used in this study have coarse resolutions (grids of about 200 km × 200 km); therefore, large uncertainties in our projections are likely at, say, the district level. However, in the future, Regional-Climate-Model-based projections at finer scales (50 km × 50 km or 25 km × 25 km) are likely to become available, and will be used to assess the impact of climate change on food production, water resources, forest biodiversity, and coastal zones.

Most parts of Karnataka could experience 1.5–2 °C warming by as early as the 2030s, relative to that in the pre-industrial period (1880s), under the high-emissions scenarios. Agreements at the global level have emphasized the need to stabilize global warming at 1.5–2.0 °C to avoid dangerous consequences of climate change for sustainable food production and ecosystem services. Thus climate change is a serious concern for Karnataka and efforts must be made to assess the impacts of climate change and build food production systems and natural ecosystems resilient to those impacts.

Impacts of Climate Change on Water Resources

Impacts of climate change on the availability of water in those parts of the basins of Cauvery, Krishna, and of the west-flowing rivers Kali, Netravati, and Sharavati, that fall in Karnataka are assessed using the distributed hydrological model SWAT. The data available in public domain on elevation, drainage network, land use, and soils have been used to set up the base SWAT model for the river basins. For assessing the impact of climate change, projections of climate change from the climate model IPSL-CM5A-MR are used. The SWAT model simulations are performed for the baseline (1961–1990) and the mid-century (2021–2050) periods for RCP 4.5 (moderate emissions) and RCP 8.5 (high emissions) for assessing the impacts of climate change on water resources in Karnataka.

The SWAT model was validated at a number of locations for which stream flow data were available and the validation was found to be satisfactory. For the validation exercise, details of the existing major infrastructure related to water resources, namely reservoirs and diversions, were taken from the National Register of Large Dams. Daily rainfall and temperature data (1979–2007) from India Meteorological Department (IMD) are used for modelling. Efforts have also been made to incorporate the current management/operation practices and existing irrigation levels. The components of the water balance used for the analyses include precipitation and water yield consisting of surface run-off, lateral and base flows, actual evapotranspiration, and groundwater recharge for each basin. Total rainfall is split more or less equally between water yield and evapotranspiration loss in both Cauvery (**Figure 8**) and Krishna basins. In contrast, the water yield is about 75%–80% of the total rainfall, and evapotranspiration losses are very small in the basin of the west-flowing rivers Kali, Netravati, and Sharavati. While stream flow in the Cauvery basin is driven by both south-west and north-east monsoons, it is mainly driven by the south-west monsoon in other basins.

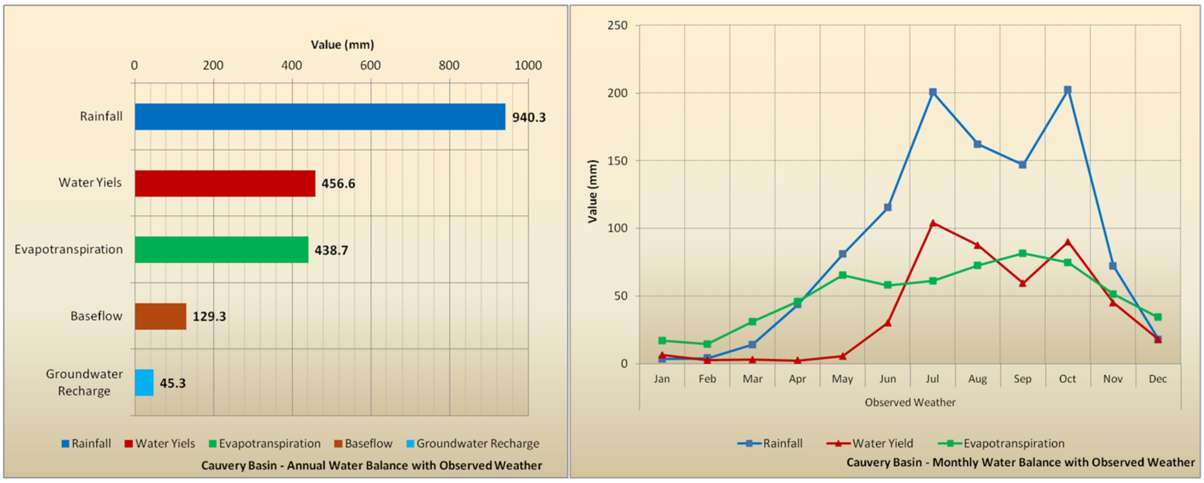

Figure 8: Water Balance Components (WBC) of Cauvery River Basin

For the mid-century period (2021–2050), water yield in the Cauvery basin is projected to increase by about 35% and 15% for RCP 4.5 and RCP 8.5 respectively, although the evaporative losses would remain nearly unchanged. The increase in water yield in the Cauvery basin is mainly driven by the projected increase in precipitation (**Figure 9**): 8% for RCP 4.5 and 13% for RCP 8.5. In the case of Krishna basin too, the simulated evapotranspiration is nearly unchanged between the baseline and mid-century (**Figure 10**). For this basin, precipitation is projected to increase by 9% for RCP 4.5 and remain unchanged for RCP 8.5. Consequently, water yield in this basin is projected to increase by 29% for RCP 4.5 but by only 4% for RCP 8.5.

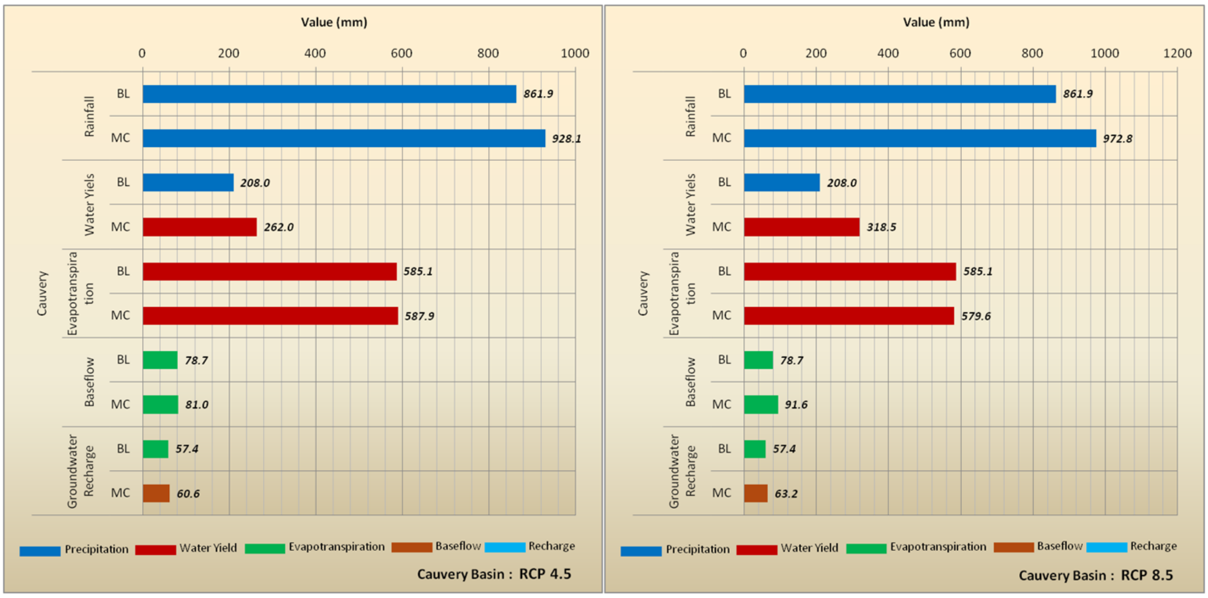

Figure 9: Annual WBC for Baseline and Mid-Century Climate Scenarios; Cauvery River Basin

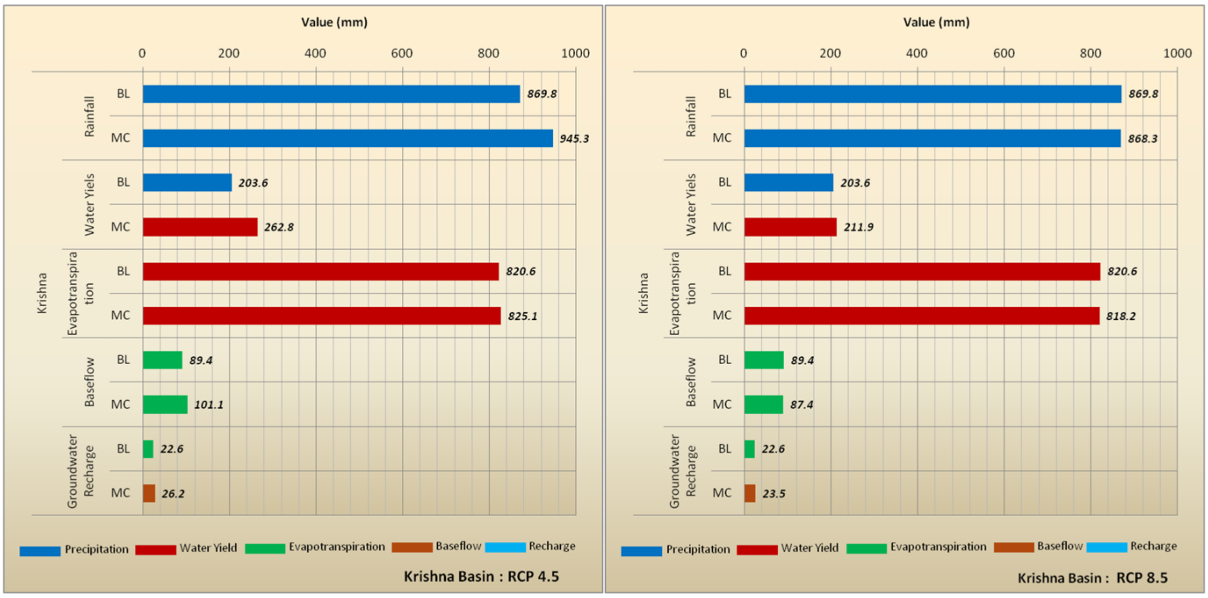

Figure 10: Annual WBC for Baseline and Mid-Century Climate Scenarios; Krishna River Basin

The basin of the west-flowing river Kali is projected to experience, similar to Krishna basin, a 14% increase in rainfall in mid-century for RCP 4.5 and nearly no change for RCP 8.5 (Figure 11). Interestingly, evapotranspiration losses are projected to decline for RCP 8.5 by approximately 6% and consequently the water yield is projected to increase by approximately 18%. For RCP 4.5, evapotranspiration in these basins is projected to remain almost unchanged whereas the water yield is projected to increase by 68%. The qualitative changes in projected rainfall, evapotranspiration, and water yield in the basins of the other west-flowing rivers, namely Netravati and Sharavati, are similar to the changes simulated for the Kali basin.

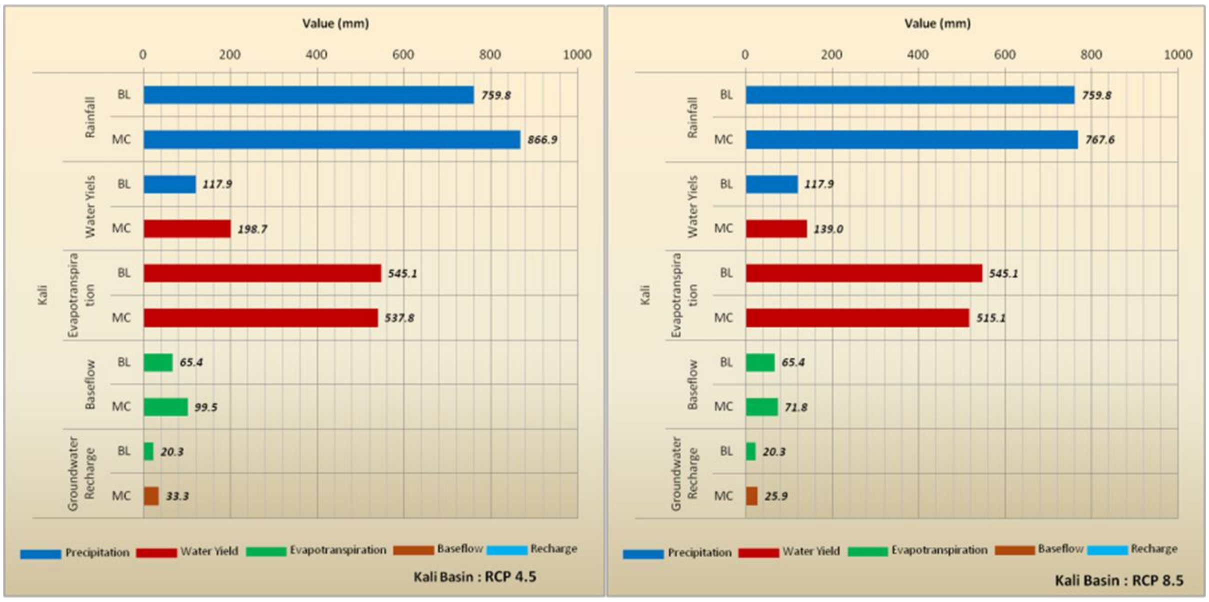

Figure 11: Annual and Monthly WBC for Baseline and Mid-Century Climate Scenarios; Kali, Netravati, and Sharavati River Basins

This assessment of the impact of climate change on water resources based on the SWAT model has some limitations. The assessment assumes no change in land use and in current crop management practices such as irrigation using surface sources and groundwater in the future. High-resolution data are not available at present on soil profiles, reservoir operation, land use, and cropping patterns. Further, only a single GCM has been used because daily data on the weather parameters were not available at the time of this study, although projections from multiple models are desirable for more confident assessments.

Water Stress and Dependable Flow in Key River Basins

The hydrological model SWAT is forced with climate change projections from IPCC AR5 to assess the impact of climate change on river basins in Karnataka. **Under RCP 8.5, high water stress is projected in parts of the Cauvery basin (parts of Hassan, Mandya, and Mysore districts) towards the mid-century (Figure 12)** whereas under RCP 4.5, high water stress is projected in the Krishna basin (parts of Bagalkote, Bijapur, Gulbarga, Raichur, and Yadgir districts) and the basins of Kali, Netravati, and Sharavati (parts of Dakshina Kannada and Uttara Kannada districts). Both these conditions may call for additional water supply for irrigation in the affected regions.

Assessment of the dependable lean-season flows along with their temporal distribution is essential for planning and developing water-supply schemes. The impact of climate change on the water yield of a river system is analysed at three levels of dependability (50%, 75, and 90%). The 90% dependability level is considered safe for determining assured water supply that will be available 90% of the time. Major reservoirs like Krishnarajasagar and Mettur in the Cauvery basin, Tungabhadra in the Krishna basin, and Supa in the Kali basin were designed for 75% dependable flow and, in fact, have been getting 75% dependable flows and are able to fulfil their designed objectives. **Based on the available projections of climate change, this study projects that supply to various reservoirs in Cauvery, Krishna, Kali, Netravati, and Sharavati river basins may not face much reduction at the 75% dependable flow level.**

However, under the IPCC AR5 RCP 8.5 scenario, reduction in flow dependability at 75% and 90% towards mid-century is projected for many reservoirs (Figure 13).

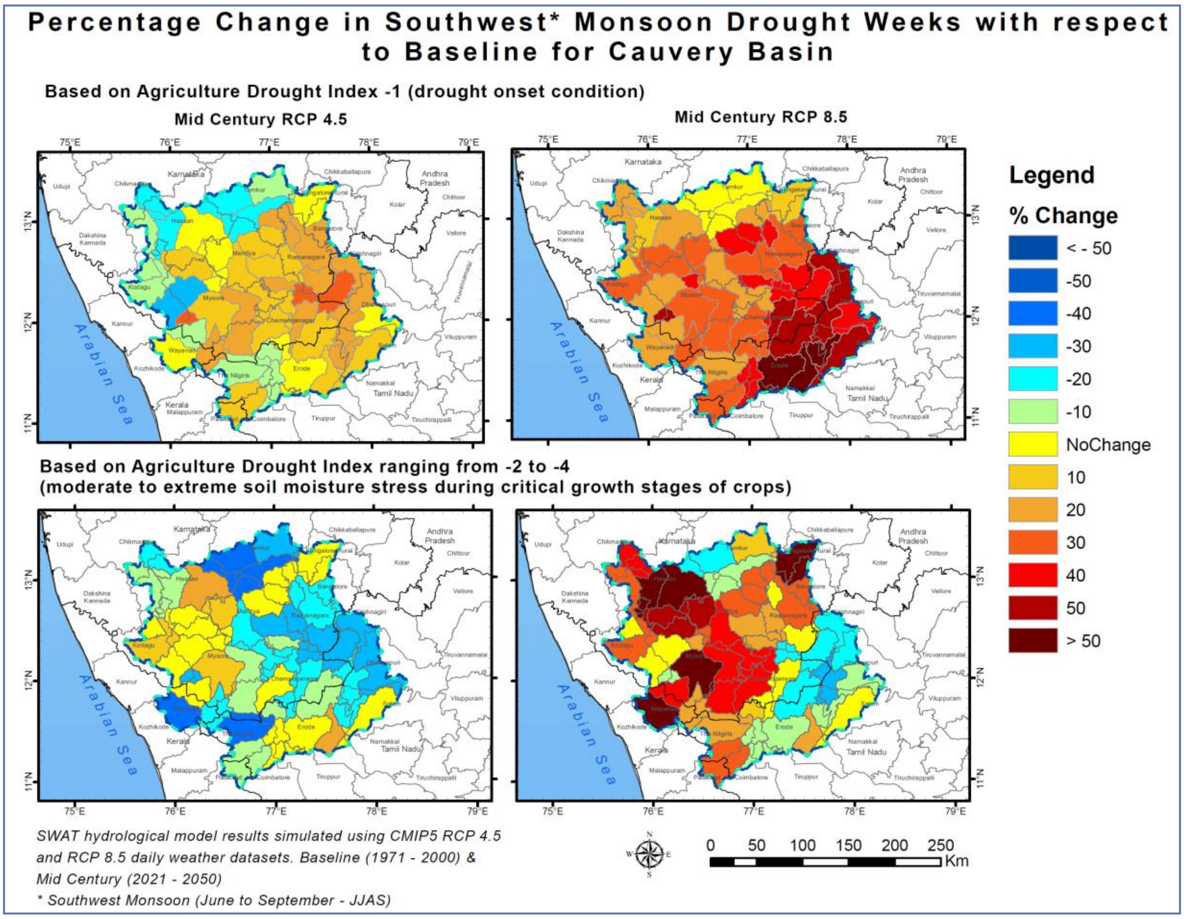

Figure 12: Spatial Distribution of Soil Moisture Deficit Weeks in Cauvery River Basin

(Source: JJAS)

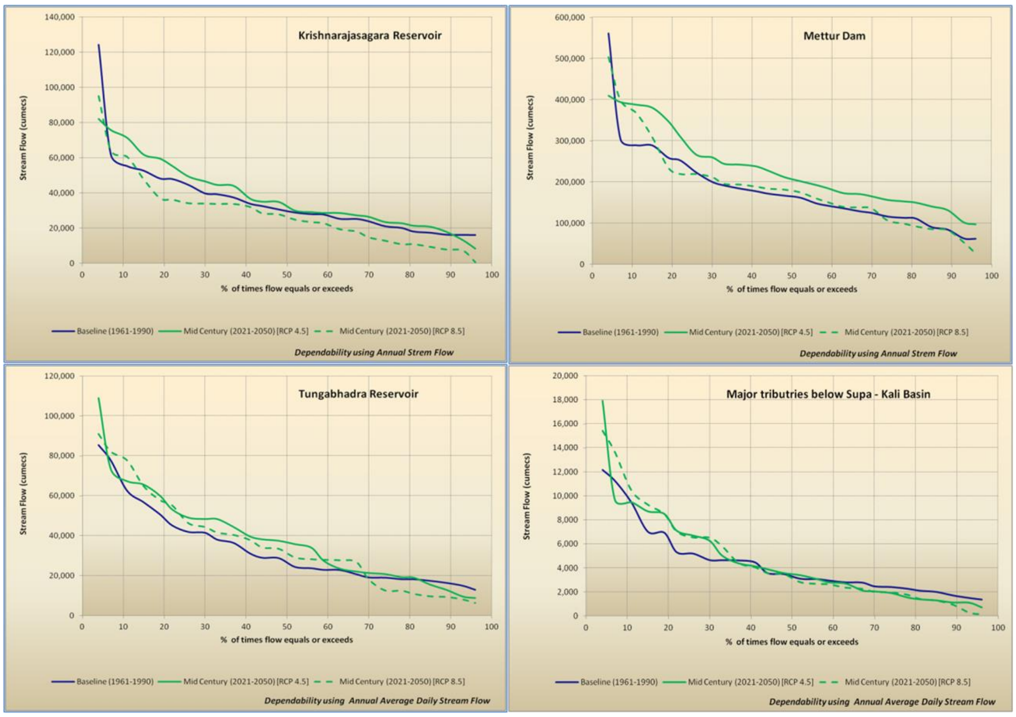

Figure 13: Dependable Flow for Four Major Reservoirs in Karnataka

Assessment of the Vulnerability of Water Resources to Climate Change

Assessing the vulnerability of water resources to climate change helps in identifying the districts that are vulnerable to climate change so that appropriate adaptation strategies can be developed for those districts. The vulnerability of Karnataka's water resources to climate change was estimated using the multivariate statistical method of principal component analysis of water resource indicators. The indicators used include surface water availability, groundwater recharge, crop water stress, drought weeks, and maximum flood discharge, and districts were ranked by their composite Water Resource Vulnerability Indices developed for the baseline (1961–1990) and projected (Mid-term of 2021–2050) climatic conditions for the south-west monsoon season (June, July, August, and September) and the north-east monsoon season (October, November, and December). Cluster analysis was performed on the indices to group the districts by their degree of vulnerability using the Ward method of agglomeration wherein districts are ranked for vulnerability as low (1), moderate (2), high (3), and very high (4).

Current (1979–2007) water resource vulnerability index

Water Resource Vulnerability Index (WRVI) for the 30 districts of Karnataka is constructed using five water indicators. Three districts, namely Gulbarga, Raichur, and Yadgir, have very low values of WRVI and therefore belong to the category of very high vulnerability (cluster 4) compared to all the other districts. Three factors make these districts most vulnerable to climate change: low availability of surface water, high crop water stress, and exposure to flood and drought (**Figure 14**).

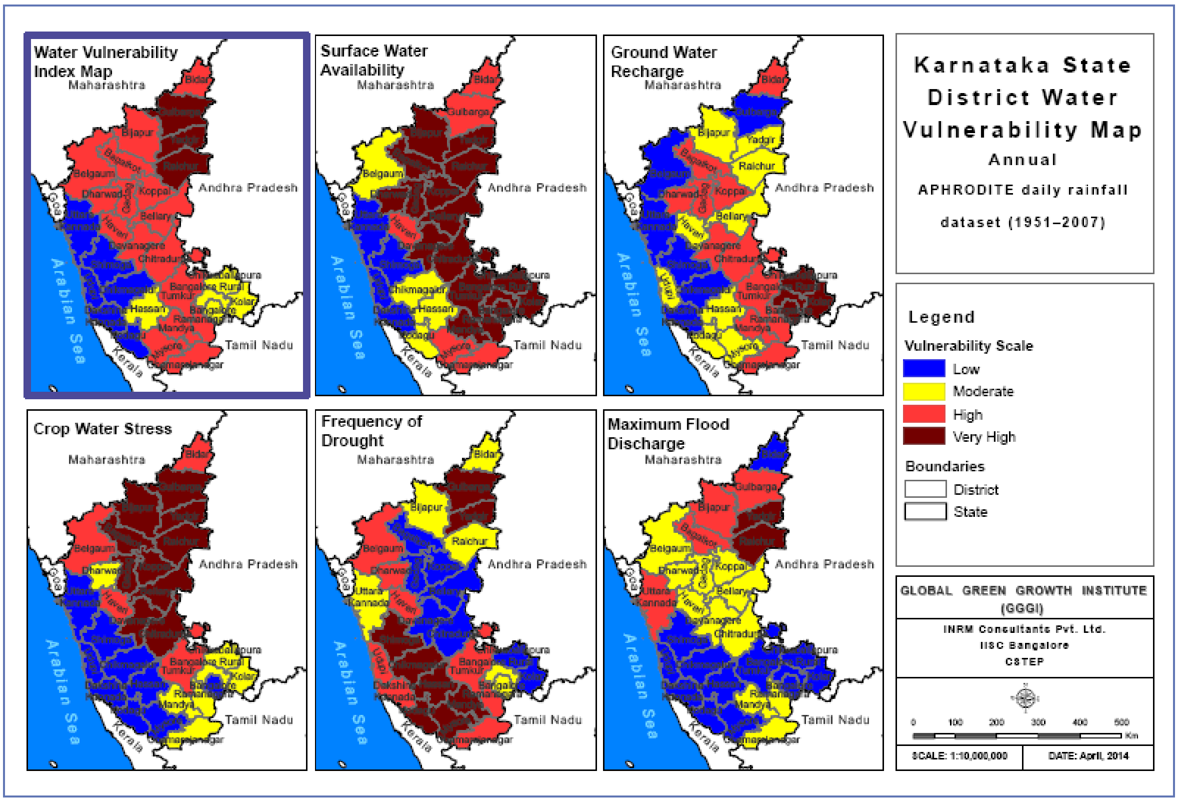

Figure 14: Water Resource Indicators used to Estimate Water Resource Vulnerability Index (1979-2007)

It can be seen from Figure 15 that these districts have comparatively low adaptive capacity and show higher sensitivity and exposure to climate change. The districts in the very high vulnerability cluster fall in north-eastern Karnataka. The third cluster (high vulnerability) comprises 16 districts that are also vulnerable but not as much as the districts in the fourth cluster. The second cluster (moderate vulnerability) comprises five districts, namely Bangalore, Bangalore Rural, Chikballapur, Hassan, and Kolar, which are moderately vulnerable. Six districts, namely Chikmagalur, Dakshina Kannada, Kodagu, Shimoga, Udupi, and Uttara Kannada, are the least vulnerable districts (cluster 1) because they have the maximum availability of surface water and groundwater, less crop water stress, and less exposure to floods compared to other districts. Thus districts in this cluster have higher adaptive capacity (shown by blue in the graph) and show lower sensitivity and exposure (shown by red in the graph) to climate change (**Figure 15**).

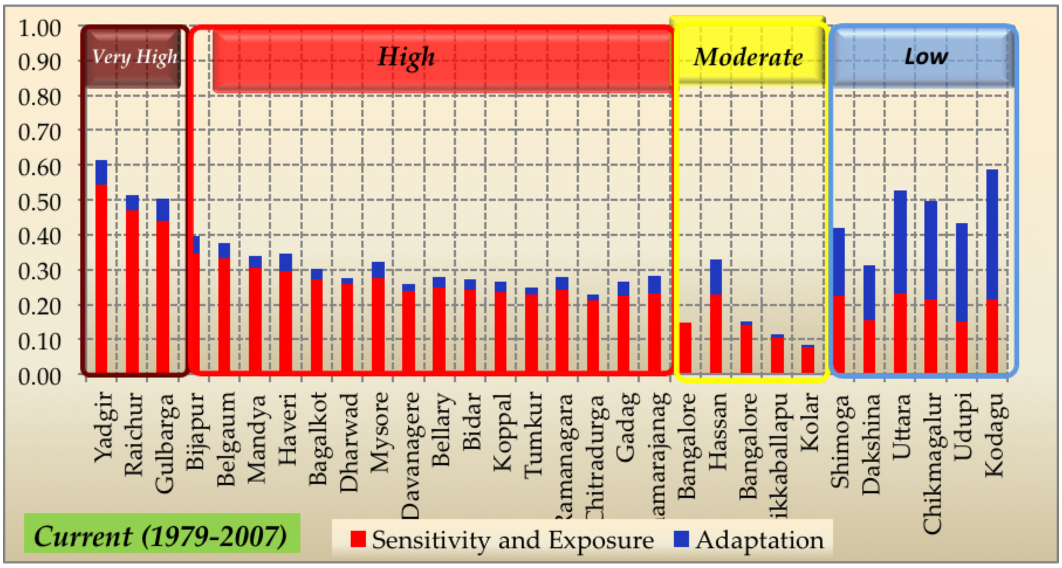

Figure 15: Sub Index Values for Sensitivity, Exposure and Adaptive Capacity (1979-2007)

Water resource vulnerability index during the south-west monsoon season

Spatial spread of water resource vulnerability increases from baseline to mid-term periods under RCP 4.5 and RCP 8.5. The number of districts characterized as highly vulnerable increases from 9 (30%) in the baseline to 14 (47%) in the mid-term in RCP 4.5 (**Figure 16**). Similarly, the percentage of districts under very high vulnerability category also increases from 17% to 20% from the baseline to mid-term period under RCP 4.5. Under RCP 8.5, Bagalkote, Chikballapur, Gulbarga, Hassan, Tumkur, Yadgir, etc. shift to the highly vulnerable category by the mid-term from being in the moderately vulnerable category in the baseline, increasing the number of districts in the highly vulnerable category to 17 (57%) from 9 (30%) in the baseline.

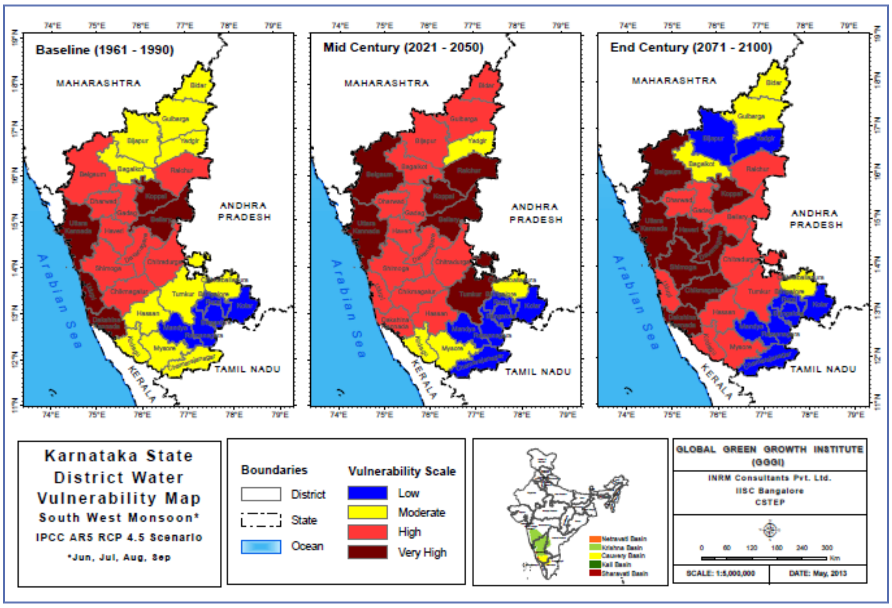

Figure 16: Water Resource Vulnerability Index for the South-West Monsoon

Water resource vulnerability index during the north-east monsoon season

Water resource become more vulnerable from the baseline to the mid-term under RCP 4.5: 8 out of 30 districts are categorized as moderately vulnerable in the baseline; this number increases to 13 by mid-term, thereby increasing the proportion of districts in the highly vulnerable category from 23% to 27% from the baseline to mid-term.

Overall water resource vulnerability for RCP 8.5 decreases in the mid-term compared to the baseline: 8 out of 30 districts fall in the highly vulnerable cluster in the baseline, which drops to 3 in the mid-term, decreasing the proportion of highly vulnerable districts from 23% to 17% (**Figure 17**).

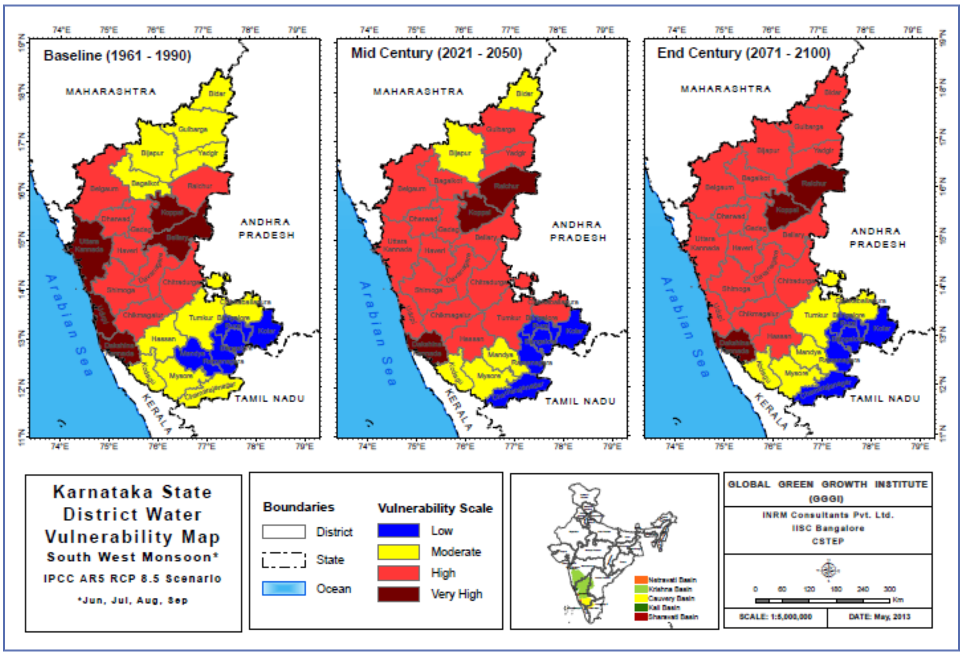

Figure 17: Water Resource Vulnerability Index for the North-East Monsoon

Real-time flood forecasting, greater water use efficiency, water harvesting, groundwater recharge, and taking climate into consideration in designing and management of reservoirs are necessary. Rainfall pattern in the future is likely to be more variable: rainfall is projected to be more intense but rainy days will be fewer. All-round warming is projected. In the absence of dedicated research on adaptation, some potential measures to cope with climate variability and climate change are listed below.

- Incorporate considerations related to climate change – especially changes in stream flow, water availability, evapo-transpiration, and rainfall intensity – in designing new irrigation projects.
- Revise the operating rules of reservoirs for efficient flood and irrigation management (real-time flood forecasting).
- Transport and distribute irrigation water more efficiently: plug conveyance losses and rehabilitate and remodel irrigation infrastructure to provide on-demand irrigation.
- Use irrigation water more efficiently: adopt more efficient irrigation systems such as micro irrigation (drip or sprinkler) and promote participatory management across projects.

- Incorporate renewable energy based micro-irrigation systems to overcome water energy nexus challenges.
- Build water-harvesting structures to recharge groundwater, introduce in-situ conservation of soil moisture, and control soil erosion.
- Rejuvenate existing infrastructure and systems for water management - desiltation and rehabilitation of tanks and reservoirs, promoting local tank management.
- Build capacity to deal with the problems: develop appropriate modelling tools for all aspects of water resources management, create a comprehensive database of relevant information, and make the public aware of the need to conserve water.

Impact of Climate Change on Agriculture Sector

Karnataka is one of the few states with the lowest proportion of area under irrigation and second only to Rajasthan in having a large share of drought-prone areas. Karnataka is a leading producer of coarse cereals (maize, ragi, sorghum, etc.) and sunflower in the country. Nearly 68% of the total cultivated area is under rain-fed farming. In view of the limited water available for irrigated agriculture and uncertainty and irregular distribution of rainfall, crop productivity suffers greatly. In addition to these natural vagaries, poor dissemination of technologies with regard to various improved agricultural practices is also a limiting factor to productivity and production.

To assess the impact of climate change on agriculture, one needs to know the current status of agriculture in the state. Out of the total geographical area of 19 million ha, 12.38 million ha is cultivable; the net cultivated area is 10.17 million ha, and 3.9 million ha is under irrigation. Major crops are sorghum (1.4 million ha), rice (1.28 million ha), red gram (1.1 million ha), ragi (10 million ha), and maize (4.6 million ha). Total food production in the state is about 11.5 million tonnes as against a requirement of 10.6 million tonnes (cereals). The higher temperatures and altered patterns of precipitation – the likely results of climate variability and change – could lower water supplies and increase water demand. To investigate the changes in productivity of major crops under a changed climate, the INFOCROP simulation model and stochiometric crop weather models were used, and crop coefficients and management practices for different crops were identified and incorporated.

Recent Trends in Crop Yields

Karnataka is divided into ten agro-climatic zones. Total annual rainfall in the state ranges from 585 mm to 3890 mm. July receives the highest rainfall (303 mm), followed by August (220 mm). Trends in area, production, and productivity of different crops grown in all districts of Karnataka for the period from 1951 to 2008 (Table 4) indicate a change in the yields of principle crops of Karnataka. Trends in both rainfall and crop status clearly indicate that hardly any parameter remains unchanged.

Table 4: Current Trends in Area, Productivity and Production of Major Crops and Seasonal Rainfall

Particulars		Increase	Decrease	No change	Particulars		Increase	Decrease	No change
Rice	Area	9	11	6	Cotton	Area	7	15	1
	Prdn	12	14	0		Prdn	17	6	0
	Prdty	11	13	2		Prdty	16	6	1
Maize	Area	25	1	0	Red gram	Area	9	11	4
	Prdn	24	2	0		Prdn	6	11	7
	Prdty	18	8	0		Prdty	12	5	7
Sorghum	Area	8	12	3	Groundnut	Area	9	13	4
	Prdn	16	6	1		Prdn	8	13	5
	Prdty	14	8	1		Prdty	10	11	5
Ragi	Area	7	16	1	Sugarcane	Area	7	16	0
	Prdn	17	6	1		Prdn	20	3	0
	Prdty	20	4	0		Prdty	18	5	0
Rainfall		**Pre monsoon**		**S-W monsoon**		**N-E monsoon**		**Annual rainfall**	
Increase			17		12		16		12
Decrease			8		14		11		15
No change			4		3		2		2

Note: All figures refer to the number of districts.

Impact of Climate Change on Crop Yields by 2035: RCP 4.5 and RCP 8.5

Total annual rainfall in Karnataka is likely to increase from 1218 mm to 1454 mm. However, some of the districts are likely to receive less rain from the south-west monsoon, which is very important for the kharif season. Further, the overall duration of the rainy season and, in turn, the growing season, are expected to change. This alters the sowing window, the growing period, and the length of the growing period. As a result, several crops are likely to be affected. Climate projections (from RCP 4.5 and RCP 8.5), projected levels of carbon dioxide from the Bern climate change model, and crop coefficients and crop management information for 10 years (1991–2000) were used as inputs for the INFOCROP model to forecast the productivity of major crops.

Rice yield is likely to decline by 0.4% but the productivity of ragi is likely to increase by 3.5%; that of maize, by 1.9%; sorghum, 1.7%; and red gram, 1.1% for the state as a whole under RCP 4.5. By the 2030s, crop yields are likely to decline in many districts: in 12 districts for maize and sorghum; in 9 for rice; in 8 for ragi (**Figure 18**). Major rice-growing districts like Bagalkote, Belgaum, Bellary, Mandya, the coastal districts, and Shimoga will witness a decline in yields by 1% to 18%. Haveri and Raichur will see sorghum yields decline by 6% to 10%; and yields of red gram will decline by 10% to 38% and those of ragi by 10% to 20% in six districts.

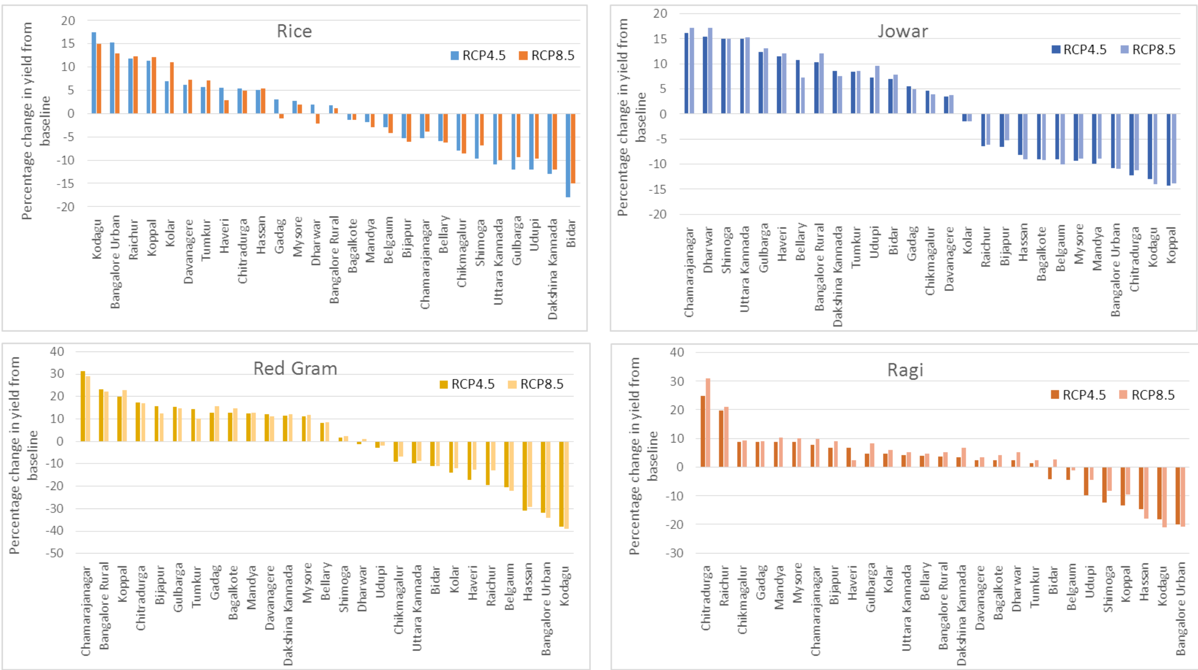

Figure 18: Percentage Change in Yields of Major Crops

Recommendations for Adaptation for Irrigated and Rain-fed Crops

Suitable adaptation strategies for the vulnerable zones and crops in Karnataka to overcome the threat of climate change and thereby improve the GDP and food security are listed below.

Rice
• Sow and transplant early: late transplanting exposes the crop to the cold spell during November–December; low temperatures favour the rice blast disease, delay panicle

emergence, and reduce grain formation. Late transplanting also increases the chances of floods during harvesting.
- Introduce dwarf varieties to minimize lodging due to wind.
- Introduce salt-tolerant varieties that can withstand a considerable degree of salinity.
- Build and maintain proper embankments to protect fields from incursion of saline water.
- Create good drainage network to drain excess water.

Maize

- Adopt crop rotation; incorporate maize stalks into soil so that they can serve as manure.
- Use more of organic manures; demonstrate the right methods of producing organic manures.
- Popularize the existing hybrids through large-scale demonstrations.
- Ensure adequate supply of seeds through farmer's participation in seed production.
- Treat the seed with chemicals to control downy mildew.
- Control stem borer and early shoot borer.
- Organize training and demonstrations at the level of Raitha Samparka Kendra (RSK).

Sorghum

- Organize large-scale demonstrations in farmers' fields on integrated crop management practices involving moisture conservation, integrated nutrient management, and improved varieties.
- Produce and supply seeds through farmers' participatory seed production programmes.
- Popularize the "seed village" programme through gram panchayats or farmers' societies.

Red gram

- Sow early (from the last week of May to the first week of July) to obtain higher yields.
- In the event of one or two dry spells of more than 15 days during this season, arrange one or two protective irrigations in late July for the crop sown in early June.
- If the rains are late but adequate rains are received in August, grow crops like cowpea, soybean, black gram, green gram, and horse gram instead.

Ragi

- Popularize the existing varieties through large-scale demonstrations.
- Stagger nursery planting for timely transplanting.
- Promote seed treatment with bio-fertilizers.
- Promote organic manures.
- Conduct demonstrations or harvesting at the level of RSK.
- Popularize seed drills and organize large-scale demonstrations of the use of seed drills.
- Make seed drills available on hire.

Improved risk management through early warning system and crop insurance

Rainfall information takes the form of data on weekly, monthly, and seasonal rainfall and probabilities of wet weeks and dry weeks, rainfall shift due to climate change, sowing and growing periods, water available for rain-fed agriculture through rainfall during different seasons, water required to grow different crops under rain-fed conditions, and crops recommended as suitable for the available rain water. These are important bits of information for rain-fed agriculture, and panchayat- or block-level bi-weekly weather forecasts and weekly Agromet Advisory (block level) should be prominently displayed at public places, including milk societies of the village, for real-time utilization of such information by farmers. High alerts need to reach all villages so that appropriate mitigation measures can be taken immediately. A special farmers' awareness programme on the impact of climate change on agriculture should be conducted at the village or panchayat level. Climate-resilient agriculture and adaptation strategies need to be implemented and regularly monitored. The increasing probability of floods and droughts and other uncertainties related to climate may make the state increasingly vulnerable. Policies that encourage crop insurance can protect farmers when extreme events result in poor yields or failed crops. In view of these and the uncertainties in future agricultural technologies and trade scenarios, it will be very useful to have an early warning system to warn the public of environmental changes and their onset, extent, and duration. Such a system could help in determining potential food-insecure areas and communities. The increase in frequency and magnitude of extreme weather events like torrential rains, heat waves, cold waves, and floods besides year-to-year variability in rainfall affect agricultural productivity significantly and lead to stagnation or decline in production across various agro-climatic zones.

To adapt to the projected impacts of climate change on agricultural production and productivity, a range of adaptive strategies need to be considered. Changing the cropping calendar and pattern will be the best immediate option for available crop varieties to adapt to climate change. Other major options include new cropping sequences, late- or early-maturing crop varieties depending on the available growing season, conserving soil moisture through appropriate tillage practices, and efficient water harvesting. Developing drought-tolerant crop varieties by utilizing genetic resources that may be better adapted to the new climatic and atmospheric conditions should be the long-term strategy. One of the promising approaches would be gene pyramiding to enhance the capacity of plants to adapt to climate change. It is therefore necessary to address issues related to climate change and variability holistically and urgently by improving the natural resource base, diversifying cropping systems, adapting the farming-systems approach, and strengthening the extension system and institutional support.

Specific Recommendations

Some specific recommendations for different agro-climatic zones and different scenarios of the impacts of climate change are provided in this section.

1. Recommendations in the event of reduced availability of water for some of the districts vulnerable to climate change

Zone	Suggested cropping patterns for different agro-climatic zones
North–Eastern Transition	Increase the area under rain-fed maize and sorghum; grow these crops instead of red gram where required.
North-Eastern Dry	Increase the area under rain-fed maize and sorghum; grow these crops instead of red gram where required.
Northern Dry	Increase the area under rain-fed sorghum, which has shown higher productivity, in

	Bijapur. Put more area under maize, sorghum, and red gram and reduce the area under cotton in Gadag.
Central Dry	Extend the area under sorghum to the entire Bellary district, replacing rice. Increase the area under rice, maize, and red gram by growing these crops as intercrops in sorghum and ragi.
Eastern Dry	Increase the area under maize, sorghum, and red gram, substituting them for part of rain-fed finger millet in Bangalore and some parts of Tumkur. Increase the area under maize, red gram, and ragi to replace sorghum in Kolar, which is likely to receive more rainfall.
Southern Dry	Replace rice with maize, sorghum, and red gram but increase the area under rice in Mysore and Mandya and parts of Hassan in view of the high yield potential and water availability. Continue ragi where it is grown at present. Increase the area under rice and sugarcane by increasing the cropping intensity of irrigated tracts.
Southern Transition	Increase the area under kharif sorghum in view of its high productivity. Divert the area under summer rice to other crops with low water requirements.
Northern Transition	Increase the area under kharif sorghum in view of its high productivity. Replace a part of the area under rain-fed rice with maize.
Hilly (Malnad)	Increase the area under red gram in Chikmagalur. In Shimoga, increase the area under rice. In the uplands, replace some of the area under rice with ragi. Introduce green gram and black gram in rice fallows. Increase the area under plantation crops.
Coastal	Reduce the area under rice and groundnut and take up horticultural crops instead.

2. Vegetables can be recommended when the growing period has been shortened. Rain-fed horticulture can also be recommended under low rainfall with a longer growing period.

3. Under the changed scenario, sowing windows and growing periods have been identified for different districts. The recommended sowing windows differ by a few days to a few weeks from the current values and are based on availability of adequate soil moisture for different crops at all stages from sowing to harvest. Based on such information in real time, crops, variety, and length of the growing period can be decided at the beginning of a season. Crop weather calendars generated for different districts would specify optimum sowing windows, growing periods, etc., which would be different for different districts, and aid choosing crops suitable for a given zone or district and that complete their life cycle within the available period. Cropping plans can be made in advance for different contingencies likely under the changed scenario to help early decision-making by farmers. Potential crops for some districts have been identified, and crop replacement can be effected accordingly in a phased manner as a mitigation strategy.

4. High floods and prolonged dry spells require appropriate strategies. In the event of flash floods or prolonged dry spells at the time of sowing, switching to short-duration or medium-duration varieties is normally recommended. In the event of a medium-duration drought in the middle of the growing season, protective irrigation is recommended using run-off water collected in farm ponds. In the event of a prolonged drought, crops can be harvested early so that they can be used at least as fodder. If the south-west monsoon is unduly prolonged, short-duration crops can be sown for the rabi season. In black soils, as an alternative, rabi crops can be sown a little earlier than normal.

Impacts, Vulnerability and Adaptation to Climate Change of Forest Ecosystems in Karnataka

Forests in Karnataka account for 19% of the geographic area (compared to a national average of 21%), of which about 56% is dense forest and about 44% is open and scrub forests. Even as Karnataka is implementing afforestation programmes at around 40,000 ha annually over the past decade, forest area in Karnataka has declined by about 2% during this period and in addition large parts of dense forests have been converted to open and degraded forests. The Western Ghats account for nearly 55% of the total area under forests in Karnataka. The impact of climate change on the forests of Karnataka is assessed using a dynamic global vegetation model - the IBIS (Integrated Biosphere Simulator) and an ensemble of five Earth System Models from CMIP-5 for RCPs 4.5 and 8.5 for the 2030s and the 2080s.

Impacts of Climate Change on Forests of Karnataka and the Western Ghats

In Karnataka, 33% and 34% of the grids are projected to undergo change in forest type by the 2030s as compared to the baseline period (1960–1990) under RCP 4.5 and RCP 8.5 respectively, which means that the future climate may not be suitable for the existing forest types and biodiversity. The grids that are projected to experience vegetation shifts for the 2030s currently support tropical evergreen and moist and dry deciduous forests (**Figure 19**). The impacts could include impaired forest regeneration and establishment and disturbance to physiological functions such as fruiting, flowering and pollination, leading to large-scale mortality and loss of existing biodiversity.

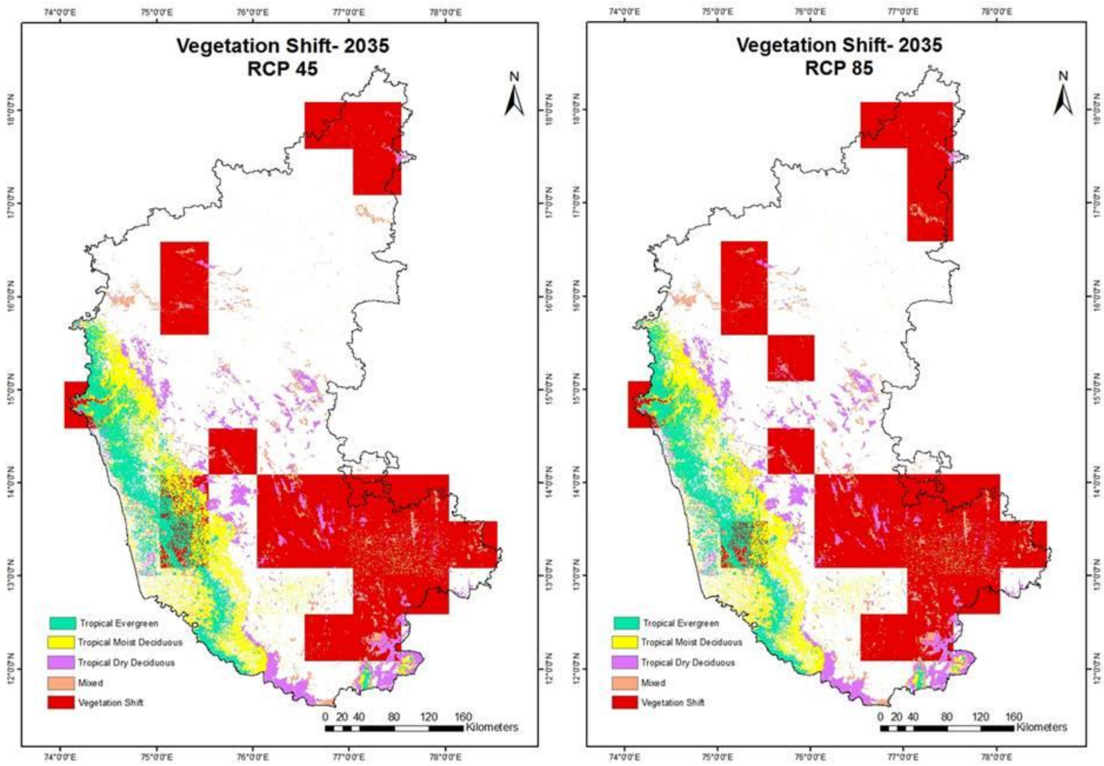

Figure 19: Vegetation Grids Undergoing Change in the 2030s

Note: Red indicates change according to model projections.

In the long term, change in forest type is projected for 57% and 62% of the grids under RCP 4.5 and RCP 8.5 respectively by the 2080s. The tropical evergreen and deciduous forests of Chikmagalur, Dakshina Kannada, Shimoga, and Uttara Kannada are projected to undergo changes in forest types by the 2080s (**Figure 20**). Similarly the dry deciduous forests in the grids of most of the south-eastern districts, Belgaum, and Gulbarga are projected to undergo shifts in forest type.

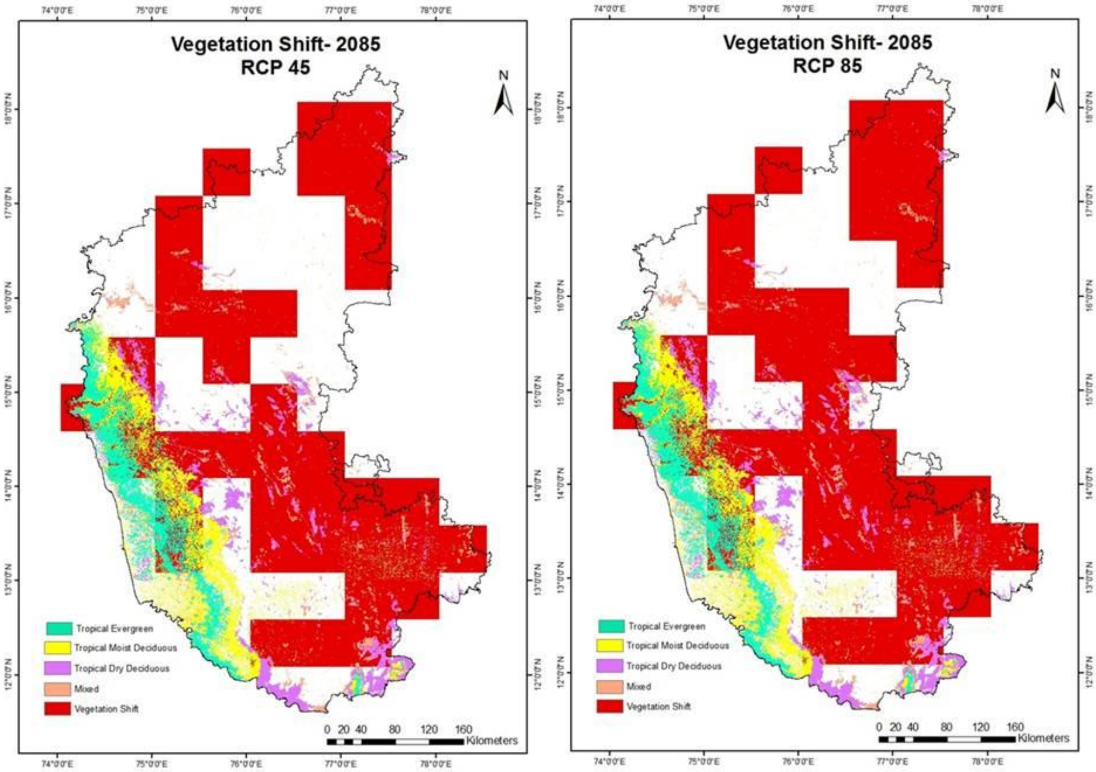

Figure 20: Vegetation Grids Undergoing Change in the 2080s

Note: Red indicates change according to model projections.

Net primary productivity (NPP) and carbon stocks are projected to increase over most parts of Karnataka by the 2080s under RCP 4.5 and RCP 8.5. Satellite-based observations for Karnataka have shown that NPP over the Karnataka region has increased over the historical period of 1982–2006. This trend is projected to continue: NPP is projected to increase by 20% to more than 90%, compared to the historical period (**Figure 21**). Further, dry deciduous forests are projected to experience higher NPP increase than that experienced by the evergreen forests of the Western Ghats. The projected increase in NPP is largely due to elevated concentrations of CO_2 in the atmosphere; however, the model does not adequately address the implications of nitrogen deficiency of tropical forest soils, pests, and fire.

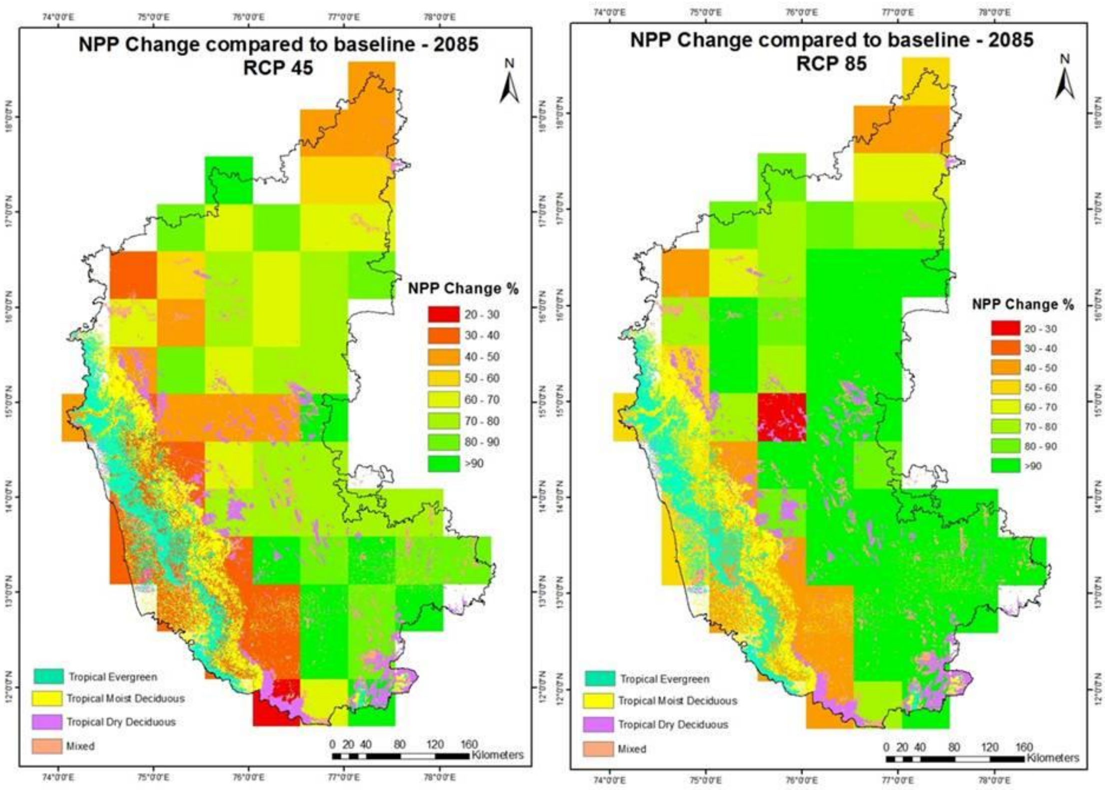

Figure 21: Impacts of Climate Change on NPP in the Forested Grids by 2085

Note: Values indicate percentage change in NPP compared to the baseline scenario.

Western Ghats are much more resilient than other forest systems in Karnataka. Nearly 13%–14% of the forested grids of the Western Ghats are projected to undergo change under RCP 4.5 and RCP 8.5 respectively by 2035, and 36% of the forest grids are projected to undergo change under the same scenarios by the 2080s. It should be noted that in the short term, the relative impact of different RCP scenarios is not clear. However, in the long term, the impact of different emission scenarios is evident as many more grids are projected to undergo change in RCP 8.5 than in RCP 4.5.

Implications of Projected Impact of Climate Change on Forest Product Flow and Livelihoods in the Western Ghats

The tropical deciduous forests of the Western Ghats are likely to turn into tropical evergreen forests. This change implies that the future climate will not be optimal for the existing vegetation type or species assemblage. This could mean that in the next 30 to 50 years, bulk of the species that provide multiple forest products are likely to suffer from dieback or will die altogether, with serious consequences for the flow of ecosystem services and biodiversity. Given that many communities in the Western Ghats districts are highly dependent on forests for livelihood, nutrition, and as a source of raw material for household consumption and for a range of commercial purposes, climate change is likely to adversely affect the flow of forest products to forest-dependent households and communities.

Assessment of Inherent Vulnerability of Forests in the Western Ghats

The Western Ghats are a biodiversity-rich hot spot and account for 55% of the total forests in Karnataka. Assessment of inherent vulnerability enables vulnerable locations to be identified based on the past and current climate and anthropogenic pressures. Once identified, appropriate steps could be taken to make the locations resilient to long-term climate change. Inherent vulnerability is assessed for the current climate using indicators such as biological richness, canopy cover, disturbance index, and slope. Inherent vulnerability has been assessed for the Western Ghats landscape by aggregating the above indicators.

Among the natural forests, dry deciduous forests are the most vulnerable whereas semi-evergreen and evergreen forest types are less so. Out of the 2372 forest grids in the Western Ghats landscape (4.32 × 4.32 km), 718 (30.27%), 847 (35.71%), 443 (18.68%), and 364 (15.35%) fall into low, medium, high, and very high inherent vulnerability classes respectively (Table 5).

Table 5: Forest Grids in Low, Medium, High, and Very High Vulnerability Classes, by Forest Type

Forest type	Inherent vulnerability (percent of grids)			
	Very high	High	Medium	Low
Evergreen	2.85	8.99	25.44	62.72
Semi-evergreen	0.00	10.69	35.85	53.46
Moist deciduous	1.92	11.82	51.26	35.01
Dry deciduous	10.64	36.78	48.63	3.95
Plantations	40.35	24.50	22.24	12.92

Among the natural forest types, dry deciduous forests are in the high and very high vulnerability class, accounting for nearly 50% of the grids. On the other hand, evergreen and semi-evergreen forests have low vulnerability, with most forest grids falling in the low to medium vulnerability classes. Plantations are the most vulnerable, with 40% of the grids under plantations falling into the very highly vulnerable class and 25% falling in the highly vulnerable class.

The eastern flank of the Western Ghats, dominated by dry deciduous forests and plantations, is inherently more vulnerable. Generally, grids showing high and very high vulnerability are located along the fringes of dry deciduous forests and plantations (**Figure 22**). The dry deciduous forests and plantations are inherently more vulnerable for several reasons. 1) The more gentle terrain on the eastern flank makes the forests more accessible and therefore puts them under higher biotic pressure. 2) The forests on the eastern flank are drier with low productivity and limited regeneration capacity under the high biotic pressure and forest fires. 3) In the dry deciduous belt, plantations have been raised only because such forests could not regenerate themselves owing to continuing biotic pressure and were at various stages of degradation. Therefore, it can be concluded that natural forests are inherently less vulnerable than man-made plantation forests.

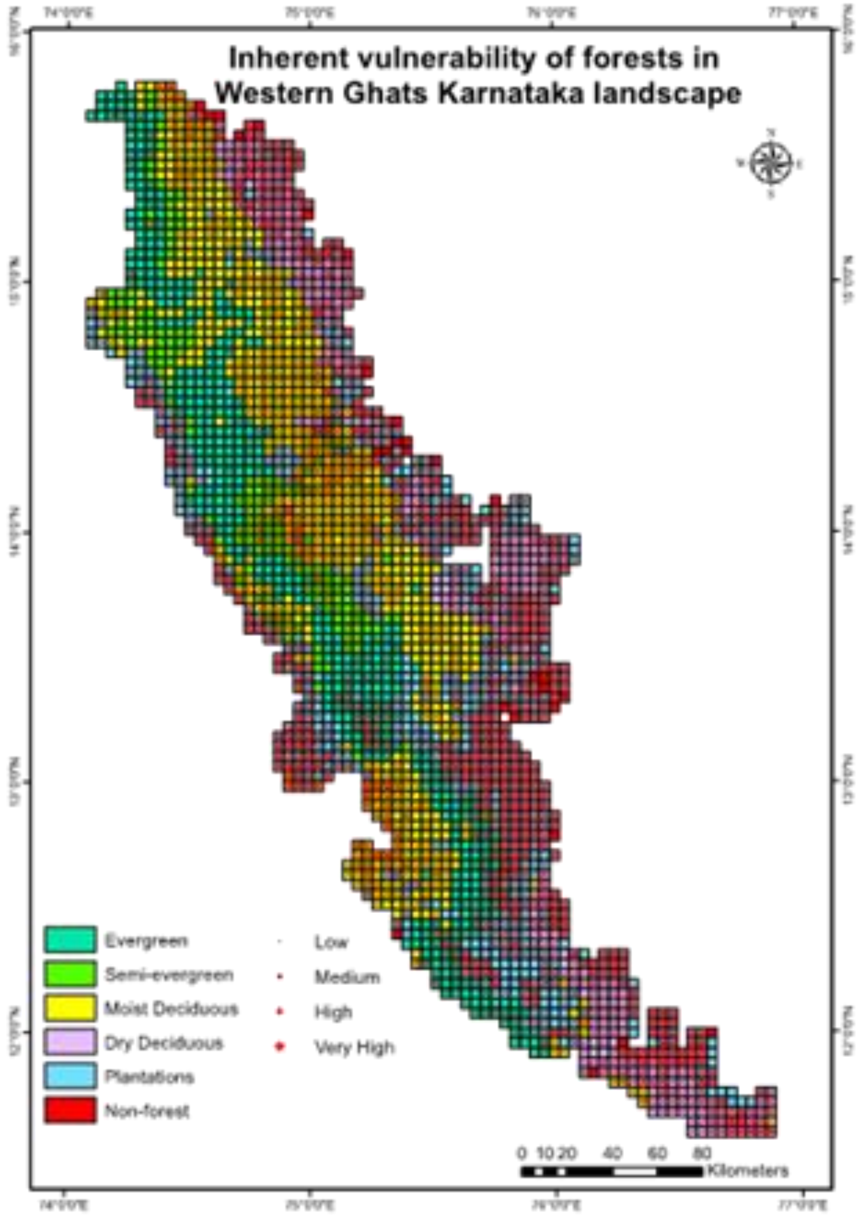

Figure 22: Inherent Vulnerability of Forests in the Western Ghats Landscape

The Western Ghats forests, apart from being rich in biodiversity, include sources of several rivers and also provide livelihood to a large proportion of the forest-dependent population. Inherent vulnerability assessment shows that nearly a third of the forests belong to high and very high vulnerability categories. Therefore it is particularly important to develop adaptation strategies and practices and implement them in the Western Ghats landscape as a precautionary measure.

Adaptation to climate change in the forest sector

The impacts of climate change on forest ecosystems and biodiversity are irreversible, requiring adaptation even in the short term. The forest ecosystems are slow in responding to the changing climate and take a long time to adapt. Therefore, it is essential to plan adaptation measures immediately to make the forest ecosystems and forest-dependent communities resilient to climate change. However, currently there is no research on developing adaptation strategies for the forest sector.

The Karnataka Forest Department could integrate the components of the National Mission for a Green India to build resilience to the projected climate change at species and ecosystem levels and also among the forest-dependent communities, in their programmes. The Government of India has formulated the mission aimed at mitigation and adaptation to enhance ecosystem services such as carbon sequestration and storage, biodiversity conservation, and provision of biomass and non-timber forest products (NTFPs). Critical forest corridors in Karnataka should be identified and regular afforestation activities should be integrated with appropriate components of the mission to revive these corridors and also to provide protective cover to the biodiversity hotspots.

In the absence of dedicated research on developing adaptation strategies to build resilience in forest ecosystems, the forest department could adopt a set of 'win–win' adaptation strategies. There are no scientific studies yet to recommend specific adaptation measures suitable for different vulnerable forest types and regions. Climate change considerations should be incorporated into the working plans and forest management programmes of the forest department. Some of the potential 'win–win' adaptation measures to be adopted in the forest sector are listed below.

- Conservation of biodiversity-rich forests of the Western Ghats since biodiversity-rich forests are less vulnerable to climate change.
- Promotion of natural regeneration and mixed-species plantations in afforestation programmes, particularly in the districts likely to be adversely affected by climate change.
- Effective fire prevention and management to cope with more frequent forest fires and pest attacks, a likely consequence of climate change, particularly in the dry deciduous forests of Karnataka.
- Linking of Protected Areas and reduction in forest fragmentation by conserving contiguous forest patches to facilitate migration of plant and animal species.
- Anticipatory planting of tree species that are tolerant of higher temperatures, fires, and pest attacks.
- Research on developing temperature-, pest-, and fire-tolerant species and silvicultural practices to cope with the changing climate and its adverse impacts; establishment of long-term forest monitoring programmes to detect, document, and analyse changes to generate information for planning adaptation measures and for assessing the efficacy of adaptation measures already implemented.
- Strengthening of forestry infrastructure and personnel so that they are equal to the challenges of research, monitoring, assessment, planning, and implementation of adaptation plans for forests and managing forests under climate change.
- Establishment of a climate change cell in the Karnataka Forest Department for information on, and assistance to forest and wildlife planning and management.

Vulnerability of Agriculture and Communities to Climate Risks at Household, Village, and District Levels

According to IPCC (2007), vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. Vulnerability to climate risks is a function of exposure, sensitivity, and adaptive capacity. The main purpose of vulnerability assessment is to identify and prioritize the regions, sectors, and communities that are most likely to be adversely impacted by the risk of climate change; to develop adaptation practices and strategies; and to mainstream adaptation to climate change in broader developmental programmes and projects. Vulnerability assessment has been carried at the household level for selected villages, at the village level for a selected district (Chikballapur), and at the district level for the state of Karnataka. A vulnerability profile has been created by developing separate vulnerability indices such as agricultural vulnerability index and livelihood vulnerability index. A set of indicators was identified, followed by data collection from the field and/or secondary sources, normalizing the indicators to enable aggregation, providing weights for different indicators to reflect their importance, and finally aggregating the weighted values to arrive at the vulnerability index.

Vulnerability Profiles at Household Level

Vulnerability profiles were developed for two drought-prone villages (Saddapalli and Gundlapalli) of Bagepalli taluk of Chikballapur district, where all the households in a village were included in the study. The mean annual rainfall for Bagepalli taluk is 716 mm, although it was only 350 mm during the study year (2012). Agriculture is the dominant occupation in both the villages, characterized by rain-fed crop production.

The agricultural vulnerability assessment showed that majority of the households was in the moderate-to-high vulnerability scale. However, the distribution of households from the two study villages on the vulnerability scale varied with the village (**Figure 23**): the majority of households from Saddapalli were in category 4 (indicating high vulnerability) whereas the majority of households from Gundlapalli were in category 3 (indicating moderate vulnerability). The cumulative percentage of households in the moderate-to-high vulnerability categories was 73% and 88% in the two study villages, indicating high vulnerability. The key causes of higher vulnerability are lack of irrigation and variability of crop yields. The other causes include lack of diversity in sources of income, inadequate access to agricultural inputs and institutional support, and, finally, lack of access to information.

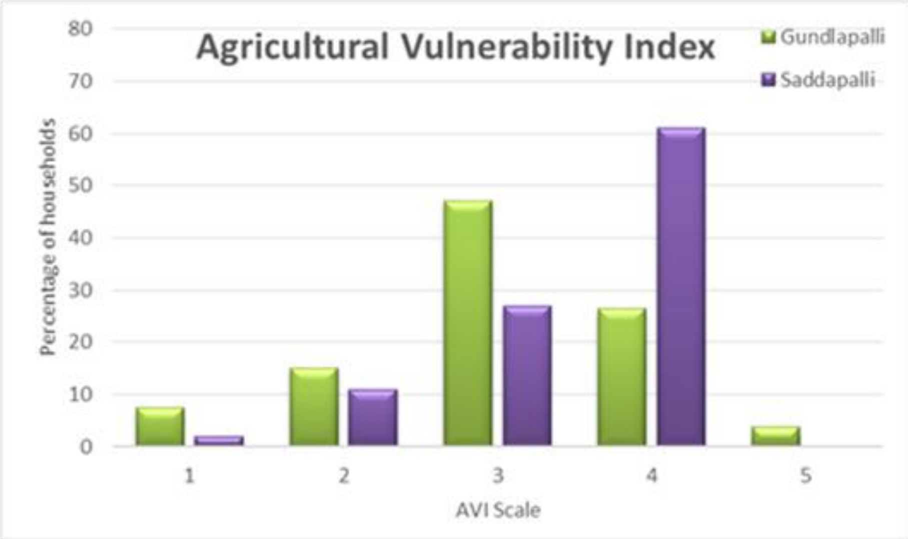

Figure 23: Agricultural Vulnerability Index of Households in Study Villages

Livelihood vulnerability for a majority of rural households in the study villages is moderate to high. The cumulative percentage of rural households ranking moderate to high on the vulnerability scale was 89% to 95% in the study villages. However, a majority of households (74%) from Saddapalli were moderately vulnerable whereas a majority of households (50%) from Gundlapalli were highly vulnerable (**Figure 24**). The average livelihood vulnerability in the study villages was 67%, indicating moderate vulnerability. The indicators contributing to this vulnerability include lack of diversification of income sources (39% to 44%), low education and skills (about 30%), and lack of livelihood support institutions such as credit societies and self-help groups (27%% to 31%).

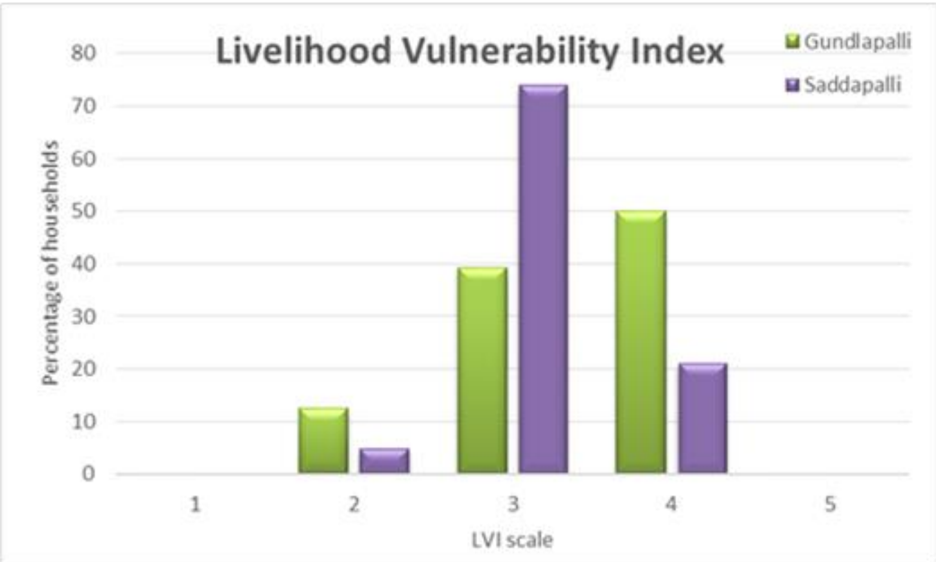

Figure 24: Livelihood Vulnerability Index of Households in Study Villages

Absence of reliable irrigation, lack of diversity in sources of income, and inadequate institutional support systems for improving livelihoods are critical factors that contribute to making rural households highly vulnerable. Inadequate banking facilities, absence of credit societies and self-help groups, and limited access to government developmental programmes such as MGNREGA make rural households increasingly vulnerable, and so do the low proportion of horticultural and agro-forestry tree species (which are hardier and more resilient than field crops to climate variability) and absence of forests and plantations (which provide NTFPs, fuelwood, and fodder for livestock). However, more evidence from different agro-climatic zones of Karnataka is required to identify the critical factors contributing to vulnerability of rural households in general and of those who are landowners but differ in their level of access to reliable irrigation in particular.

Socio-Economic Vulnerability Profiles at Village Level for Chikballapur District

Vulnerability profiles are developed at the village level within a district to enable ranking, prioritization, and identification of the most vulnerable villages to focus adaptation programmes on these villages to build resilience to current climate-related risks and long-term climate change. Chikballapur district was selected for developing vulnerability profiles because irrigation is inadequate and droughts are frequent. Of 1324 villages in the district, 1220 villages were selected and each ranked on a scale of 1 (very low vulnerability) to 5 (very high vulnerability). Socio-economic vulnerability profile was developed based on available data. The main indicators selected were as follows: extent of irrigation, crop diversification, access to agricultural inputs, change in crop yields, support institutions for agriculture, access to information and knowledge, diversity of income sources, level of education and skills, and presence of livelihood support systems. Data were obtained largely from secondary sources such as the census.

In Chikballapur district, 89% of the villages were highly vulnerable, with lack of irrigation and absence of diversity in sources of income contributing the most to vulnerability. The percentage of villages ranked as highly vulnerable ranged between 82% and 94% in the seven blocks of the district (Table 6). This indicates high levels of exposure and low adaptive capacity. The key indicators that contribute to socio-economic vulnerability include inadequate irrigation (32% of the villages), lack of diversity in sources of income (23%), absence of livelihood support institutions (23%), and lack of land for grazing and collection of fuelwood and NTFPs (17%).

Table 6: Socio-economic Vulnerability in Chikballapur

Block	Socio-economic vulnerability (5 indicates the highest vulnerability)							
	2		3		4		5	
Gauribidanur	0	0%	20	15%	112	85%	0	0%
Chikballapur	0	0%	23	10%	197	89%	2	1%
Gudibanda	1	1%	7	8%	77	91%	0	0%
Bagepalli	0	0%	12	6%	200	94%	0	0%
Sidlaghatta	0	0%	43	18%	199	82%	0	0%
Chintamani	0	0%	23	7%	304	93%	0	0%
Overall	**1**	**0.08%**	**128**	**10.5%**	**1089**	**89.3%**	**2**	**0.16%**

Note: Numbers and percentage of villages from different blocks.

All districts in Karnataka need to be assessed for vulnerability at the village level. Ranking of villages within a district makes it possible to prioritize adaptation interventions, especially since limited financial resources make it impossible to implement such measures in all villages.

Socio-Economic Vulnerability Profile Development at the District Level

Karnataka has 30 districts, and all are endowed to varying extent with land, water, and forest resources. Climate change is likely to impact all the districts, although to different degrees. The district is an important administrative and financial unit for developing and implementing adaptation programmes. Therefore, the socio-economic vulnerability profile was developed at the district level. The indicators used for this assessment are as follows: population density, proportion of people that belong to Scheduled Castes (SC) or Scheduled Tribes (ST), literacy rate, percentage of marginal land-holders (less than 1 ha), proportion of non-workers, livestock units per 100,000 population, per-capita income (average of 3 years), cropping intensity, and percentage of irrigated area to total cropped area (average of 3 years).

The districts of Chamarajanagar, Chikballapur, Chitradurga, Raichur, and Yadgir are the most vulnerable, whereas Bangalore (Urban), Dakshina Kannada, Dharwad, Udupi, and Uttara Kannada are the least vulnerable (**Figure 25**). Low per-capita income, high population density, low literacy rate, and fewer livestock units per 100,000 population are the major causes of high livelihood vulnerability.

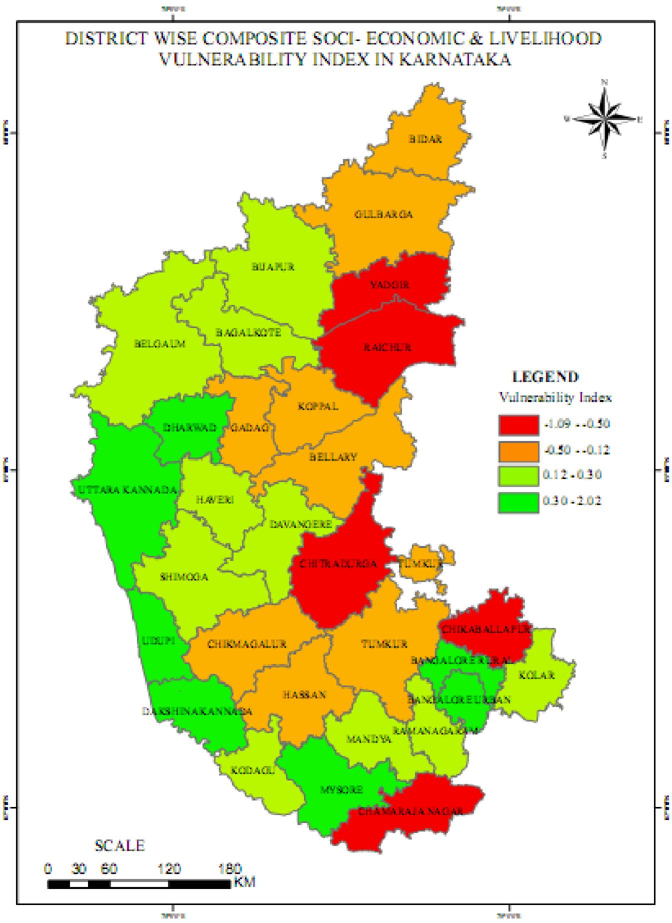

Figure 25: Socio-economic Vulnerability Profile of Districts of Karnataka

Identification of the most vulnerable districts in terms of agricultural and socio-economic vulnerability based on primary data is necessary to identify those districts that are the most vulnerable so that adaptation programmes and interventions can be developed for such districts on priority. Specific recommendations for addressing socio-economic vulnerability include the following: 1) skill-based training, 2) job creation in urban areas, 3) strengthening the National Literacy Policy, especially to promote literacy among women (by opening schools and colleges in less accessible areas), 4) policies aimed at benefitting the deprived population (in terms of housing, food, subsidies, etc.), 5) strengthening of other sources of income besides agriculture (livestock, skill-based jobs, etc.), 6) reduction in population growth by family planning and making people aware of the benefits of small families, and 7) dairy and livestock activities that have greater market linkages and government support.

A micro–level case analysis was conducted in two villages of Bagepalli block of Chikballapur district of Karnataka, to assess adaptation to current climate risks. The district was selected as it was found to be one of the most vulnerable in terms of agriculture and livelihoods. Chikballapur is in the Eastern dry agro-climatic zone. It experiences a semi-arid climate, characterized by typical monsoon tropical weather with hot summers and mild winters and is drought-prone. This makes the district sensitive to current climate variability, and the vulnerability of the district could potentially increase in future.

Strategies to Cope with Current Climate Risks

To develop planned adaptation strategies, it is necessary to understand the current strategies adopted by rural communities to cope with current climate-related risks. IPCC distinguishes two types of adaptation, namely autonomous or spontaneous and planned. Rural communities, particularly farmers, have been exposed to weather-related climate risks over decades to centuries, and farmers and rural households would have developed coping strategies to deal with current climate-related risks. Findings from the two village case studies (from Bagepalli block of Chikballapur district) on the current coping strategies are presented here. Bagepalli block is one of the drought-prone blocks of Karnataka with very low annual rainfall (400–1000 mm).

Farmers and rural households have diverse coping strategies to adapt to current climate variability or climate-related risks. Rural households exposed to inherent climate risks develop their own adaptation or coping strategies to deal with intra- and inter-annual climate variability. The current coping strategies adopted by the rural households include the following.

- Shift in cropping patterns
- Crop diversification
- Mixed cropping
- Changes in the date of sowing
- Irrigation from diverse sources
- Agroforestry
- Livestock diversification
- Income source diversification
- Migration
- Development programmes
- Distress sale of assets

Agroforestry is a critical coping strategy adopted by rural households to diversify their incomes. In the two study villages, 75% to 88% of the rural households adopted agroforestry practices including growing fruit trees such as coconut, mango and jamun. However, agroforestry can be expanded to make rural households even more resilient to current as well as future climate-related risks.

Livestock production is an important coping strategy and an alternative source of livelihood for rural households. Livestock ownership is characterized by diverse types of livestock such as dairy cows, sheep and goats, and poultry. About 50% of the households in the two villages owned only cattle; 18% to 26% owned both cattle and sheep and goat; and less than 10% owned only sheep and goats (**Figure 26**).

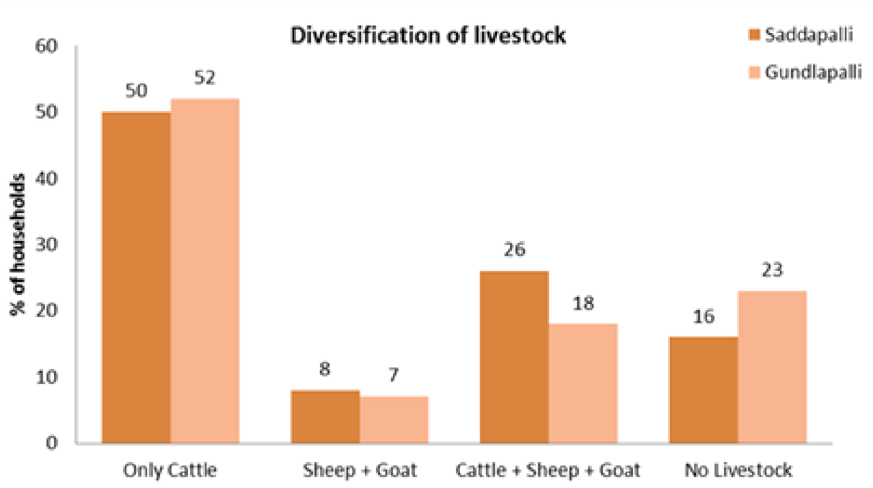

Figure 26: Livestock Diversification Strategies in the Study Villages

Income diversification is a dominant coping strategy adopted by the rural households, especially to cope with weather-related risks. In the study villages, 63% to 67% of the rural households depended on livestock and other sources of income in addition to crop production, and for only 3% to 16% of the rural households was crop production the only source of income (**Figure 27**).

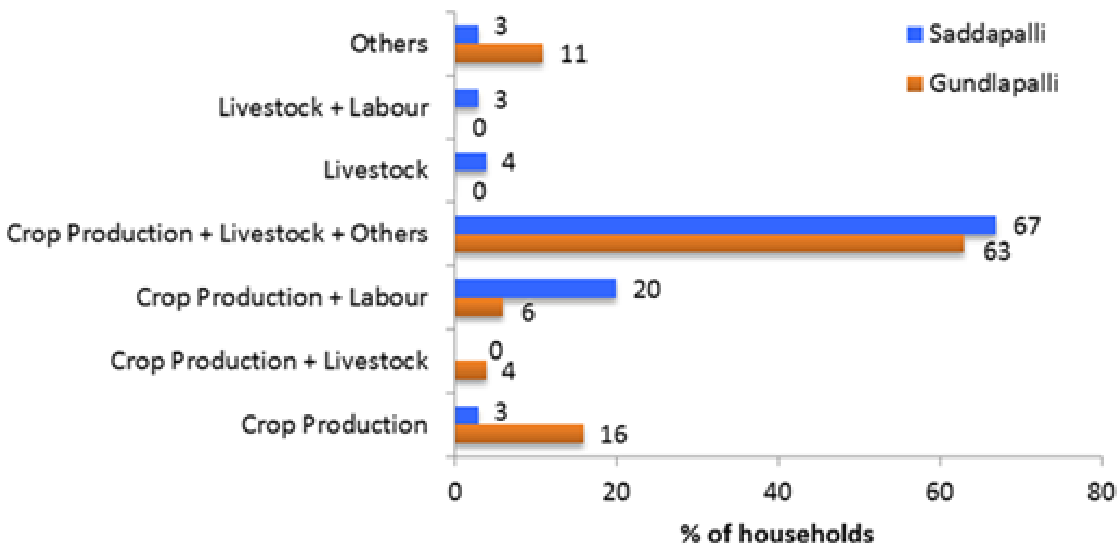

Figure 27: Income Diversification Strategies Adopted in the Study Villages

The current coping strategies adopted by the rural households are inadequate to deal with the current climate-related risks and come at a high cost to the households. The analysis showed that the strategies and practices that have evolved over the years in response to weather-related adversities are inadequate to deal with their severity, often leading to loss of income and assets and to migration. Some strategies demonstrating their inadequacy are listed below.

- ***Leaving land fallow:*** 57% to 78% of the households left land fallow during the study year where the rainfall was low, leading to loss of crop production, income, and employment.

- ***Shifting to low-income-yielding crops:*** 48% to 97% of the households substituted high-income crops with drought-resistant, low-income crops such as maize, ragi, or groundnut with horse gram and rice with maize
- ***Distress sale of assets:*** the households reported selling livestock and trees in low-rainfall years leading to loss of livelihood: about 25% of the households in Gundlapalli and 22% in Saddapalli resorted to this coping strategy.
- ***Migration:*** during the study year, which happened to be a low-rainfall year, 17% to 30% of the rural households reported migrating to urban centres such as Bagepalli, Bangalore, and Chikballapur.

Government development programmes are critical for rural households to cope with current climate-related risks. The programmes that enabled the villagers to cope with the current climate-related risks included MGNREGA, crop insurance, and compensation for crop loss: 50% to 82% of the households in the two study villages reported participation in MGNREGA to earn income and livelihood. Compensation for crop loss was claimed by 14% to 41% of the households. Claims for crop insurance, however, are still low at the village level.

Building resilience to current climate-related risks also builds resilience to long-term climate change, and some of the potential strategies for enhancing the current coping abilities are listed below.

- Agroforestry, particularly on rain-fed lands
- Adjustments to cropping calendar such as changing sowing dates
- Livestock diversification
- Soil and water conservation
- Improved irrigation
- Enhanced access to developmental programmes such as the MGNREGA, IWMP and afforestation
- Financial compensation through crop insurance
- Diversification of income and livelihood opportunities.

Mainstreaming Adaptation into Development Programmes

Adaptation is the adjustment made by physical, ecological, and social systems to reduce their vulnerability or enhance their resilience to current climate-related risks as well as to future climate change. In Karnataka, a climate-sensitive sector like agriculture is the main source of income for about a third of the total population. The state is also one of the few states with the lowest proportion of area under irrigation (approximately 68% of total cultivated land is rain-fed).

Rural communities that are dependent on agriculture are currently exposed to intra and inter seasonal variations such as extreme rainfall, heat stress, delayed rainfall, and droughts, leading to changes in cropping patterns, reduced crop and livestock productivity, and, in turn to loss of livelihoods. This consequence is evident from the analysis of the temperature and rainfall trends over the past century for Karnataka undertaken as part of this study: Karnataka has warmed by about 0.4 °C in the 20th century and overall, annual rainfall has decreased by 10%. Further, more reliable climate change projections based on the ensemble mean of 18 GCMs have projected a mean warming relative to that in the pre-industrial period of 1–3 °C by the 2030s and as high as 5 °C by the 2080s under the high-emissions scenarios, and have also projected wide changes in rainfall over Karnataka. Thus, there is an immediate need to build resilience to current climate variability as well as to future climate change.

Adapting to climate change needs to be distinguished from adapting to climate variability. Essentially, adapting to the current climate variability should enhance resilience to future climate change, but this depends on the type of adaptation undertaken. As part of this study, surveys were conducted in villages of Bagepalli taluk to assess the current coping strategies. The surveys revealed that farmers have been following coping strategies that are harmful in the long term such as shifting to hardier crops with low economic value, distress sale of productive livestock and trees, and leaving lands fallow in order to reduce their vulnerability to current climate-related risks, and thereby compromising their future capacities to adapt to climatic stresses. It is therefore essential to build capacity in such communities to enhance their resilience and lower their vulnerability to current climate variation as well as to future climate change.

Adaptation can be achieved in six ways, which, in many cases, are complementary to one another. 1) ***Technology-based approach*** to adaptation involves climate-proof technologies in the light of future climate change. 2) ***Development-based approach***, besides climate-proofing, focuses on developmental efforts consciously aimed at reducing poverty and vulnerability by including priorities that are essential for successful adaptation. 3) ***Community-based approach*** is a community-led process, based on communities' priorities, needs, knowledge, and capacities, to plan for and cope with the impacts of climate change. 4) ***Ecosystem-based approach*** includes promoting biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. 5) ***Disaster-risk-management approach*** provides organizations and communities with tools and practices to lower the frequency of disasters and to reduce the magnitude of the negative impact of disasters on societies. 6) ***Sustainable livelihoods approach*** focuses on reducing poverty and vulnerability through livelihoods that can cope with and recover from stresses and shocks while sustainably managing the natural resource base. Some examples of how different developmental programmes inherently incorporate a combination of different approaches are provided below.

Climate change will impact all sectors and all communities, although to different levels, and considerations of climate need to be incorporated into all developmental programmes such as MGNREGA, IWMP, NAP, and NRLM to build resilience to short-term climate variability and risks as well as to long-term climate change.

International agencies and organizations are already mainstreaming adaptation into their programmes. The World Bank recognizes the importance of integrating climate and disaster risk into development and emphasizes the importance of tackling poverty and environmental degradation to achieve effective adaptation. Asian Development Bank has uniquely pioneered the integration of programmes aimed at reducing both poverty and risks from disasters. ADB recognizes that a common thread of community participation and involvement is necessary to not only lower the inherent system vulnerability through poverty reduction but also increase system resilience through disaster risk reduction, as the latter is key to preparing a community to absorb or mitigate the shocks of climate variability or climate extremes. UNEP and UNDP recognize that addressing the nexus of poverty and environment is crucial to achieving comprehensive sustainable development. As long as rural communities are dependent on locally available natural resources for a significant part of their livelihood, the inherent vulnerability of the system is high.

The Planning Commission recognizes the importance of mainstreaming adaptation and has incorporated it into the national missions. They all promote mainstreaming of adaptation into developmental programmes. The National Action Plan on Climate Change (NAPCC) addresses the urgent and critical concerns pertaining to adaptation through a directional shift in the developmental pathway of current and planned programmes. Key elements of the NAPCC are protection of the poor and vulnerable sections of society; deploying appropriate technologies for both adaptation and mitigation; engineering new and innovative forms of market, regulatory, and voluntary mechanisms to promote sustainable development; strengthening institutional linkages at the local level; fostering multi-level cooperation for research and development; and sharing and transfer of technologies (GoI, 2008). Key development programmes implemented under the 12th Five-Year Plan feature many adaptation co-benefits, and selected flagship programmes implemented in Karnataka have been assessed and analysed to measure the extent to which adaptation to climate change has been mainstreamed in these programmes.

Adaptation co-benefits in 13 programmes in five sectors – agriculture, water, forests, rural development, and health – were analysed using seven criteria that include risk management, vulnerability, and resilience. The criteria include key components such as whether the programmes feature contributions towards the following aspects.

(1) Disaster risk mitigation and management **(risk mitigation component)**
(2) Diversification of employment and income, betterment of poor and marginalized groups, access to information, access to technologies, and participation of communities in decision-making **(vulnerability component)**

(3) Most important, ecological and natural resource conservation and management **(resilience component)**.

The programmes that ranked the highest for adaptation co-benefits, including MGNREGA, IWMP, and NAP (Figure 28) were those that incorporated four approaches to adaptation. These programmes also proved that activities undertaken to achieve development objectives incidentally achieved adaptation objectives as well. The four approaches were as follows.

(1) **Ecosystem-based approach** through works such as water conservation and harvesting, irrigation provisioning, afforestation, horticulture, land development, and improvement of drinking water quality in rural areas
(2) Providing opportunities to rural households to diversify **sustainable means of livelihood** through promoting non-farm-based income opportunities
(3) Flood control through bunding works and drought proofing through horticulture development and afforestation activities that contribute to **disaster risk management**
(4) Employing a **community-based approach** to decision-making at project planning and implementation levels through activities such as village forest committees.

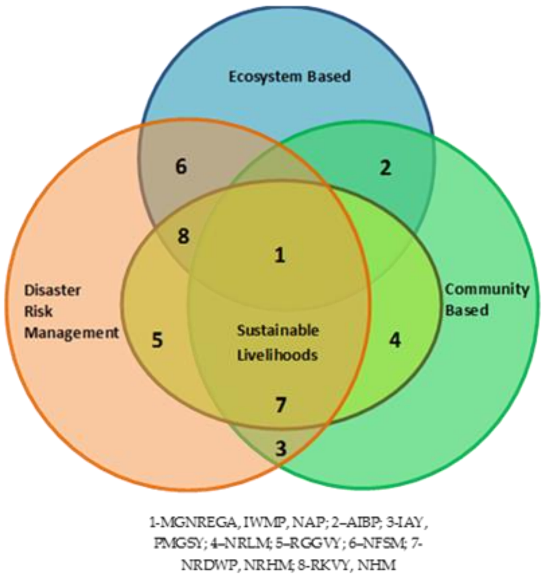

Figure 28: Classification of Development Programmes in Karnataka by Adaptation Approach

Programmes that scored high on incorporating adaptive co-benefits in development objectives were **agriculture and rural development sector programmes**, which emphasize the most important adaptive co-benefits of natural resource conservation as well as employment diversification opportunities through development of horticulture and other activities allied to agriculture.

Programmes that scored low on incorporating adaptive co-benefits in development objectives **mostly demonstrated adaptation to current climate variability but did not contribute significantly to adaptation to long-term climate change.** These programmes tend to focus on hazards or disasters, where the main goal is to reduce the exposure of systems and communities to current climate-related risks. In order to build the capacity of these programmes to contribute to climate resilience, the programmes need to focus on sustainable development that includes the provision of sustainable livelihoods opportunities in order to reduce vulnerability as well as natural resource conservation and management to increase the resilience of systems to long-term climate change. This requires that activities added to the programme objectives need to demonstrate that the activities would contribute to adaptation to climate change.

The project design of rural development programmes needs to change so that the programmes supplement their core objective of poverty reduction by adding activities designed to enhance adaptation at the local level to current climate-related risks and long-term climate change. Dedicated activities, programmes, and practices to deliver co-benefits of adaptation to current climate risks and also build long-term climate resilience are necessary and have a great potential. It has been suggested that greening of rural development programmes such as MGNREGA, IAY, NRLM, and IWMP can stimulate rural economies, create jobs, and help maintain critical ecosystem services, thereby strengthening climate resilience of the rural poor.

Such greening requires an assessment of climate-related risks, impacts, vulnerabilities, and identification of risks and mitigation options relevant to each sector and region. These measures call for outlining a strategy for mainstreaming adaptation components into development programmes at various levels. The following four-stage process suggests how this might be achieved.

i. Develop climate change projections and estimate the impacts of current or short-term climate variability or risks and those of long-term climate change at district and block levels as well as for different regions and sectors (rain-fed agriculture and cropping systems, forest types, river basins, watersheds, etc.).
    - *During the current project phase, finer-scale climate change projections were not available but are likely to become available for reliable projections at block and district levels soon.*
    - *Impacts were assessed using projections from only one global climate model and using a single response model for agriculture and water sectors owing to limited availability of climate and non-climate data for the impact models. More reliable assessments based on multiple climate-response models will be possible soon.*
    - *Currently, the impact models do not evaluate the impacts of extreme climatic events such as droughts and floods, which could be explored in the future.*

ii. Develop vulnerability profiles and rank the most vulnerable districts, cropping systems, forest types, and watersheds to prioritize them for interventions aimed at adaptation.
    - *Vulnerability profiles for the agriculture sector have not been developed for different crops, districts, and agro-climatic zones; the assessment was based only on a single climate and impact model. Developing such vulnerability profiles is necessary at panchayat and block levels.*

iii. Evaluate current development programmes for adaptation co-benefits; identify those programmes that are lacking in such benefits; and develop strategies to incorporate and mainstream adaptation into current programmes aimed at lowering current climate-related risks and building long-term resilience climate change.
    - *The planning, designing, implementation, and monitoring of development programmes and their current performance are yet to be assessed in detail for developing concrete recommendations for mainstreaming adaptation.*

iv. Develop institutional mechanisms to design, implement, and monitor adaptation programmes and, most important, identify the sources for financing the interventions aimed at adaptation.

- *The existing institutions and mechanisms for designing, implementation, and monitoring of different programmes need to be assessed in detail to suggest concrete recommendations on institutional arrangements, financial mechanisms, and capacity building required to mainstream adaptation.*

The current phase of the study is characterized by the absence of multi-climate-model-based reliable climate projections at block and district levels, adoption of a single climate impact assessment model, and near-absence of dedicated research on developing short- and long-term adaptation strategies. Currently, the government and other developmental agencies could adopt 'win-win' strategies to cope with climate-related risks in the short term and build resilience to long-term climate change in different sectors. Some of these strategies are as follows. Advanced weather forecasting and access to climate information, soil and moisture conservation, improved irrigation provisioning along with improved water use efficiency, mixed cropping, agroforestry, adjustments to the cropping calendar, afforestation involving mixed species, forest and biodiversity conservation, linking protected areas, improved monitoring of forest fires, and anticipatory tree planting along the altitude and latitude gradient. Research must be initiated to develop adaptation strategies and practices for different sectors and regions of Karnataka.

Knowledge Gaps and Focused Research for Karnataka

1. Improved climate change projections at district and block levels. Regional climate change projections based on multiple Earth System Models at finer scales (50 km×50 km and 25 km×25 km) based on the outputs of CORDEX experiments will become available soon and these could be used for improved climate change projections at district and block levels for impact assessments.
2. Impact assessment for agriculture and water resources using multiple climate models, potentially using CORDEX outputs. Currently, assessments of the impacts of climate change are limited to only one Earth System Model for agriculture and water resource sectors because data on the climate parameters required for impact modelling are not available at present.
3. Impact assessment for agriculture using multiple crop response models, preferably for all the rain-fed and irrigated crops, particularly for the short term period of the 2030s. Primary data are needed on crop production and water management practices in agriculture for different agro-climatic regions.
4. Impact assessment for water resource sector at finer scales based on multiple Earth System Models and outputs of CORDEX at the watershed level. Primary data are needed on various parameters such as historical stream flow, land-use pattern, cropping pattern, and implication of land development programmes.
5. Development of vulnerability profiles separately for current climate variability and projected climate change. Vulnerability profile development and ranking of crops, cropping systems, watersheds, and forests types that are most vulnerable are necessary at finer scales, preferably at district or block levels.
6. Understanding of current coping strategies as a baseline for developing planned adaptation for different agro-climatic zones, crops, and water and forest management systems.
7. Long-term research on developing adaptation policies and practices on food, water and energy nexus; crop varieties tolerant to higher temperatures, drought, and pests; alternative cropping systems; and silvicultural and water management practices.
8. Assessment of planning, designing, implementation, and monitoring of development programmes and their current performance for developing recommendations for mainstreaming adaptation in different developmental sectors and programmes.
9. Assessment of the existing institutions and mechanisms for planning, designing, implementation, and monitoring of different programmes to recommend institutional arrangements, financial mechanisms, and capacity development required for mainstreaming adaptation.