Climate Change Adaptation Approaches for SUSTAINING AND IMPROVING RURAL LIVELIHOODS IN GUJARAT

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Study on **Study Climate Change Adaptation Approaches for Sustainable and Improving Rural Livelihoods in Gujarat**

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TIFAC-IRMA Study Climate Change Adaptation Approaches for Sustainable Livelihoods

The study has provided the methodology specifying the trans-disciplinarily approach of combining the biophysical, socioeconomic and demographic factors. For climate change impacts on crop suitability and agro-ecologically attainable yield, the study applied the Agro-Ecological Zones (AEZ) methodology, which was jointly developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The AEZ approach is a GIS-based modeling framework that combined land evaluation methods with socio-economic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture. The AEZ methodology provides data on current and future agricultural production. Based on the data on migration, the spatial pattern of future livelihoods could be analyzed. This would help spatial pattern of livelihoods and climate change adaption strategies. All this would devise guidance towards policies and governance of land and water, and mechanism for effective climate change adaptations.

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List of Abbreviations

AEZ	Agro-Ecological Zones
AKRSP	Aga Khan Rural Support Programme
AR	Assessment Report
BADC	British Atmospheric Data Centre
BAIF	Bharatiya Agro Industries Foundation
CBDR	Common But Differentiated Responsibilities
CCLVI	Climate Change Livelihood Vulnerability Index
CDM	Clean Development Mechanism
CEC	Cation Exchange Capacity
CGWB	Central Ground Water Board
CID	Cognitive Interpretive Diagram
CMIP	Coupled Model Inter-Comparison Project
COP	Conference of Parties
CRU	Climate Research Unit
CWRDM	Centre for Water Resources Development and Management
DEM	Digital Elevation Model
DFID	Department of International Development
DMIC	Delhi Mumbai Industrial Corridor
DPAP	Drought Prone Area Programme
ESRI	Environmental System Research Institute
ET0	Reference Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization
FCM	Fuzzy Cognitive Mapping
FCMs	Fuzzy Cognitive Maps
GCM	General Circulation Models
GFDL	Geophysical Fluid Dynamics Laboratory
GHGs	Greenhouse Gases
GIDC	Gujarat Industrial Development Corporation
GIS	Geographic Information System
GPCC	Global Precipitation Climatology Centre
GSDP	Gross State Domestic Product
GWRDC	Ground Water Resource Development Corporation
HadGEM	Hadley Centre Global Environmental Model

ICAR	Indian Council of Agricultural Research
ICZMP	Integrated Coastal Zone Management Project
IIASA	International Institute for Applied Systems Analysis
INCAA	Indian Network for Climate Change Assessment
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace
IRMA	Institute of Rural Management Anand
ISNC	India's Second National Communication
ISRO	Indian Space Research Organisation
IWMP	Integrated Watershed Management Programme
JFM	Joint Forest Management
LGP	Length of Growing Period
LULC	Land Use Land Cover
LUP	Land Use Planning
LUT	Land Utilization Type
MCM	Million Cubic Meters
MIROC	Model for Interdisciplinary Research on Climate
MoRD	Ministry of Rural Development
NAPCC	National Action Plan on Climate Change
NBSS	National Bureau of Soil Survey
NGO	Non-Governmental Organization
NIH	National Institute of Hydrology
NorESM	Norwegian Earth System Model
NPP	Net Primary Production
NRSC	National Remote Sensing Centre
NWDT	Narmada Water Dispute Tribunal
NWRWS	Narmada Water Resources Water Supply
PET	Potential Evapotranspiration
PIM	Participatory Irrigation Management
RBS	Royal Bank of Scotland
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RWAs	Resident Welfare Associations
SEZ	Special Economic Zone
SHG	Self-Help Group
SIR	Special Investment Region
SL	Sustainable Livelihoods
SPPWCP	Sardar Patel Participatory Water Conservation Project
SQ	Soil Quality
SRI	System of Rice Intensification

SSCN	Sujalam Sufalam Canal Network
SSP	Sardar Sarovar Project
SSPs	Shared Socio-Economic Development Pathways
SWI	System of Wheat Intensification
SWRD	State Water Resources Department
TIFAC	Technology Information, Forecasting and Assessment Council
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WASMO	Water And Sanitation Management Organization
WATCH	Integrated Project Water and Global Change
WCs	Watershed Committees
WMO	World Meteorological Organization
WRI	World Resources Institute
WUAs	Water Users Associations

Executive Summary

This study seeks at identifying adaptations that provide resilience to climate variability and change, projecting environmental perturbations for the State of Gujarat. In this regard climate-related impacts and adaptations have been captured to explain vulnerability of rural livelihoods. Scenarios of agriculture in Gujarat for various Representative Concentration Pathways(RCPs) in the 21st century is developed. The Agro-Ecological Zones (AEZ) methodology has been in use since 1978 for determining agricultural production potentials and carrying capacity of the world's land area. A new methodological approach has been developed to assess livelihood vulnerability by combining the Fuzzy Cognitive Mapping (FCM) with the proposed sustainable livelihood framework, which explains communities' understanding of climate-related impacts and adaptations by capturing interconnected interactions that occur in the dynamic climate-human-environment interaction space. Further, the study has deployed the simulations that allow analytically tracing feedback mechanisms captured in the cognitive maps, and helps to develop future scenarios to facilitate decision makers in order to identify pathways to climate resilient development and to prioritize adaptations. A typology of adaptations being practiced has also been provided for the case studies.

The Agro-Ecological Zones (AEZ) Methodology

This study applies the Agro-Ecological Zones (AEZ)methodology developed by Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). The AEZ approach is a GIS-based modeling framework that combines land evaluation methods with socio-economic and multiple-criteria analysis to evaluate spatial and dynamic aspects of agriculture. The AEZ methodology provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production. Crops modeling and environmental matching procedures are used to identify crop-specific environmental limitations under assumed levels of inputs and management conditions. The suitability of land for the cultivation of a given crop/LUT depends on crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. The AEZ Gujarat combines these two components by successively modifying grid-cell specific agro-climatic suitability according to edaphic suitability of location specific soil and terrain characteristics. The AEZ simulation modeling includes generation of a range of scenarios for crop productivity for year 2041–2070 (2050s) and 2071–2100 (2080s) using the climatic condition based on 4 Representative Concentration Pathways (RCPs) adopted by the IPCC. This phase quantifies the impact on individual crops, largely by predicting changes in crop production/yield due to changes in climatic, physical as well as other atmospheric factors. This include identification of areas which specify climate, soil, and terrain constraints to crop production; estimation of the extent and productivity of rain-fed and irrigated cultivable land and potential for expansion; quantification of cultivation potential of land currently in forest ecosystems; and impacts of climate change on food production, and geographical shifts of cultivable land.

The Fuzzy Cognitive Mapping (FCM) Methodology

The fuzzy cognitive mapping (FCM) is a perception-based technique used to model, study and understand complex systems. It is an important tool that aids in visualizing how interrelated variables affect one another and represent feedbacks. Fuzzy cognitive maps are product of local knowledge, valuable in supplementing and complementing scientific data, and easy to apply in data deficient situation and complex environments, particularly where human behavior needs to be understood in order to comprehend complex problems.

Fuzzy cognitive maps (FCMs) portrays interconnectedness among variables/concepts and explains complex interactions occurring within system dynamics.

To obtain fuzzy cognitive maps, we selected marginal farmers (land holding < 0.3 hectare) who have a few livestock, as our stakeholder groups. The community participants prepared cognitive maps for three central variables/concepts i.e. variabilities of summer temperature, winter temperature, and rainfall, around which they established direct and indirect connections between the variables. Individual fuzzy cognitive maps were then coded into separate excel sheets with concepts listed in vertical and horizontal axes; these formed adjacency matrices. The values were coded into the square matrix when a connection existed between two concepts. All individual fuzzy cognitive maps were aggregated through arithmetic mean at each interconnection of the adjacency matrix. In order to simplify and understand the structure of the complex maps concepts are condensed by replacing sub-groups with a single unit. The process can be called as qualitative aggregation. The condensed social cognitive maps were analyzed using FCMapper software. Cognitive interpretive diagram (CID) was prepared using the visualization software Visone-2.16. Concepts in the CID are represented based on their centrality, which depicts the connections between the concepts while reflecting the importance of different concepts within the system.

We have combined FCM approach with modified DFID sustainable livelihoods (SL) framework to better represent communities' perception of climate related impacts on various asset classes, i.e. natural, human, financial, physical, and social assets, and to understand assets sensitive to climate variability and change, and assets that serve as adaptive capacities. The SL approach helped in understanding the livelihoods of the poor. The SL framework allows to identify sensitivity of livelihood assets to cope up with and to adapt to climate-related risks. By simulating scenarios through what-if analysis explains the behaviour of a dynamic system. FCM Wizard software was used to run simulations. System dynamics, as perceived by stakeholders, relevant to impacts concerning climate variability and change along with adaptations are encapsulated in the social cognitive map, which forms the neural network. We have developed two future scenarios using FCM-based simulations: a) climate change without adaptation, i.e. business-as-usual scenario, and b) climate change with adaptation, i.e. scenario after scaling up certain adaptation interventions. These scenarios were generated to get better insight into the system's behaviour from baseline or steady state. The simulations provide policy options for decision makers to design flexible, long-term, and pro-active climate change adaptations.

Spatial and Temporal Heterogeneity of Climatic and Bio-Physical Parameters

Climatic variability is prepared for the use in the AEZ Gujarat through conversions and temporal interpolations. Temporal interpolations of the gridded monthly climatic variables into daily data, provides the basis for the calculation of soil-water balances and agro-climatic indicators relevant to crop production. Spatial and temporal heterogeneity of climatic parameters such as: mean annual temperature, mean annual precipitation, total number of rainy days, and number of consecutive rainy days during monsoon season are calculated. The projections for mean annual temperature, mean annual precipitation, total number of rainy days, and number of consecutive rainy days during monsoon season fordifferent RCPs for periods 2020s (2011–2040), 2050s (2041–2070), and 2080s (2071–2100) illustrated for different parts of Gujarat. Spatial and temporal heterogeneity of bio-physical parameters such as soils—texture, organic carbon, salinity, pH, etc.; land—topography, elevation, slope, land use and land cover, etc.; forest—mangroves, wetlands, waste lands, etc.; water—water resources, water demand, etc. were mapped. Spatial and temporal heterogeneity of above mentioned climatic and bio-physical parameters helps to illustrate crop suitability and agro-ecologically attainable production for various crops.

South Gujarat, having highest rainfall and temperature in Gujarat in current climatic condition, is also projected to have highest mean annual rainfall and temperature in future. Temperature data also indicates that the region along the border between south and central Gujarat are experiencing highest temperature in Gujarat in current conditions. Reference climate averaged data indicates homogenous rise in annual mean temperature in entire Gujarat. The 30-year average annual temperature for duration 1981–2010, 1971–2000, and 1961–1990 has shown continues increase of 0.01 to 0.5°C.Projection using different RCPs pathway suggests maximum rise of 1 to 2.5˚C for period 2020s (2011–2040), 1.3 to 2.7˚C for period 2050s (2041–2070), 1.3 to 4.6˚C for period 2080s (2071–2100), mostly in the region of south Gujarat and small portion of Kutch and north Gujarat regions. Rest part of the Gujarat is likely to experience a rise in temperature between 0.5 to 1.0˚C during the same period.

The results suggest a significant increase in rainfall in entire Gujarat. Kutch, most of the region in Saurashtra, and north Gujarat is likely toexperience an increase in the number of rainy days during 2050s and 2080s. Precipitation varies from 40 days in Kutch to 160 days in south Gujarat. Eastern and southern part of Gujarat can face a decline in the number of rainy days, whereas, northern part will receive larger numbers of rainy days.Most of the region in Kutch, Saurashtra, and western part of north Gujarat may experience an increase in mean annual rainfall by 0 to 200 mm. The Southern part of south Gujarat may experience the highest increase in mean annual rainfall by 400 to 600 mm. There is increasing trends of number of consecutive dry days during rainy season in most parts of Gujarat except Kutch and parts of Saurashtra. The southern part of south Gujarat,where temperature and precipitation are likely toincrease, may experience the highest decrease in numbers of rainy days by 60 to 80 days.

The central part of Gujarat contains sandy loam, sandy clay loam, silt clay and sandy clay soils. Clay soil is the major soil in Saurashtra, whereas, sandy clay loam, clay loam, confined mainly on coastal region of Saurashtra. Northern part of Gujarat contains sandy loam, sandy clay loam, clay loam soil and sand. The Kutch region consists of sandy loam, sandy clay loam, sand, silt clay, loam and clay. Soil organic content of northern Gujarat varied between 0.1 to 0.6%. Sizable portion of central Gujarat has a soil organic carbon content of 0.1 to 0.3%, while western part of central Gujarat has a soil organic carbon of 0.3 to 0.6% and higher SOC content of 0.6% to higher confine to very small region in western part of central Gujarat. Western Kutch, western and eastern part of Saurashtra, coastal region of southern Gujarat, and eastern part of central and northern Gujarathave majority of the saline soils.

As per remote sensing data, Gujarat has a total land surface area of 196,024 km^2. The land under agriculture is 60% of the total area of the state. Around 6.2% is occupied by built-up areas. The remaining land consists of forests (13%), wastelands (13.2%), wetlands (3%), and water (4.3%). Gujarat's tree cover outside the forest area is about 5.3% of geographical area in comparison to only 2.8% in India. Water resources in Gujarat are characterised by colossal regional variation in the context of richness and scarcity. The state's water resources are mainly concentrated in its southern and central regions. Coastal wetlands are mainly concentrated around the Gulf of Khambat, Gulf of Kutch, and the two Ranns. The Saurashtra, Kutch, and north Gujarat regions have limited surface and ground water resources. Gujarat experiences uneven distribution of rainfall which varies from 400 to 2000 mm. Seventy one percent of its total area is water deficient.

Crop Suitability and Agro-Ecologically Attainable Production

The agro-climatic analysis using reference data and projections for different RCPs and periods (2020s, 2050s, and 2080s) are calculated for actual evapotranspiration, reference evapotranspiration deficit, potential evapotranspiration of reference soil, length of growing period, and actual P/PET ratio. Agro-climatic constraints cause direct or indirect losses in the yield and quality of produce. Yield losses in a rain-fed crop due to agro-climatic constraints have been formulated based on principles and procedures originally proposed in FAO (1978–1981a, b) and on experiences in individual countries. Terrain suitability is estimated from terrain-slope and rainfall concentration characteristics. Soil and terrain characteristics are read from 3 arc-second grid-cells in which prevailing soil and terrain combinations have been quantified. Soil units are characterized by the following soil parameters: Organic carbon, pH, water storage capacity, soil depth, cat-ion exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry. For this AEZ Gujarat study, the calculations are crop/LUT specific and are performed for an assumed high input level, including rain-fed conditions, sprinkler irrigation, gravity irrigation and drip irrigation. Separate files are generated by crop, input level, water supply system, and scenario/time period. Each database contains information in terms of suitable extents and potential production by suitability classes.

Projecting higher annual actual evapotranspiration in this region is directly related to higher temperature as well higher water availability from rainfall in this part of Gujarat. Higher temperature as well as availability of increased amount of water cause higher evapotranspiration rate, consequently South Gujarat, as expected, may show highest annual actual evapotranspiration. In the current climatic condition in Gujarat, reference evapotranspiration deficit varies between 1065 to 2002 mm with a maximum and minimum deficit in the region of Kutch and southern part of the south Gujarat respectively. The rainfall intensity varies significantly higher than temperature across the south Gujarat and Kutch. Therefore, potential evapotranspiration, affected by atmospheric demand specifically temperature; vary relatively less than rainfall from south Gujarat to Kutch. Therefore, P/PET remains higher in south Gujarat and reduces significantly toward Kutch in parallel to reduction in rainfall. Net Primary Production (NPP) under rain-fed condition has close relation with actual evapotranspiration because it is related to plant photosynthetic activity which is also driven by radiation and water availability. Therefore, considering high actual evapotranspiration in presence of high water availability in south Gujarat, Net Primary Production under rain fed condition also becomes higher in south Gujarat. Reference evapotranspiration deficit is higher in Kutch because of higher difference between potential evapotranspiration and actual evapotranspiration. The atmospheric demand of evapotranspiration is much higher than the available water for evapotranspiration in the region of Kutch which relatively decreases toward the south. Therefore, reference evapotranspiration remain higher in Kutch and reduces toward south Gujarat.

Assessing crop suitability is an important component of assessment studies, including changes to crops geographic distribution under climate change in coming decades. On the one hand, it is well known that crops will respond to specific changes in temperature and precipitation at the locations where they are currently grown; on the other, it is also expected that not all crops and cultivars will remain suitable within their current geographical ranges, with tendencies to migrate towards higher latitudes and a push out of production in areas already at the margin of production. Yet most crop modeling platforms available today present fixed grid simulations of crops, i.e. they do not allow for dynamical movements of ideal crop ranges, and thus tend to underestimate likely adaptation responses by farmers.

Climate Change Impacts on Crop Suitability, Average Output, and Attainable Yield

Results of the analysis for the various crops are summarized by regions and districts of Gujarat showing: (i) suitability index, area and percentage, occurrence of very suitable and suitable agricultural land; (ii) average output per unit area; and (iii) agro-ecologically attainable yield for current and future climates, i.e. reference climatic conditions (1981–2010) and for the ensemblemean of RCP4.5 climate scenarios (2041–2070). Ensemble mean was calculated based on five climate models: CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M.The AEZ results show that projected climate change affects crop production differently for different crops in different parts of Gujarat.

In comparison to the reference climate data for harvested area to the predicted future model, the projected areas show drastic reduction everywhere except Saurashtra which shows an increase in harvested area by only a couple thousand square kilometers. The harvested are of mustard, groundnut, bajra, castor, pigeon pea, mango, wheat, and white potato is visibly decreasing drastically varying from 63 to 100%. Important drivers, apart from economic considerations, were adverse climatic conditions in recent years. For rain-fed conditions only sorghum has sustenance in future in Kutch specifically but also has growth in the rest of Gujarat as well. Mustard, BT Cotton, mango, wheat, and white potato have never been grown under rain and there's only the same in future also. Cotton, maize, and sorghum show an increase in production by 5 to 10%. For irrigated conditions as for production, the substantial decline of harvested areas has been mirrored by yield decreases, with only sorghum, cotton, BT cotton, and maize showing promise of increase in yield between 8 and 32%.

Adaptation Options for Enhancing Livelihoods of Rural Communities

The stakeholders percieved an increase in temperatures during summer and winter seasons and also increase in rainfall during rainy season. It is apparent that increased summer and winter temperatures influenced their natural and human assets the most. Increased temperatures has resulted into declining vegetable and wheat production reduced agricultural production due to increasing temperatures has resulted into decrease in fodder availability. Less availability of fodder has decreased livestock number, their health, and milk production, which consequently led to plunge in the financial reserves of the community memebrs. Another major impact of increased temperature is the surge in heat during summers. This climatic extreme has degraded human and livestock health severly. Declining water resources during summer and winter seasons such as lower availability of ground water, drinking water, and water for irrigation have further impacted agricultural production, and human and livestock health. Drudgery among women has increased due to scarcity of drinking water. Water quality has also lowered negatively affecting human health. They have adopted several adaptation practices such as micro-irrigation, better agricultural inputs, water resource management, water infrastructure, and diversification of production systems to increase the agriculture production. Stakeholders use fertilizers to increase soil fertility and agriculture production. Building of check dam has increased water availability during lean seasons helping them in maintaining the agriculture production and fodder availability. Drip irrigation and sprinklers have increased soil moisture and improved soil quality, and also increased agriculture production. To tackle the issue of lesser availability of drinking water, water storage tanks have been installed at various places which provides drinking water to villagers, and reduces drudgery among women.

The simulation results show that agricultural production, livestock and milk production, fodder availability, water and land resources, financial reserves, human health, and education show changes in future scenarios.

Guidance Toward Policies and Governance

The projected changes of precipitation, temperature, and water flow and storage, a region wise plan to address climate change concerns is need of the hour. Rapid industrialisation and urbanisation of the state have compounded the already complex water management issues faced by the state. Government responses have a central role to play while addressing the issues related to water and land management. There is a need for serious efforts to increase natural resource base, promote sustainable and organic agricultural practices. Appropriate measures of land acquisition which could provide a win-win situation for all the stakeholders is required.

Some efforts have been made by the Government to reduce these impacts. The initiatives worth noting are looking at increasing agricultural productivity and ensure land tenure security. The central and state governments that play the key role in the management of water resources such as water conservation and management including watershed development, construction of recharge structures, micro-irrigation, inter-linking of rivers, and the creation of marketing infrastructure among others. The thrust on participatory village level institutions through Water and Sanitation Management Organization (WASMO) has played an effective role in improving water management at village level with a definite scope for further improvement. Participatory village level institutions in case of watershed and irrigation management require strengthening and scaling up. Schemes like Sujalam Sufalam, the interlinking of rivers, plus a state-wide grid for domestic and drinking water supply have some positive impact of good rainfall and an almost complete SSP over the Narmada. WASMO and Jyoti Gram are two institutional responses that have had major positive impacts on the water sector in Gujarat. The detrimental environmental consequences of over-exploitation of groundwater need to be effectively prevented by legislation and its enforcement by local level institutions.

For effective and economical management of water resources, the frontiers of knowledge need to be pushed forward in several directions by intensifying research efforts in various areas, including the following: (i) hydro-meteorology, (ii) assessment of water resources, (iii) groundwater hydrology and recharge, (iv) water quality, recycling and reuse, (v) prevention of salinity ingress, (vi) prevention of water-logging and soil salinity, (vii) water harvesting in rural areas in an integral manner, (viii) water harvesting and groundwater recharge in urban areas, (ix) economical and easy to operate and maintain designs for water resource projects, (x) better water management practices and improvements in operational technologies, (xi) crops and cropping systems, and (xii) sewage treatment on smaller scales and reuse of water after treatment. Since the overall thrust of the policy is towards people’s participation at all stages, the highest priority should be accorded to the training of those who are to manage the water resources at all levels. Gujarat has set an example in taking lead to set up Climate Change Department. In this context, Gujarat needs to look for a paradigmatic change in terms of managing its water holistically to sustain its hard-earned growth momentum.

Gujarat's agricultural growth has been encouraging with the increased cultivation of cash crops and non-traditional food crops facilitated by increased irrigation. Water efficient and traditional crops like pearl millet, sorghum, and groundnut were grown in Kutch and north Gujarat region in the past. Rising rainfall in the last decade and increased groundwater irrigation measures has led to a shift towards water intensive crops like cotton and wheat. The western portion of north Gujarat and Kutch is highest afflicted in the state with soil salinity. The soils in this region are unfit for the cultivation of crops like cotton and wheat although these happen to be the most dominant crops in this region. Central and southern region of Gujarat have fertile soils, which can support most varieties of crops.Increase in rainfall trends has been observed in central and southern regions of Gujarat. Water intensive crops are cultivated in these regions and have shifted from traditional food crops to non-traditional food and cash crops such as rice, wheat, cotton, and sugarcane. Rainfall has increased from north to south Saurashtra, yet north Saurashtra receives lower rainfall than south Saurashtra. Irrigation in north and south Saurashtra is relatively low as compared to the state; though it has increased considerably over time. Increased irrigation has shifted cultivation towards water-intensive crops like wheat, cotton, and cumin.

The shift towards higher water demanding cropping patterns in Gujarat have depleted groundwater in most regions of the state. Further, the rate of groundwater extraction can potentially increase soil and water salinity. There is an immediate need to shift to sustainable cropping patterns that would facilitate soil and water conservation and increase yield, without hindering the high agricultural growth witnessed in the last decade. Soils are being degraded while groundwater utilisation has rendered most parts of Gujarat water insecure despite good rainfall in the past decade. Should the higher water demanding cropping patterns persist they will degrade the ecological soundness of the state's agricultural ecosystem and further degrades the soil and water resources.

To ensure the sustainability of cropping patterns in Gujarat, crop cultivation compatible to soil type along with climate and availability of water for irrigationneeds to be promoted. Farmers need to be educated to shift towards the cropping patterns based on results of AEZ modelling. Growing crops unsuitable for rainfall, soil type, and reliance on groundwater have caused serious environmental perturbations calling for immediate sustainable agricultural interventions. There is an urgent need to return to water efficient crops and help prevent further degradation of agricultural land. There needs to be a shift towards sustainable cropping patterns like system of crop intensification along withmicro-irrigation practices, and water and soil conservation to reduce groundwater depletion while integrated nutrient management needs to be adopted for maintaining sustainability. Sustainable agricultural practices will also help mitigate climate change, build resilience against climate vagaries, and reduce environmental burden. Improving groundwater regime through recharge movements and arresting groundwater mining could go a long way in attaining environmental sustainability. With efforts in the right direction Gujarat can become a model for sustainable agricultural practices and water management which can be replicated in similar agro-climatic regions of India.

CHAPTER-1

Introduction

The anthropogenic climate change today is at a pace and has overcome paleo climate changes. Many studies have shown a high correlation between climate variability and the concentration of green house gases. The first decade of this millennium has received a global consensus to accelerate the rate of global warming, exacerbated mainly by past and present unsustainable anthropogenic practices. The anthropogenic practices include large volumes of greenhouse gas emissions, deforestation, reduction of global biodiversity, increased consumption of limited resources, and pollution of water resources (Behnassi 2014). The concentration of greenhouse gases is now higher than ever, including pre-industrial ages (before 1750) (WMO 2011). Today there are peer-reviewed scientific evidences and new findings connecting the dots between anthropogenic greenhouse gas emissions and their effects on the natural climate system and the consequent impacts on humans. Climate variability and change can affect different sectors of the economy in several ways, for example, through the introduction of severe and frequent flooding due to abnormal precipitation. The increase in the maximum temperature may increase the mean sea level which may directly affect large populations in the peninsular and coastal areas. It is assumed that climate change can increase average annual rainfall between 15 and 40% and raise the average annual temperature between 3 and 6˚C (Ajay and Sharma 2013). The change in water and the seasonal cycle can directly affect the agricultural production. Therefore, global climate change imposes a major food security challenge on all countries affecting agricultural production directly or indirectly. In such circumstances, many researchers, policy makers, planners, and stakeholders increasingly believe that the interaction between climate change and food security is of critical importance. There are enough scientific evidences which conclude that climate change affects humans in various sectors, increases food and water insecurity, affects human health, the economy, and the livelihoods of poor and vulnerable communities. It is necessary to communicate the causes and impacts of climate change to increase resilience. The world continues to negotiate a global climate agreement and countries begin to implement their national greenhouse gas emission reduction targets as actions under the precautionary principle. However, skepticism remains mainly among those who deny assuming responsibility for the climate system and want to annoy it without looking at the implications of their actions. Human societies today have to adapt to rapidly changing climates and the risks posed are not for the Earth, but for humans. It is necessary to strengthen resistance to the impacts of climate change.

The Brundtland Commission Report of 1987, entitled "our common future", opened the eyes of the world to the imminent environmental fate due to rapid industrial development. The World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) provided global governments with reliable scientific evidence on the climate system and the potential pressures and impacts on humans, created the Intergovernmental Panel on Climate Change (IPCC) in 1988. The first assessment report by the IPCC in 1990 provided scientific evidence of anthropogenic emissions and their effects on the climate system and the importance of addressing climate change on a political platform. The Brundtland Commission report and the first IPCC assessment report were the highlights of the United Nations World Commission on Environment and Development in Rio de Janeiro (Earth Summit); the deliberations led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992.

The climate system is a common global phenomenon and climate change is a global phenomenon manifested through land, air, and life, with which the climatic systems are intertwined. There is much certainty about climate-induced changes, although predictions about the precise nature of their changes are uncertain. The UNFCCC recognized the climate system as a global group whose stability could be affected by industrial emissions and other greenhouse gas emissions. As a common property resource, climate systems would also be subject to the principle of "tragedy of the commons". There is a need for a global solution and the fulfillment of common but differentiated responsibilities (CBDRs) to sustain this global common. The convention established a framework for intergovernmental efforts to address the issue of climate change and today the convention has 192 countries involved in combating climate change. In 1997, a second and far-reaching treaty on climate change was signed and adopted in Kyoto, where it imposed binding targets on greenhouse gas emissions for major world economies, greenhouse gas reduction commitment protocols varies from nation to nation. It established flexible mechanisms to achieve these goals through international emissions trading, intergovernmental emissions trading, the Clean Development Mechanism (CDM) and joint implementation. The protocol was intended to be effective against a complicated problem and was also politically accepted, except for the United States of America that remained outside the protocol.

In February 2007, the IPCC concluded: "warming of the climate system is unequivocal, as evident by observations of increases in global average air and ocean temperatures, widespread snow and ice melting and rising average sea". The convention defines climate change in Article 1(2) as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which adds to the natural variability of the climate observed in periods comparable" (UNFCCC n.d). The definition has accentuated the role of anthropogenic factors influencing climate change. However, to understand the severity of climate change, attention must be paid to climate variability and its impacts. The IPCC's Third Assessment Report (TAR) has suggested that despite the full implementation of the Kyoto Protocol, the impacts of global climate change will begin to be felt in the coming decades, especially by the most vulnerable countries and communities. The Fourth Assessment Report (AR4) of the IPCC (IPCC 2007) has highlighted the impacts of climate change as an increased risk of extinction of animal and plant species, glacier melting and snow cover, displacement due to sudden disasters related to climate change and impacts adverse health effects. At this juncture, it is relevant to differentiate between impact in developed and developing countries. Developing and least developed countries do not have the means to address climate change challenges, making them the most vulnerable to the impacts of climate change. The UNFCCC and the IPCC have also identified that vulnerable communities are urgently needed to increase their adaptive capacity.

Most countries have agreed that climate change is a crucial symptom of intensified anthropogenic exploitation of terrestrial resources. The Human Development Report (UNDP2008) sees the phenomenon as a "threat to the freedom of people in terms of limiting their ability to make decisions that enable them to lead lives that they value" (Chatterjee and George 2011). Therefore, it becomes essential to transform our institutional and individual practices to inherit a sustainable future for the coming generation. Recognizing environmental, social and economic problems, this concern about climate change is also reflected through the growing number of related academic research papers and articles of literature since 1960. The evidence collected so far clearly signifies an increase in the global average temperature which results in melting glaciers, more precipitation, extreme weather events and changing seasons (Chatterjee and George 2011). Therefore, the mitigation of the current stress imposed by climate change lies in the adoption of new sustainable practices. The transformation of past unsustainable practices into a sustainable one requires significant changes in the current economic paradigm, which emphasizes the disproportionate use of resources and increasing per capita consumption patterns. Therefore, the mitigation strategy is likely to require a complete change in the current model of economic development.

The global community must follow the UNFCCC and the Kyoto Protocol to address the impacts of climate change. The UNFCCC has two policy frameworks to address climate change. One is through "mitigation" where there is a prevention of dangerous interference with the climate system and the second is through the "adaptation" process where there is a reduction of vulnerability to climate change. Adaptation relates to development issues and related policies (UNFCCC n.d.). These actions reduce pressure on the climate system and increase the ability of humans to respond to the impacts of climate change. The adoption of technological advances in agriculture supported by high investments in irrigation, infrastructure and institutions over the last decades has pushed India out of the threat of food insecurity. However, the intensification of food demand due to the increase in population growth holds the challenge as significant as in the past. Therefore, current food production systems continue to be influenced by a series of tensions including climate change. The stress imposed by climate change will most likely severely affect countries like India in the coming decades, which depends heavily on agriculture but have limited agricultural land. These countries also demonstrated that they have underdeveloped technological, financial and institutional capacities to initiate effective strategies for mitigation and adaptation to climate change. Measures can be taken in two major forms of mitigation and adaptation. The UNFCCC defines mitigation as "an anthropogenic intervention to reduce sources or increase sinks of greenhouse gases". Climate adaptation is "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate the damage or exploit beneficial opportunities." Types of adaptation can be distinguished, such as autonomous and planned adaptation. Climate change mitigation is an action to reduce the intensity of radiative forcing in order to reduce the potential effects of temperature rise due to the increase of greenhouse gases. Adapting to global warming and climate change seeks to reduce the vulnerability of natural and human systems to the effects of climate change. However, if action against climate change is not accepted, and if the climate system warms up faster or reaches a critical level that precipitates a flip, then it could be too late. Measures taken now must focus on making economic sense, which can delay global warming and may have additional benefits in reducing the risks of extreme events.

Measures should be taken to reduce imminent impacts of climate variability and change. Despite the consensus of the international scientific community on climate change, critics continue to deny that climate change exists or that humans are causing it. There has been agreement in terms of reducing the accumulation of greenhouse gases in the atmosphere, but the limited real action and bitter arguments surrounding the negotiations show that the achievements of a lasting reduction of greenhouse gas emissions will imply rather than setting goals. This attitude has led to international negotiations where negotiators use uncertainty among risks to avoid making planned responses to adapt and mitigate. Wary remarks about the challenges governments face to make decisions about actions to minimize the threat of climate change seem like an escape. Climate change will affect humans and ecosystems, therefore, it is imperative to mitigate or adapt to climate change. When there is a risk with the uncertainty of harm that is caused to society and the environment, preventive action must be taken. The precautionary principle should be applied here to reduce these impacts. The Rio Declaration of 1992, which defines the precautionary principle "in order to protect the environment, the precautionary approach will be widely applied by States according to their capabilities". Where there are threats of serious or irreversible damage, the lack of absolute scientific certainty will not be used as a reason for postponing cost-effective measures to prevent environmental degradation (United Nations General Assembly, 1992). In accordance with the 1992 United Nations Convention on Climate Change, the ultimate objective of this convention and related legal instruments adopted by the Conference of the Parties (COP) is to achieve, in accordance with the relevant provisions of the convention, greenhouse gases in the atmosphere to a level that would avoid dangerous anthropogenic interference with the climate system. This level must be achieved in sufficient time to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to progress in a sustainable manner. Depending on what is done and the speed with which it is applied, the growth rate will slow down, but the consequences will become appreciable in the long run.

National Action Plan on Climate Change (NAPCC)

On 28 March 2008, the UN Commission on Human Rights adopted a resolution on human rights and climate change. It was for the first time in a UN resolution that explicitly recognized that climate change has implications for the full enjoyment of human rights. The application of human rights principles and norms can bring a number of benefits to international and national efforts to respond to global warming and that the obstacles to doing so are mainly practical difficulties, especially related to the ingrained "path dependence" of two (Limon 2009). After this, there had been another change in developing countries; India presented its National Action Plan on Climate Change (NAPCC) in June 2008, which identifies India's contribution to the fight against climate change. There are eight missions under the NAPCC, namely:

i. National Solar Mission

ii. National Mission on Enhanced Energy Efficiency

iii. National Mission on Sustainable Agriculture

iv. National Water Mission

v. National Mission for Sustaining Himalayan Ecosystem

vi. National Mission on Sustainable Habitat

vii. Green India Mission

viii. Nation Mission for Strategic Knowledge for Climate Change

The ministries concerned would be responsible for developing objectives, implementation strategies, timelines, and monitoring and evaluation criteria. After 2008, India's position on the climate change debate became convincing at the next Conference of the Parties 15 in Copenhagen in 2009, where, India signed the Copenhagen agreement with China and accepted a reduction from 20 to 25 % growth strategy with low carbon emissions. In a historic decision at COP 17 in Durban (2011), the first commitment of all countries was to develop a legally binding global framework to reduce greenhouse gas emissions. Although the three largest emitters in the world, the US, India, and China have pledged to sign a legal framework to reduce their greenhouse gas emissions, India has shown strong resistance. The contribution of this agreement will be felt over the long-term, as it will increase food and water security, provide clean air and improve the livelihoods of people in the country. In Durban, it was also decided that the Kyoto Protocol existed until 2017 and during this period a new legally binding commitment to replace the Kyoto Protocol was decided. India requires equitable access to sustainable development for developing countries without being hampered by reductions in emissions at the local level. At the local level, there has been a lot of action in the energy sector to mitigate climate change on the part of the government through clean energy projects, it has done a bit to facilitate adaptation and increase the resilience of poor and vulnerable communities. Although the image of Gujarat is of high economic growth, it cannot do away with the subsistence needs of the poor and perform welfare functions for its citizens. There is a critical need for Gujarat to implement adaptation projects in the agriculture, water resources, and coastal areas to increase resilience.

Between 1969 and 2005, India’s surface temperature has risen by 0.3˚C at a rate of 0.08˚C per decade(Ajay and Sharma 2013; Behnassi 2014). Simultaneously, the climate change impact as also witnessed through growing occurrence of natural calamities such as floods, cyclones, droughts, and heat waves (Goswami et al. 2006), such extreme natural events have the potential to drastically reduce agricultural production and exacerbating food insecurity problems. India's agricultural sector, despite the decline in its share of national income (from 37% in 1970-1971 to < 15% in 2010-2011), remains an important sector considering its strategic importance for security food security, employment generation and poverty alleviation. The agricultural sector still employs around 54% of the country's total workforce.East India estimated a decline from 24 to 58 % in household income along with an increase from 12 to 33% in the poverty of agricultural households in a single year of drought (Bhandari et al. 2007). It is also understood that small farmers are perhaps the most vulnerable to climate change due to their inaccessibility to technologies, inputs, information, and finance for mitigation and adaptation. Therefore, taking into account that two-thirds of the total land of farmers measures of less than or equal to 1.0 hectare, the livelihoods of large numbers of farmers are directly vulnerable to climate change. Given the agrarian structure and potential threats of climate change for sustainable agricultural development and food security, it is important that India addresses the issue immediately (Birthal et al. 2014).

This study seeks to identify the adaptation measures that provide resistance to climate variability and change. In this regard, climate-related impacts and adaptations have been captured to explain the vulnerability of rural livelihoods in the State of Gujarat. A new methodological approach has been developed to assess livelihood vulnerability by combining blurred cognitive mapping with the proposed sustainable livelihoods framework, which explains communities' understanding of climate-related impacts and adaptations by capturing interconnected interactions which occur in the climate-human-environment interaction space. This approach illustrates livelihood assets sensitive to climate risks / shocks, and subsistence assets that provide resistance to climate risks/ shocks. This approach also allows the creation of models of impacts and adaptations based on the perceptions of the communities. In addition, the study has deployed simulations that allow analytical tracking of feedback mechanisms captured in cognitive maps and helps to develop future scenarios to facilitate decision makers in order to identify pathways for climate-resistant development and to give priority to adaptations. Climate impacts and adaptations have been analyzed and the vulnerability of livelihoods has been estimated. A typology of adaptation options has also been provided for the case studies.

1.1 Objectives of the Study

The chief objectives of this study are:

- Generation of a range of scenarios for climate change
- Generation of a range of scenarios for land based production systems
- Elaboration of adaptation options for enhancing livelihoods of rural communities, who are primarily dependent on land and water resources
- Providing guidance toward policies and governance of land and water

1.2 Study Area

The study area is the Gujarat plains and hills agro-climatic region of India, which also coincides with the boundaries of the state of Gujarat. Gujarat plains and hills agro-climatic region covers a wide range of climatic and agro-ecological conditions which is called microcosms of India. This has resulted in a rich diversity of rural livelihoods exposed to a variety of possible future impacts of climate change. In addition, since socio-economic data are usually collected by administrative units, ecological and statistical data can easily be integrated in this case throughout the study area. The study was carried out on two spatial scales. Data generation and first-level scenarios are performed at 30 arc-seconds resolution for the Gujarat. Gujarat has a total area of around 196,024 km^2 out of which, the maximum of the area is under agricultural cultivation (about 60%).

Table 1.1: Land Cover in Gujarat

Land cover type	Area (km^2)	Proportion of total area
Agriculture	118441	60
Forest	25315	13
wasteland	25829	13
water	8349	4

Built up	12054	6
wetlands	6036	3
Total	196024	100

Gujarat, a western state in India with the longest coastline with a large part of the state falling under arid and semi-arid with exposure to sea coasts, state becomes relatively higher vulnerable to climate change. Therefore, it becomes imperative to address climate change in order to maintain the harmony of agricultural growth, food security, human health, biodiversity, and overall development of the state. Western India is anticipated to receive increased rainfall as temperatures goes higher. Therefore, the need of the time forces us to largely understand the agricultural impact from variation in rainfall intensity, duration, and occurrence. Considering the probability of extreme weather conditions such as droughts, floods and cyclones that may wipe out the standing crops leaving farmers impoverished and helpless, it becomes important to address this issue by forecasting of future agricultural scenario.Proper management of land, water, forests, minerals, grasslands, and wildlife is crucial for sustainable development.

The state of Gujarat comprises 27 districts and 225 talukas (sub-district) comprising 18,618 villages and 242 cities. For the purpose of this study, the state is broadly classified in the north, central, south, Saurashtra, and Kutch regions. Kutch is the state's largest district that owns 23% of its total geographic area. The Dangs is the smallest district that owns less than one percent of its total geographic area. Large parts of the state include the plains more or less concentrated in the central and northern Gujarat.

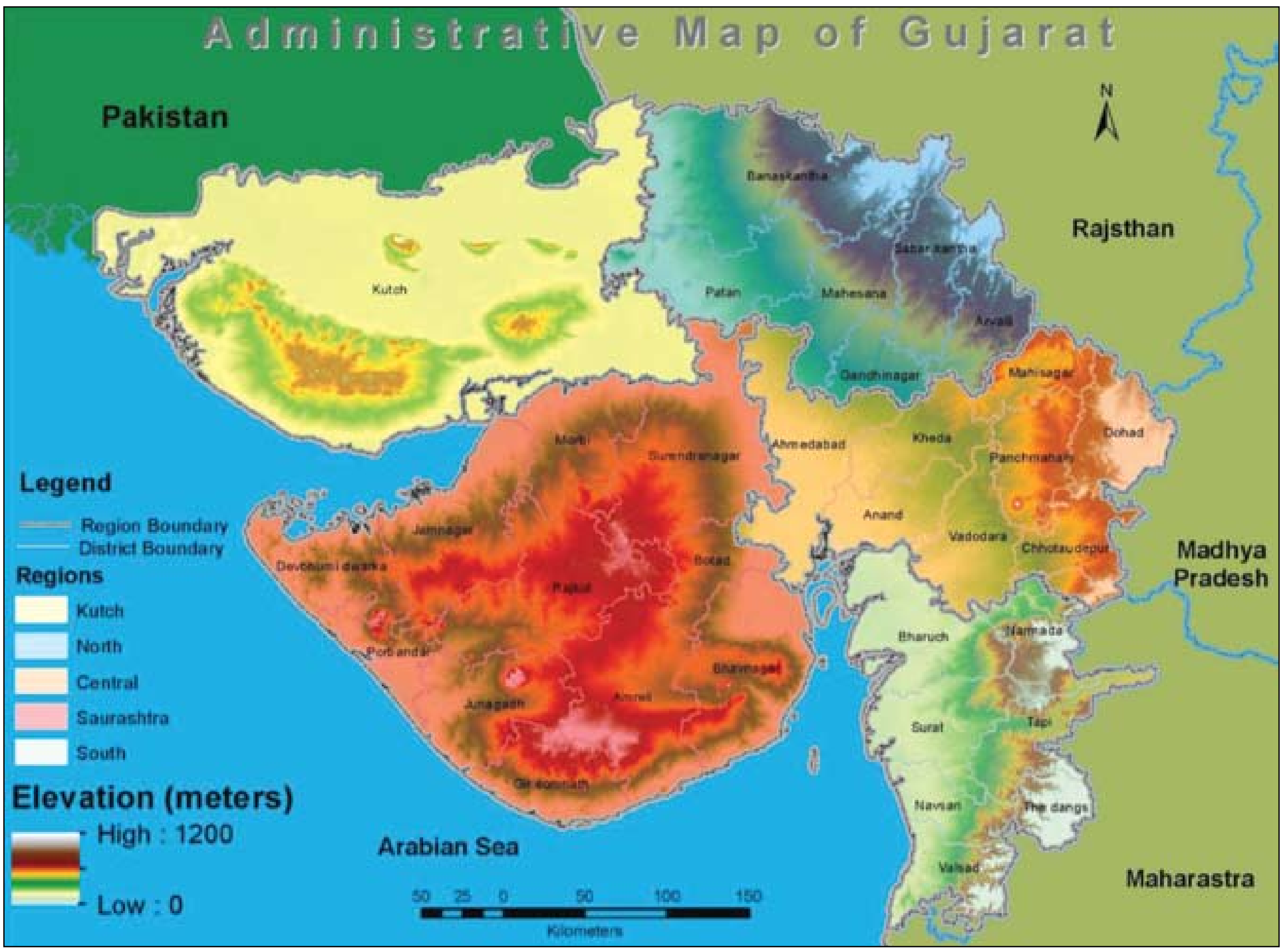

Figure 1.1: Administrative Map of Gujarat Showing Five Regions of the State

South Gujarat: The southern region includes the districts of Bharuch, Narmada, Surat, Tapi, Navsari, Valsad, and The Dangs. Its total geographic area is 23.60 lakh hectares. The region has the highest forested area in the state.

Central Gujarat: The central Gujarat region includes the districts of Ahmedabad, Anand, Kheda, Vadodara, Mahisagar, Panchmahals, Chhotaudepur, and Dahod. The total geographic area of the region comprises 31.18 lakh hectares.

North Gujarat: The north Gujarat region includes the districts of Banaskantha, Sabarkantha, Patan, Mehsana, Gandhinagar, and Aravalli. Its total geographic area comprises 31.84 lakh hectares.

Saurashtra: The Saurashtra region includes the districts of Devbhumi Dwarka, Jamnagar, Porbandar, Junagadh, Gir Somnath, Morbi, Rajkot, Amreli, Surendranagar, Botad, and Bhavnagar. The total geographic area of the region consists of 62.94 lakh hectares.

Kutch: The Arid north western region of Gujarat encompasses the Kutch district. The total geographical area of the region is 46.46 lakh hectares. The region of Kutch consists of the Ranns, which are wasteland encrusted with salt and rises only a few meters above sea level. Flooded during the monsoons are divided into the great Rann to the north and the small Rann of Kutch to the east, the Banni plains between the great Rann and the rocky continent and the mountainous region with the island belt of four rising rocky projections on the Rann, the continent of Kutch and the southern coastal plains.

As shown in Figure 1.2, Gujarat is represented by all climatic types i.e. Humid to Arid. Scenario generation at 3 arc-second (about 90 meter) resolution is undertaken for the entire state.

The first level data and scenario generation is done at 1:250,000 scale for the whole Gujarat. Within this region, nested case-based scenario generation for adaptation is done at a higher scale to represent livelihoods in different sub agro-climatic regions according to various scenarios of climatic, biophysical and development futures. Nested case-based detailed studies have been carried out in three districts namely Surendranagar, Mahesana, and Valsad, to capture diverse impacts, adaptation interventions, and to assess livelihood vulnerability to climate variability and change, while providing insights for decision-making.

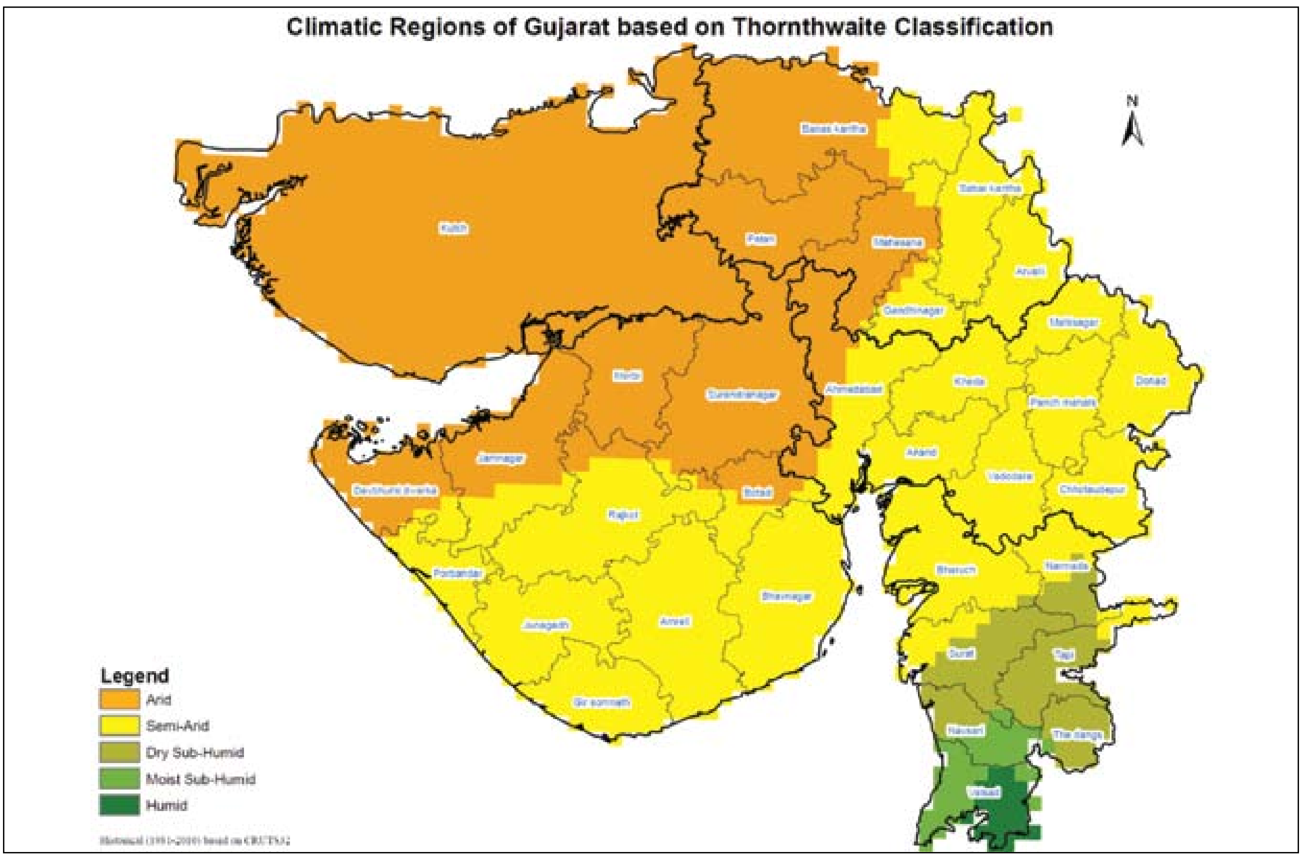

Figure 1.2: Climatic Regions of Gujarat

Surendranagar district falls in the Arid region. In the district stakeholders from 6 different villages were interviewed to study the impacts of climate variability and change, and respective adaptation practices. The district has a population of over 1.7 million people and an area of 10,489 km^2. The main crops are cotton, sesame, bajra, wheat, castor, groundnut, and pulses.

The second case study district is Mahesana district, which falls in the Arid to Semi-Arid region. The rationale for selecting this district is to compare it with the case study prepared by National Institute of Hydrology (NIH) Roorkee in Tikamgarh district of Madhya Pradesh, which also falls in the Semi-Arid region. The district has a population of over 18 lakhs and an area of over 4,500 km^2. The main crops grown in the area are bajra, sorghum, cumin, cotton, oil seeds (castor and mustard), vegetables, mung, gowar, etc.

The third case study district is Valsad district, which falls in the Humid region. The rationale for selecting this district is to compare it with the case study prepared by Centre for Water Resources Development and Management (CWRDM) in Kozhikode district of Kerala, which also falls in the Humid region. In the Valsad district stakeholders from six villages were interviewed to study the impacts of climate variability and change, adaptations, and community resilience. The district has a rural population of over a million and an area of over 2947.49 km^2.

CHAPTER-2

Methodology

2.1 The Agro-Ecological Zones (AEZ) Methodology

The AEZ methodology is developed by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the International Institute for Applied Systems Analysis (IIASA) (Fischer et al. 2012).

2.1.1 Structure and Overview of AEZ Gujarat Procedures

The suitability of land for the cultivation of a given crop/land utilization type (LUT) depends on crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. The Agro-Ecological Zones (AEZ) study in Gujarat combines these two components by successively modifying grid-cell specific agro-climatic suitability according to edaphic suitability of location specific soil and terrain characteristics. The structure allows stepwise review of results. A detailed description of objective is given below:

The Agro-Ecological Zones (AEZ) Simulation

The Agro-Ecological Zones (AEZ) simulation modelling procedure for Gujarat includes generation of

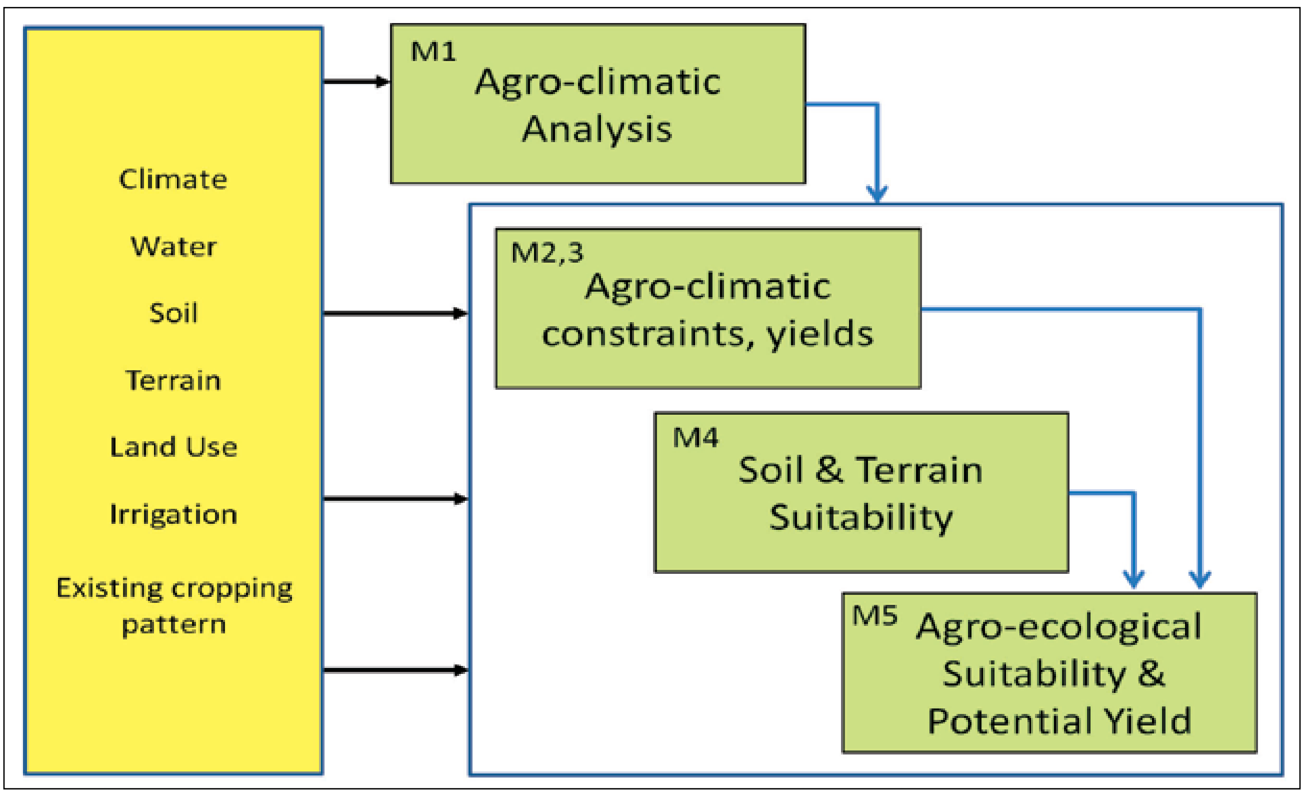

Figure 2.1: Overall Structure and Data Integration of AEZ Gujarat V4 (Module I-V)

range of scenarios for crop productivity for year 2050s and 2080s using the climatic condition based on Representative Concentration Pathways (RCPs) 4.5 adopted by the IPCC. However, the climatic scenarios were depicted across all the four RCPs (2.6, 4.5, 6.0, and 8.5) across four models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M). This phase quantifies the impact on individual crops, largely by predicting changes in crop production/yield due to the changes in climatic, physical as well as other atmospheric factors. Additionally, another important factors; yield gap, quantifying the gaps between potential attainable crop yields, and current crop yield, are also estimated. Yield gap, based on current status of production and actual potential ability, suggests for further improvement scope in order to enhance crop productivity. Modelling simulation, which is also a lengthiest phase of the study, undertakes following activities in order to obtain results (figure 2.1).

i. Adaptation of agro-system models to regional data and context which includes:

   (a) Compilation of a land resources database for the AEZ simulations based on geographic layers of climate, terrain, soil types and soil attributes, land use/cover;

   (b) Review and adaptation of the AEZ land utilization types to conditions of study area; and

   (c) Compilation of climate input variables for various climate change scenarios derived from base period climate data and RCP outputs for 2050s

ii. Contribute to assembling and simulation of scenarios for bio-physical parameters

iii. Simulate impacts of climate change for agro-climatic conditions and bio-productivity based on gridded data of land resources and climate change scenarios for the study area

iv. Provide information from simulation analysis to contextualize the case-based investigations

v. Incorporate case-based information to adaptation simulation experiments at the regional scale

The AEZ approach is a GIS-based modelling framework that combines land evaluation methods with socio-economic and multi-criteria analyzes to evaluate the spatial and dynamic aspects of agriculture. It is the instrument for evaluating the agro-ecological potentials of agricultural crops, as well as the specific crops of biofuels and perennial herbs. The AEZ methodology comprises an inventory of land resources to evaluate all viable agricultural land use options for specific management conditions and input levels and to quantify the expected production of relevant cropping activities. Characterization of land resources includes components of climate, soils, and landforms, which are basic for water, energy, nutrient and physical support to plants. Based on this agronomic assessment and using the available socioeconomic data to formulate constraints, objectives and production options, the allocation of spatial resources to multiple objectives can be optimized (Fischer et al. 1998). The results of the AEZ Gujarat assessment are estimated by grid cell and aggregates at national, regional and global levels. This includes identifying areas with specific restrictions on climate, soil and land for crop production; estimation of the extent and productivity of arable land irrigated and fed with rainwater and potential for expansion; quantification of the potential for cultivation of land currently in forest ecosystems; and the impacts of climate change on food production, geographical changes in arable land. Performance evaluation of alternative types of variables such as land use, a specific criterion function often does not adequately reflect the actions of decision makers, who are multi-purpose nature in many practical problems related to resource planning. Therefore, the multi-criteria interactive model analysis should be applied to the analysis of the AEZ models. It is at this level of analysis that socio-economic considerations can be effectively taken into account, thus providing a spatial and integrated approach to ecological-economic planning for sustainable agricultural development.

The AEZ methodology has been in use since 1978 for determining agricultural production potentials and carrying capacity of the world's land area. An agro-ecological zone, as originally defined, is comprised all parts of grid cells on a geo-referenced map that have uniform soil and climate characteristics. The AEZ methodology provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. Crops modelling and environmental matching procedures are used to identify crop-specific environmental limitations under assumed levels of inputs and management conditions. Further, the recent availability of digital global databases of climatic parameters, topography, soil, terrain, and land cover allow for revisions and improvements in calculation procedures.

More specifically, the AEZ approach attempts to address several issues such as what would be the techniques of availability and adoption of agricultural technology for various crops in the future? What kinds of genetic crop varieties will be available? How will climate change affect cropping areas and yield? How can scientists and researchers reduce the negative consequences of socioeconomic and climatic factors on crop growth? It is also useful to generate a scenario based on assumptions predicted related to such changes in the future allows the evaluations and a distribution of the results. It would facilitate political considerations and decision-making in the face of future uncertainty. The AEZ approach, using grid cell and added to national, regional and global coverage, provides the basis for several applications. These include the following process:

- Selection and identification of areas with specific climate, soil, and terrain constraints to additional crop and production, and land utilization types (LUTs)
- Estimation of the extent of rain-fed and irrigated cultivable land and potential for expansion and extension of the crop/LUT definitions to cover irrigated conditions
- Quantification of crop productivity under the assumptions of three levels of farming technology and management
- Expansion of crop ecological adaptability inventory
- Application of soil-specific moisture regimes for the calculation of length of growing periods
- Evaluation of land in forest ecosystem with cultivation potential for food crops
- Regional impact and geographical shifts of agricultural land and productivity potentials and implications for food security resulting from climate change and variability
- Application of gridded monthly average for long-time series and reference climate year-by-year climatic resources databases
- Enhancement of the assessment procedures for year-by-year crop suitability analysis
- Expansion of the agro-climatic constraints inventory to cover additional crop/LUTs
- Assessment of agro-climatic crop suitability by grid-cell (enabling calculations of biomass, constraint-free yields, agro-climatically attainable yields, crop water requirements and deficits)
- Expansion of land suitability assessment procedures for irrigated crop production

Based on the suitability of land for the cultivation of a given crop/LUT depends upon crop requirements as compared to the prevailing agro-climatic and agro-edaphic conditions. The AEZ Gujarat includes these two components by successively modifying grid-cell specific agro-climatic suitability according to the edaphic suitability of location-specific soil and terrain characteristics. The structure of the AEZ methodology follows a stepwise review of results. In generic form, the AEZ approach can be described in five basic steps. The modules generate the layers of agro-climatic factors that are associated to crop production through spatial grid of reference climate and projected future climate.

Module I: Agro-climatic data analysis—it refers to the selection of agricultural production systems with defined input and management relationships, and crop-specific environmental requirements and adaptability characteristics. It comprises climate data analysis and compilation of general agro-climatic indicators.

Module II: Biomass and yield calculation—geo-referenced climate, soil, and terrain data, combined into a database. It includes crop-specific agro-climatic assessment and water-limited biomass/yield calculation.

Module III: Agro-climatic constrains—procedures for calculating potential yields and for matching crop/LUT environmental requirements with the respective environmental characteristics contained in the land resources database, by land unit and grid-cell. It estimates the yield-reduction due to agro-climatic constraints.

Module IV: Soil and terrain suitability—the module includes edaphic assessment and yield reduction due to soil and terrain limitations.

Module V: Agro-ecological suitability and potential yield—it is useful to facilities for agricultural development planning. It is an integration of results from Modules I-IV into crop-specific grid. It involves two main activities such as obtaining grid-cell level area, yield, and production of prevailing main crops.

2.1.2 Detailed Description of Modules

Module I: Agro-Climatic Data Analysis: Climate Data Analysis and Compilation of General Agro-Climatic Indicators

Module I calculates and stores weather-related variables and indicators for each grid cell. The module processes spatial grids of reference climate, baseline, and future climate projected to create layers of agro-climatic indicators relevant to crop production. First, available monthly climate data are read and converted to variables required for subsequent calculations. Temporary interpolations are used to transform the monthly data into daily estimates required for the characterization of the thermal and soil moisture regimes. The latter includes calculation of the reference, potential, and actual evapotranspiration through daily soil-water balances. The characterization of the thermal regime generated in module I includes periods of thermal growth, accumulated temperature sums (for average daily temperatures above 0˚C, 5˚C and 10˚C), delimitation of permafrost zones and quantification of annual temperature profiles. Soil-water balance calculations determine potential and actual evapotranspiration for a reference crop, length of growth period (LGP, days) including characterization of LGP quality, latency periods and cold brakes, and dates start and end of one or more LGPs. Based on a subset of these indicators, a classification of multiple cropping zones is produced for rain-fed and irrigated conditions.

Module II: Biomass and Yield Calculation: Crop-Specific Agro-Climatic Assessment and Potential Water-Limited Biomass/Yield Calculation

In module II, all and utilization types (LUT) are evaluated for biomass and limited yields in water. The concept of land use characterizes a range of sub-types within a plant species. It includes differences in the length of the crop cycle (i.e. days from sowing to harvest), growth and development parameters. Sub-types differ with the assumed level of inputs. For example, in the low level of inputs, traditional crop varieties can be considered. It may have different qualities that are preferred but have low yield efficiencies (crop index). Due to management limitations, the crops are grown on relatively uneven supports and exhibit a lower leaf area index. On the other hand, with high input levels, high-yielding varieties are deployed with advanced field and machinery management that provides optimum plant densities with high leaf area index. In module II, first, the maximum attainable yield and biomass determined by the radiation and temperature regimes are calculated. It also followed the calculation of the respective water balances of the rain-fed crops and the establishment of optimal crop calendars for each of these conditions. Crop water balances can be applied to estimate actual crop evapotranspiration, cumulative crop water deficit during the growing cycle (irrigation water requirements for irrigated conditions), and biomass and yields available for rain-fed conditions. First, a time window is determined when the conditions permit the cultivation of LUT (e.g. predominant LGP in each grid cell). The growth of each LUT is tested for days during the allowable time window with a separate analysis for irrigated and rain-fed conditions. Growth dates and cycle lengths that produce the highest yield (limited in water or irrigated) define the optimal cultivation schedule for each LUT in each grid.

In addition, due to the detailed calculations for a fairly large number of LUTs, module II requires a considerable amount of computer time for its processing and is the most CPU-demanding component in the AEZ assessment. The results of module II include the maximum yields defined by temperature/ radiation defined by LUT, the yield reduction factors representing the suboptimal thermal conditions, the yield impacts due to soil-water deficits, the estimated amounts of water deficit soil, potential and actual LUT evapotranspiration, and sums during each LUT crop cycle and optimal crop calendars.

Module III: Agro-Climatic Constraints: Yield Reduction Due to Agro-Climatic Constraints

Module III calculates for each grid cell-specific multiplier. The reduction of yields of the various agro-climatic constraints is evaluated as defined in the AEZ methodology. This process is carried out in a separate module to make explicit the effect of constraints due to soil viability, pests and diseases, and other constraints and to allow timely reprocessing in the case new or additional information is available. Five groups of agro-climatic constraints are considered, including:

(a) Yield adjustment due to year-to-year variability of soil moisture supply; this factor is applied to adjust yields calculated for average climatic conditions

(b) Yield losses due to the effect of pests, diseases and weed constraints on crop growth

(c) Yield losses due to water stress, pest and diseases constraints on yield components and yield formation of produce (e.g. affecting quality of produce)

(d) Yield losses due to soil workability constraints (e.g. excessive wetness causing difficulties for harvesting and handling of produce)

(e) Yield losses due to occurrence of early or late frosts

Agro-climatic constraints are expressed as yield reduction factors as per the different constraints and their severity for each crop and by the level of inputs. Due to the paucity of empirical data, estimates of constraint ratings have been obtained through expert opinion. At this stage, the results of agro climatic suitability can be mapped for spatial verification and further use in applications.

Module IV: Agro-Edaphic Constraints: Yield Reduction Due to Soil and Terrain Limitations

This module evaluates the reduction of crop specific performance due to constraints imposed by soil and terrain conditions. Soil suitability is determined on the basis of soil attributes data obtained from NBSS & LUP. Soil nutrient availability, soil nutrient retention capacity, soil rooting conditions, soil oxygen availability, soil toxicity, soil salinity and sodicity, and soil management constraints are calculated on a crop by crop basis and are combined for a crop and input specific suitability rating. The soil evaluation algorithm evaluates for the soil types and slope classes the coincidence between the soil requirements of the crops and the respective qualities of the soil as derived from the attributes of the soil. Thus classification procedures give rise to a quantification of suitability for all combinations of crop types, entry level, soil types, and slope classes.

Module V: Integration of Climatic and Edaphic Evaluation: Agro-Ecological Suitability and Potential Yields

Module V carries out the final step in the AEZ Gujarat assessing the productivity of the land and the suitability of crops. The specific results of the agro-climatic evaluation for biomass and yield calculated in module II/ III for different soil classes are read and the edaphic classification produced for each soil/ slope combination in module IV is used. Soil resource inventories and slope-land conditions are integrated by ordering all soil types in each soil map unit with respect to occurrence in different slope classes. Considering simultaneously the slope distribution of all grid cells belonging to a particular unit of the soil map, results in an overall consistent distribution of the soil-terrain slope combinations is obtained by mapping units of individual soils and 30 arc-secondgrid cells, for rain-fed and irrigated conditions.

Cropping activities are most critical in soil erosion due to their dynamics. The terrain-slope suitability rating used in the AEZ Gujarat study explains the factors that influence the sustainability of production and is achieved through: (i) the definition of permissible slope ranges for the cultivation of several crops/ LUTs and the establishment of maximum slope limits; (ii) for slopes within permissible limits, which explains the likely reduction in yield due to loss of fertilizer and top soil; and iii) to distinguish between a series of agricultural practices, from manual cultivation to fully mechanized cultivation. In addition, the degree of adequacy of the slope of the terrain varies according to the amount and distribution of rainfall, which is quantified in the AEZ Gujarat using the Fournier Index. Application of the procedures in the modules described above results in expected yield and adequacy distribution with respect to irrigated and rain-fed conditions for each 5-minute grid cell and each crop/ LUT. The suitability of the land is described in five classes: very suitable(VS), suitable(S), moderately suitable(MS), marginally suitable(mS), and not suitable (NS) for each LUT. Large databases are created, which are used to obtain additional characterization and aggregations. Examples include calculating land with crop potential, tabulating the results by ecosystem type, quantifying the risks of climate production using time series reference climate of suitability results, the impact of climate change on crop production potentials and irrigation water requirements for current and future climates.

2.1.3 Description of Input Datasets

This section discuss data used for climate analysis as well as land and water resources.

Climate Data

For the AEZ assessment of Gujarat, time series data are used from the Climate Research Unit (CRU) at the University of East Anglia, the Global Precipitation Climatology Centre (GPCC), and the EU WATCH Integrated Project. Climatic Research Unit (CRU) TS v3.21 (time-series) datasets were obtained from British Atmospheric Data Centre (BADC), which are month-by-month variations in climate over the last century covering the period January 1901 to December 2012. CRU TS v3.21 data are calculated on 0.25x0.25 degree grids. CRU TS v3.21 variables used in AEZ Gujarat v4 are daily mean temperature, diurnal temperature range, cloud cover, vapor pressure and wet day frequency. For monthly precipitation, the GPCC Full Data Reanalysis Product Version 6 is used. It covers the period from 1901–2010. The CRU TS 3.21 data and the GPCC v6 full reanalysis data product were downloaded and spatial interpolation to 5 arc-minutes resolution has been completed for the period 1981–2010. Daily data at 0.5-degree resolution was obtained from the WATCH Integrated Project data repository and compilation of within-month precipitation distribution and deviation of daily temperatures (minimum temperature, maximum temperature, and mean daily temperature) from respective monthly means were computed for each month of the period 1981–2010.

Climate Change Scenarios

The results of the IPCC fifth assessment report (AR5) climate model for four Representative Concentration Pathways (RCPs) are used to characterize a range of possible future climate distortions for agro-climatic resource inventories and crop potential assessments for the period 2041-2070. Given the importance of key linkages between climate and socio-economic development, the climate change research community seeks to develop a new framework for the creation and use of scenarios to enhance interdisciplinary analysis and assessments of climate change, their impacts and response options. To define a range of future scenarios, RCPs are combined with alternative Shared Socio-economic Development Pathways (SSPs) (Moss et al. 2010). The RCPs are a set of four greenhouse gas concentration (not emissions) trajectories developed for the climate modelling community as a basis for long-term and near-term modeling experiments adopted by the IPCC for its fifth Assessment Report (AR5). The RCP 4.5 bears the name of a possible level of radiative forcing values in the year 2100 (4.5 W/m2). The development of RCP has been completed and these pathways are documented in a special issue of climate change (van Vuuren et al. 2011), and climate model simulations based on them were undertaken as part of the Coupled Model Inter-comparison Project Phase 5 (CMIP5) (Taylor et al. 2011).

Multi-model ensembles for each of the climate forcing levels of the RCP can be analyzed based on spatial data from the IPCC's AR5 CMIP5 process, data bias-corrected and downscaled to 0.25-degree as used in the Inter-Sectoral Impact Model Inter-comparison Project (ISI-MIP) (Hempel et al. 2013). ISI-MIP data at 0.25-degree resolution of five climate models (ESM2M, HadGEM2, IPSL, MIROC, and NorESM) and for RCP4.5 have been acquired from ISI-MIP servers (a total 20 combinations of respectively RCP and climate models) and were used for generating climate input data in the AEZ v4 for the period 2041–2070.

Monthly mean temperature and precipitation data were extracted from the WorldClim 30 second arc raster databases (Hijmans et al. 2005). The WorldClim is a set of global climatic layers with a spatial resolution of 30 arc-seconds (approximately one square kilometer), which was obtained through interpolations of observed data and are representative of the period 1950-2000. For precipitation, an additional data layer, a Gujarat Isohyetal map of annual mean precipitation for the 1970-2000 period produced by the Gujarat Meteorological Services was used. Monthly precipitation grids were calculated using the distribution of the WorldClim precipitation within one year of each 30 arc-second grid cell scaled to the respective value of the Isohietal map. For other monthly climatic variables such as, turbidity, relative humidity, wind speed, and wet day frequency, data were used from the University of East Anglia's Climatic Research Unit (CRU), namely the 10 arc-minute latitude/longitude gridded monthly average climate data, version CRU CL 2.0 (New et al. 2002). The original monthly CRU 10 arc-minute climactic surfaces were interpolated to a 30 arc-second grid cell for Gujarat. For these variables, a bilinear interpolation method was applied within ArcGIS.

For the analysis of the impacts of climate change on agricultural production potential, the available climatic predictions of the General Circulation Models (GCM) were used to characterize future climates. The results of the GCM model for individual climatic attributes were processed to calculate the differences of the respective means for the period 2041-2070, with GCM control, execution climate for the period 1981-2010. A reverse interpolation of distance to a grid of 30-minutes of arc was performed on these "deltas" of the central points of each grid cell in the original GCM. The changes (deltas) of the monthly climate variables were applied to the observed reference climate (representing the period 1981-2010) to generate maximum, minimum, and mean values of future climate data.

Soil and Land Data

New soil series 370 class and older soil series 144 classes provided by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) ICAR-Nagpur were merged as some of the attributes were not available in the new series.

The elevation data is acquired from the National Remote Sensing Centre (NRSC), Hyderabad – ISRO. The Cartosat-1 (Version-3R1) satellite data has been used for DEM/ elevation information. The accuracy of the vertical resolution is 1 arc-second (~ 32 m). The slope data is acquired from the National Remote Sensing Centre (NRSC), Hyderabad – ISRO. Using the elevation data and ArcMap software by the Environmental Systems Research Institute (ESRI) slope is generated. LULC 2007–2008 is acquired from the National Remote Sensing Centre (NRSC), Hyderabad – ISRO. It is classified using the Resourcesat-1: AWiFS Orth images at the spatial resolution of 56-meters. It was further resampled at 1 arc-second. LULC 2011–2012, Resourcesat-1: LISS-III (ortho) multispectral satellite images are acquired from the National Remote Sensing Centre (NRSC), Hyderabad – ISRO and panchromatic layers of the Landsat are acquired fromthe Earth Explorer USGS. Further images processing and classification for LULC 2011-2012 is done at the Institute of Rural Management Anand (IRMA), Anand. The spatial resolution of LISS-III (24 m) image was brought to 15-meters after fusion with the Landsat panchromatic data. It was further resampled at 1 arc-second.

2.2 The Fuzzy Cognitive Mapping (FCM) Methodology

2.2.1 Assets Sensitivity and Adaptive Capacity: Fuzzy Cognitive Mapping (FCM) Approach

The fuzzy cognitive mapping (FCM) is a technique used to model, study and understand complex systems. It is an important tool that aids in visualizing how interrelated variables affect one another and represent feedbacks. The FCM is highly flexible in nature and caters to a wide spectrum of user groups. Both experts and local people who have a thorough understanding of their system can make cognitive maps. The FCM approach is used to document communities' perceptions about direct and indirect impacts of climate variability and change on different livelihood assets. The FCM approach captures the dynamics of a system better (Singh and Nair 2014). It is a semi-quantitative model that allows capturing cause-effect relations such as climate and weather events' influence on certain aspects of ecosystems and humans (Özesmi and Özesmi 2004). The FCM approach captures the functioning of a complex system based on people's perception. The fuzzy cognitive maps (FCMs) are the product of local knowledge, valuable in supplementing and complementing scientific data, and easy to apply in data deficient situation and complex environments, particularly where human behavior needs to be understood in order to comprehend complex problems (Papageorgiou and Kontogianni 2012; Singh and Nair 2014). Cognitive mapping has been employed in numerous studies to examine people's perceptions of complex social systems (Axelrod 1976; Bauer 1975; Bougon et al. 1977; Brown 1992; Carley and Palmquist 1992; Cosette and Audet 1992; Hart 1977; Klein and Cooper 1982; Malone 1975; Montazemi and Conrath 1986; Nakamura et al. 1982; Rappaport 1979; Roberts 1973).

The cognitive maps are diagraphs, or directed graphs which find their historical origins in graph theory, which started with Euler in 1736 (Biggs et al. 1976). Axelrod (1976) used diagraphs to demonstrate causal relationships among variables as defined and described by people rather than by the researchers. Axelrod refers to it as diagraphs cognitive maps the term was first used by Tolman (1948). These maps can be created by individuals as well as by groups (Özesmi and Özesmi 2004; Vliet et al. 2009). The FCMs portrays interconnectedness among variables and explains complex interactions occurring within system dynamics (Papageorgiou and Kontogianni 2012; Singh and Nair 2014). Cole and Persichitte (2000), Özesmi and Özesmi (2004) and Vliet et al. (2009) have created FCMs in a group setting. The groups making the FCMs reach a consensus and decide the important variables/concepts which are affecting a system and draw cause-effect relationships among these variables indicating the relative strength of the relationships with numeric values. Directions of the cause-effect relationships are shown with the arrowheads (Özesmi and Özesmi 2004). Özesmi (1999 a, b) used FCM for the first time to analyze the perceptions about an ecosystem held by people in different stakeholder groups. One of the major advantages of using FCM is that it does not require expert knowledge in every field and can be constructed on the simple observations by the local community. The FCM can help modelling the system using knowledge of local people even in absence of secondary scientific data (Özesmi and Özesmi 2004).

A cognitive map consists a number of variables/concepts connected through various links (Özesmi and Özesmi 2004). Relationships between these variables/concepts are shown with positive or negative polarities (Singh and Nair 2014), where, a positive sign indicates a directly proportional relationship between the variables/concepts while a negative sign indicates an inversely proportional relationship. The weights are given to each connection by groups preparing maps, ranging between 1 and 10, it describes the strength of the relationship between the variables (Özesmi and Özesmi 2004). A fuzzy cognitive map consists of a number of concepts C = (Ci, Cj…, Cn) connected through various links, where, n is the number of concepts in a map (Özesmi and Özesmi 2004; Nápoles et al. 2016). The links between these concepts arelabelled with weights having positive or negative polarities, which is defined by a function W: (Ci, Cj) - wij,where, wij- [-1, 1] (Nápoles et al. 2016). The cause and effect interconnection between two concepts Ci and Cjare described with the weight wij, with wij having value in the range -1 to +1 (Özesmi and Özesmi 2004; Jetter and Kok 2014; Singh and Nair 2014; Diniz et al. 2015; Nápoles et al. 2016). These causal relationships can be described as follows:

(a) wij> 0 indicates directly proportional relationship between the concepts. That is, an increase (decrease) in the concept Ciwill cause an increase (decrease) in the concept Cjwith intensity wij

(b) wij< 0 indicates an inversely proportional relationship between the concepts. That is, an increase (decrease) in the concept Ciwill cause a decrease (increase) in the concept Cjwith intensity wij

(c) wij= 0 indicates no relationship between concept Ciand Cj

The main advantages that the FCMs have over other tools such as structural equation modelling (SEM), system dynamics model, and causal loop diagrams are: (i) their participatory nature that allows them to use stakeholder perception (Vliet et al. 2009; Diniz et al. 2015); (ii) can model complex systems with many concepts, including those dealing with uncertainty (Kosko 1986; Özesmi and Özesmi 2004); iii) are not based on the unavailability of the data (Kok 2009, Özesmi and Özesmi 2004), but generate data on the other hand; (iv) highlight and reveal the role of hidden and important feedbacks in the system (Kok 2009; Özesmi and Özesmi 2004); (v) can easily integrate data from multiple sources and can disseminate several divergent views (e.g. expert opinion as well as indigenous knowledge) (Özesmi and Özesmi 2004); and (vi) allow multiple policy simulations (Kok 2009; Özesmi and Özesmi 2004).

The main drawbacks of FCMs are: (i) the fallacies of the respondents as misconceptions and biases are encoded in the maps (Özesmi and Özesmi 2004); (ii) The results simulated by FCM are relative estimates and not of real value parameters (Kim and Lee 1998; Özesmi and Özesmi 2004); (iii) do not provide data with respect to a period of time (Schneider et al., 1998; Özesmi and Özesmi 2004); and (iv) requires a large amount of post-processing time (Diniz et al. 2015). FCM professionals outweigh the cons, especially with respect to integrating multi-stakeholder data with different viewpoints, and modelling complex systems.

We adopted the multi-step FCM approach as delineated by Özesmi and Özesmi (2004); Papageorgiou and Kontogianni (2012); Amer et al. (2013); Jetter and Kok (2014); Singh and Nair (2014); Diniz et al. (2015) and outlined in the following sections: (Figure 2.2).

We combined the FCM approach with the modified DFID sustainable livelihoods (SL) framework to better represent communities' perception of climate related impacts on various asset classes, and to understand assets sensitive to climate variability and change, and assets that serve as adaptive capacities. The SL approach helped in understanding the livelihoods of the poor. It provided an overview about the factors that affect the people's livelihoods and the relationships between those factors.

The local community members, following the group discussion, were divided into groups of four to five individuals. These groups were formed based on simple wealth-ranking, wherein the individuals with the same landholdings/ number of cattle were clubbed together. Besides, community groups were also segregated based on gender. Consensuses of the local community were obtained on changes in summer and winter temperatures, and precipitation in last few years. We chose about 10 years as the recall window for climate change having realized respondent's probable inability to accurately report climate variability of an earlier period. The major steps involved in the FCM approach are:

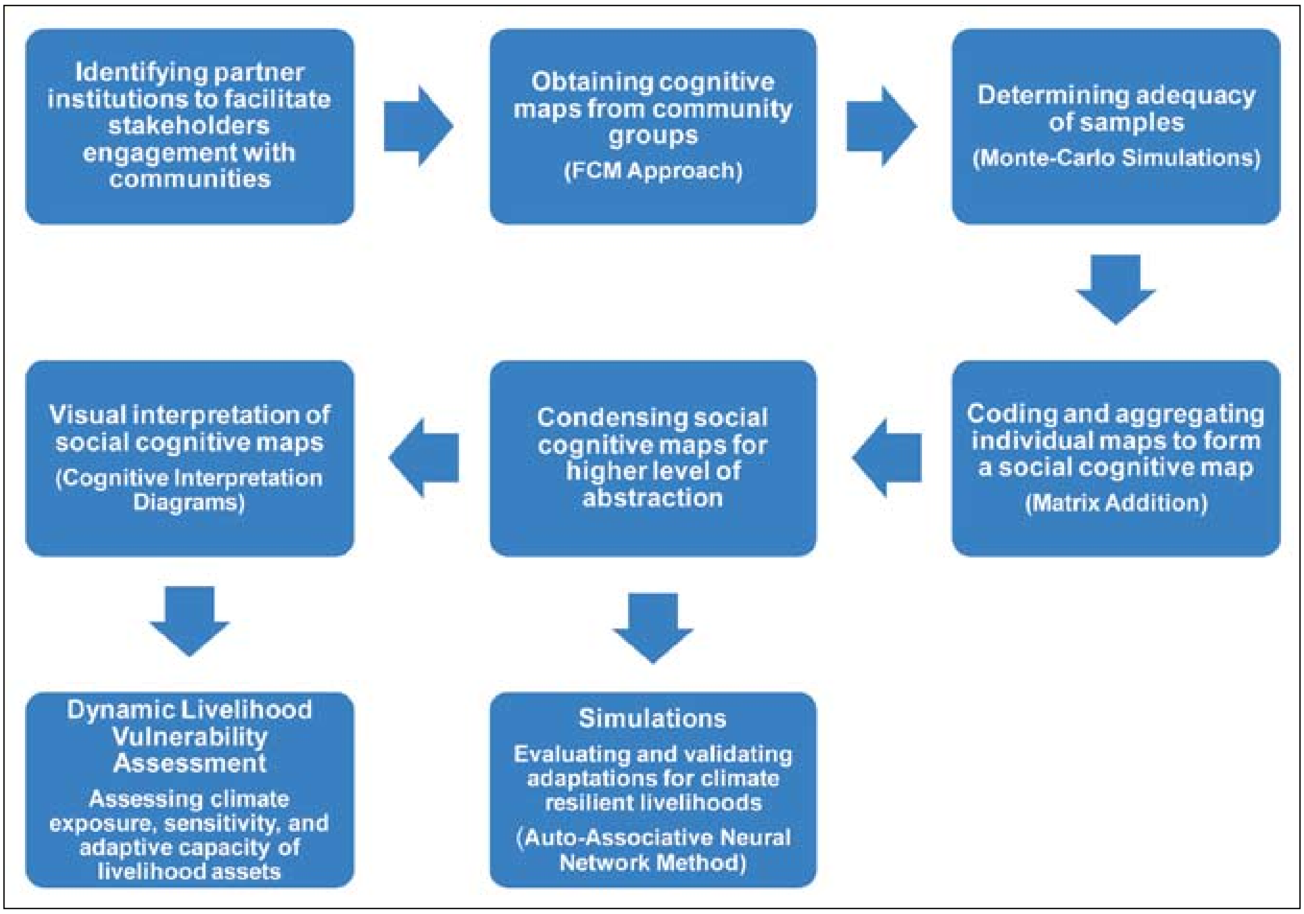

Figure 2.2: The Methodological Approach Followed for the Study

i. Obtaining Individual Fuzzy Cognitive Maps from Community Groups

To obtain fuzzy cognitive maps, we selected marginal farmers (land holding < 0.3 hectare) who have a few livestock, as our stakeholder groups. We demonstrated the construction of a fuzzy cognitive map to the participants using different context. Then, participants were divided into groups of four to five individuals per group, dividing men and women separately to understand gender-based perceptions of impacts and adaptation strategies. The questions asked to obtain cognitive maps are listed below:

i. What are the changes in climate they have observed in the past 10 years during the summer, winter, and monsoon seasons?

ii. How have your livelihoods been affected due to perceived changes in summer and winter temperatures, and rainfall patterns in the last 10 years?

iii. What are the resulting impacts arising from direct impacts due to climate variability and changes?

iv. What are the adaptation practices taken up in order to reduce the direct and indirect impacts due to changes in climate?

The community participants prepared cognitive maps for three central variables i.e. increased/decreased summer temperature, increased/decreased winter temperature, and increased rainfall variability, around which they established direct and indirect connections between the variables. Furthermore, the weights were given by stakeholders to each connection on the scale of 1–10, with 1 being minimum impact and 10 being maximum impact.

Community drawing cognitive maps

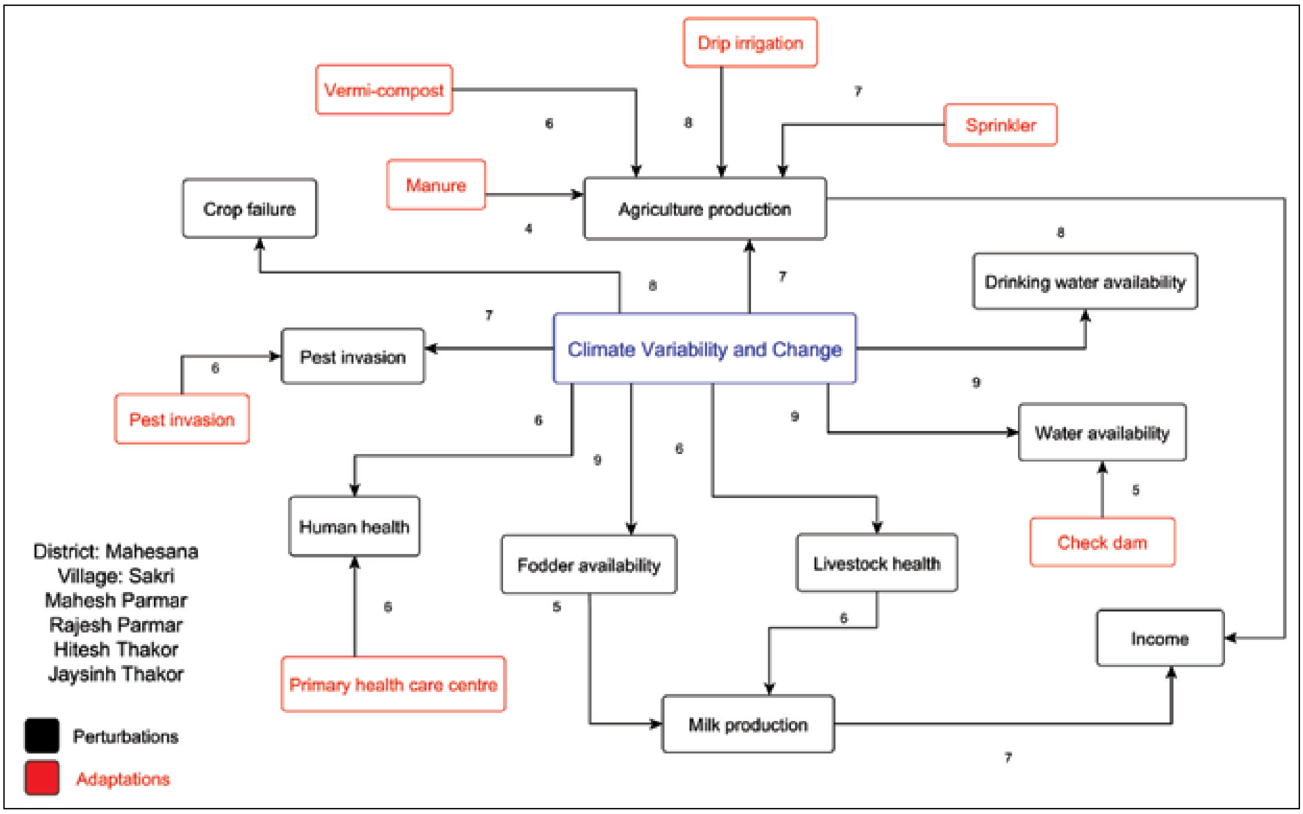

Figure 2.3: A Sample Fuzzy Cognitive Map

ii. Determining Adequacy of Samples

Sample size was determined through accumulation curves by the Monte-Carlo simulation technique to check the adequacy of sample size. "An average accumulation curve of the total number of maps versus the number of new variables added per map determined the manner in which the variables had accumulated" (Özesmi and Özesmi 2004). Fuzzy cognitive maps are created with different groups until the representative population was sampled. Monte-Carlo Simulation was used to acquire the accumulation curve.

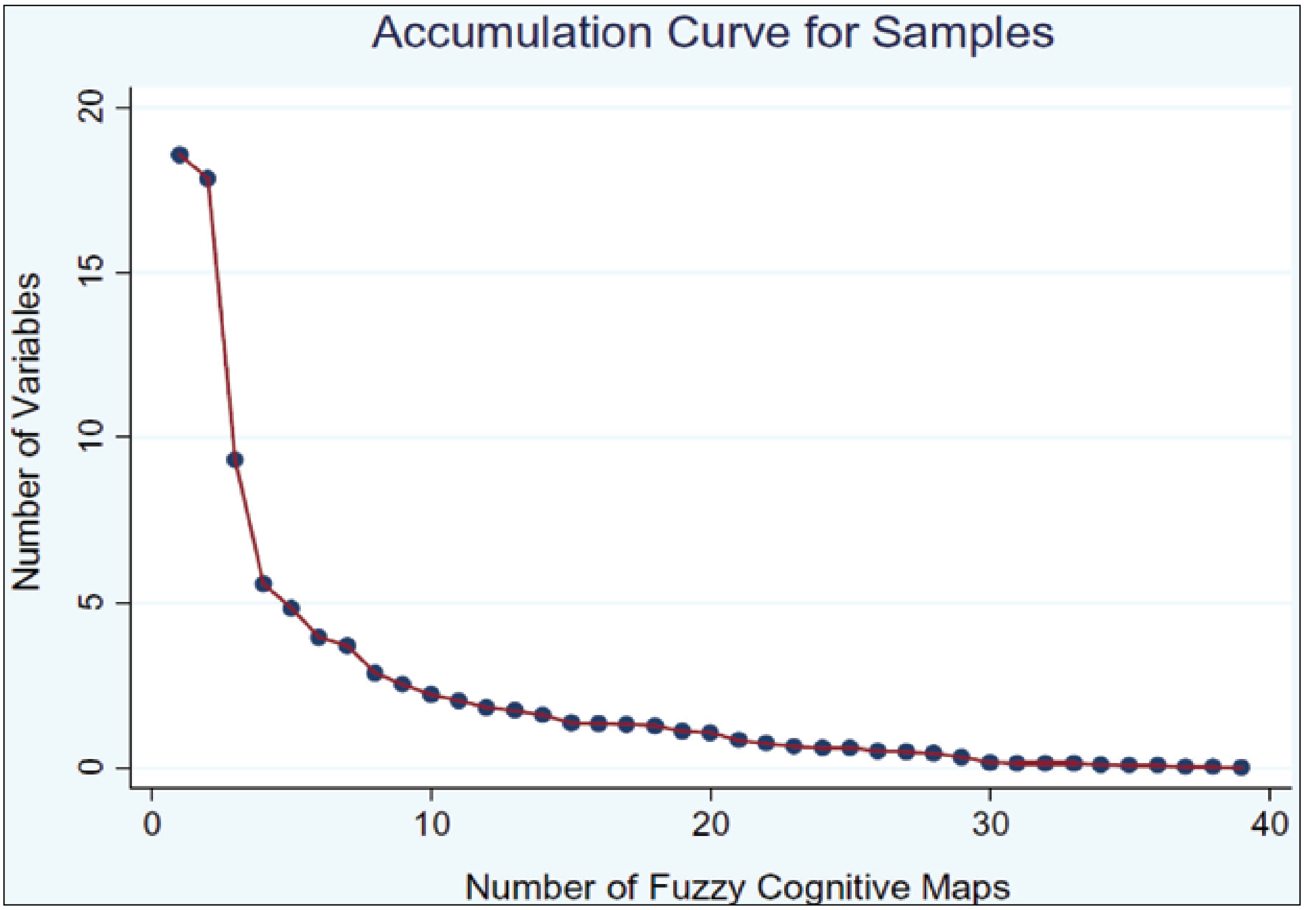

Figure 2.4: Accumulation Curve for Sampling

iii. Coding Maps into Adjacency Matrices

The individual fuzzy cognitive maps were encoded into separate excel sheets with concepts listed on vertical and horizontal axes; thus adjacency matrices formed (Özesmi and Özesmi 2004; Singh and Nair 2014). The values were coded in the square matrix when there was a connection between two concepts (Özesmi and Özesmi 2004). The weights given to each link were then normalized between -1 and +1 (if values are -6 and +7 then normalized to -0.6 and +0.7 respectively) to encode in the adjacency matrix (Singh and Nair 2014).

iv. Aggregation of Individual Cognitive Maps

The aggregation of individual cognitive maps gives consolidated views of all participants and can better represent the system. All individual fuzzy cognitive maps were added by means of an arithmetic mean at each interconnection of the adjacency matrix (Kosko 1988; Özesmi and Özesmi 2004) and normalized to create an augmented matrix in order to obtain a social cognitive map that includes all concepts of individual cognitive maps by combining individual cognitive maps.Conflicting connections with opposing polarities will diminish the causal relationship, while connections with similar polarities will strengthen the causal relationships that form a social cognitive map of consensus. These different directions could be the result of a different logical structure. Therefore, a negative-positive-neutral calculation is used to calculate the composite values of an augmented map to cope with any contradictory connection in the latter (Özesmi and Özesmi 2004). The augmentation of individual cognitive maps is based on the equivalence properties of fuzzy causal relationships between the concepts. However, these operations do not change the behavior of the system (Özesmi and Özesmi 2004). This aggregation approach is useful for constructing a collective fuzzycognitive map and is followed by many researchers (Kosko 1987, 1992a, 1992b; Özesmi and Özesmi 2004; Vanwindekens et al. 2013; Kyriakarakos et al. 2014; Singh and Nair 2014; Diniz et al. 2015).

A large number of concepts in collective (social) fuzzy cognitive map with many interconnections and feedback loops form a complex system. However, matrix algebra of a cognitive map provides many more indices in addition to the number of concepts and links, such as density, in-degree, out-degree, and centrality (Özesmi and Özesmi 2004).

The density (D) of a cognitive map is an index of connectivity, a product of number of concepts (C) and number of links (W), showing how connected or sparse the maps are:

$$D = \frac{W}{C(C-1)}$$

The in-degree of a cognitive map is the column sum of absolute values of a concept. It shows the cumulative strength of links entering the concept (w_{ij}). Where, n = total number of concepts:

$$\text{Indegree} = \sum_{k=1}^{n} w_{ki}$$

The out-degree of a cognitive map is the row sum of absolute values of a concept in the adjacency matrix. It shows the cumulative strengths of links exiting the concept (wij). Where, n = total number of concepts:

$$\text{Outdegree} = \sum_{k=1}^{n} w_{ik}$$

The centrality of a concept is the summation of its in-degree and out-degree. Transmitter concepts have a positive out-degree and zero in-degree. Receiver concepts have a positive in-degree and zero out-degree. Ordinary concepts have both a non-zero in-degree and out-degree (Özesmi and Özesmi 2004).

v. Condensing Social Cognitive Map

Cognitive maps with a large number of concepts become counterproductive in terms of getting ideas. Therefore, to simplify and understand the structure of complex maps, concepts are condensed by substituting the sub-groups into a single unit. The process can be called as a qualitative aggregation. Since the condensation process involves calculating the arithmetic mean of each sub-group in the adjacency matrix, all interconnections of the augmented matrix are maintained in the latter one.

vi. Visual Representation of Condensed Social Cognitive Map

The condensed social cognitive maps were analyzed using FC Mappersoftware. The interpretive cognitive diagram (CID) was prepared using Visone-2.16 visualization software. The concepts in the CID are represented based on their centrality, which represents the connections between the concepts while reflecting the importance of different concepts within the system. It helps to understand the contribution of a concept to the cognitive map, as well as the connection of a concept with other concepts. The largest size of a concept in the CID represents its greatest importance in the system. We have shown causal relationships with negative polarity as discontinuous lines and causal relations with positive polarity as solid lines in the CID.

2.2.2 Livelihood Vulnerability Assessment

The vulnerability is a function of exposure, sensitivity to external stress, and adaptive capacity (Adger 2006). Exposure is the nature and degree to which a system is exposed to significant climatic variations. Sensitivity is the degree to which a system is affected directly or indirectly by climate-related stimuli, either adversely or beneficially. Adaptive capacity is the ability of any system to manage sensitivity to climate-related stimuli (Fankhauser et al. 2001). We have used outcomes of balanced weighted average to calculate livelihood vulnerability index (LVI) (Hahn 2009). Data collected from the fuzzy cognitive maps provides variables arising from the functioning of a complex system. The sustainable livelihoods (SL) framework addresses the issues of sensitivity and adaptive capacity to climate change (Hahn et al. 2009). We have combined the FCM approach with SL framework to measure the sensitivity of different asset classes and the adaptive capacities. The SL framework allows identifying the sensitivity of livelihood assets to cope up with and to adapt to climate-related risks (Kelly and Adger 2000; Eakin and Luers 2006). The SL framework as proposed by Chambers and Conway (1992), Scoones (1998), and Department of International Development (DFID 1999) looks at five livelihood asset classes i.e. natural, human, financial, physical, and social assets. We added personal and organisational assets in the SL framework.

i. Calculating Climate Exposure

Climate exposure is calculated based on 30 years' data collected from the Climatic Research Unit (CRU) database. It was calculated after collecting field data, as not to influence participants' perception based on interviewee's knowledge. Climate exposures affecting livelihoods include changes in summer and winter temperatures and precipitation patterns in the study areas. Exposure is calculated for each season using the following equation (Singh and Nair 2014).

$$E_s = (O_s - O_{min}) \ (O_{max} - O_{min})$$

where, Es is the exposure during each season, O_s is the ten-year moving point averages of temperatures and precipitation recorded during the latest year. O_{min} is the minimum value and O_{max} is the maximum value observed during the period.

ii. Calculating Sensitivity and Adaptive Capacity using Weighted Balance Average

The perturbations and adaptations are categorized according to different livelihood asset classes. Sensitivity and adaptive capacity of various asset classes are calculated using weighted balance average (Sullivian et al. 2002), where each sub-component contributes equally to the overall index although having a varied number of sub-components (Singh and Nair 2014; Sullivan 2002). We adopted the methodology developed by Singh and Nair (2014) to calculate sensitivity, adaptive capacity, and exposure with the aim of assessing livelihood vulnerability to climate variability and change. Concepts adds equally to the overall index even though each major component variable contains a different number of sub-components to different livelihood asset bases, considering all the asset bases. The vulnerability of population is calculated for each season separately using the following equation.

$$CCLVI_{SLs} = E_s \ (OS_s\text{-}OAC_s)$$

Where, $CCLVI_{SLs}$ is the climate change livelihood vulnerability index for sustainable livelihoods for each season, E_s is the exposure OS_s is the overall sensitivity and OAC_s is the overall adaptive capacity calculated for each season respectively. The adaptation interventions observed at the local level only contribute towards reducing sensitivity, not exposure. In the context of exposure, various climate models have projected an increase in temperature and change in precipitation patterns in the Indian sub-continent (INCAA 2010; ISNC 2008). Exposure to a climate hazard is not reduced owing to current adaptation interventions. We have, thus, subtracted adaptive capacity from sensitivity and multiplied it with exposure. Here, we assume that as exposure increases, the necessity to adapt will also increase as adaptation is a process for subsistence. The $CCLVI_{SLs}$ lies in the range of -1 to +1, where, -1 is the least vulnerable and +1 is the most vulnerable.

2.2.3 Simulations to Evaluate Effectiveness of Existing Adaptation Practices

A scenario is defined as, "the level of importance given to a set of variables in the FCM" (Samarasinghe and Strickert 2013). By simulating scenarios through what-if analysis explains the behaviour of a dynamic system. **FCM Wizard** software was used to run simulations. System dynamics, as perceived by stakeholders, relevant to impacts concerning climate variability and change along with adaptations are encapsulated in the social cognitive map, which forms the neural network. The social cognitive maps perceived by stakeholders form the neural network. While generating scenario through simulation processes, it is possible to determine if the system is in a steady state or chaotic. It explains how a system will react if things continue in future as they are (Singh et al. 2014).The simulations provide policy and decision makers to design flexible, long-term, pro-active climate change adaptations.

Nápoles et al. (2016) defined FCMs using a 4-tuple, M = (C, W, A, f), where, C is the set of all concepts in the map, W : $(C_i, C_j) \rightarrow$ wijis a function which defines the causal weight matrix, $W_{M\times M,}$ A : $(C_i) \rightarrow A^{(t)}_i$ is a function that computes the activation degree of each concept Ciat the discrete-time step t (t = 1, 2, . . . , T), and f (.) is the transfer function.

Knowledge and experience of the stakeholders on the system determines the type and the number of concepts, as well as the weights of the links in FCM_s. The value A_i of a concept C_i, expresses the quantity of its corresponding value. With values assigned to the concepts and the weights, the FCM converges to an equilibrium point (Carvalho 2013; Nápoles et al. 2016).

At each step, the value A_i of a concept is calculated, following an activation rule, which computes the influence of other concepts to that specific concept. The given equation iteratively compute the activation vector $A^{(t)} = [A_1^{(t)}, A_2^{(t)}, \ldots, A_N^{(t)}]$ using the state vector $A^{(0)} = [A_1^{(0)}, A_2^{(0)}, \ldots, A_N^{(0)}]$ as the initial state of the concepts. It uses the activation value $A_i^{(t)}$ of the concept to computing the next state $A_i^{(t+1)}$ of the concept (Nápoles et al. 2016). The most widely used activation rule is originally proposed by Kosko:

$$A_i^{(t+1)} = f\left(\sum_{j=1}^{N} W_{ji} \text{ x } A_j^{(t)}\right), i \# j$$

where, N is the number of concepts, Ai(t+1) is the value of concept Ci at simulation step t +1, wji is the weight of the interconnection between concept Cj and concept Ci,Aj(t) is the value of concept Cj at simulation step t, and f is the transformation function. The restriction i ≠ j is used when self-causation is assumed as impossible (Carvalho 2013).

An alternative approach has been introduced by Stylios et al. (1997), also referred as "modified activation rule" and has been increasingly popular, which allows "memory integration" into the FCM, as the system can now hold information of its previous state and use that information while calculating its new state.

$$A_i^{(t+1)} = f\left(A_i^{(t)} + \sum_{j=1}^{N} W_{ji} \text{ x } A_j^{(t)}\right), i \# j$$

The previous value of the concept is always added to itself in the present iteration in case of modified activation rule, which is not in the case of Kosko's activation rule. Hence, each concept has a self-feedback link with w = 1. Considering this merit we will use modified activation rule.

Some of the transformation functions (f) used for the above mentioned activation rule are bivalent, trivalent, sigmoid, and hyperbolic.

The following equation shows the bivalent transformation function:

$$f(x) = \begin{Bmatrix} 1, & x > 0 \\ 0, & x \leq 0 \end{Bmatrix}$$

The following equation shows the trivalent transformation function:

$$f(x) = \begin{Bmatrix} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{Bmatrix}$$

The following equation shows the sigmoid transformation function:

$$f(x) = \frac{1}{1 + e^{-\lambda x}}$$

where, λ> 0, is a constant value which determines slope steepness factor. Higher values of λ increase the steepness and make it more sensitive to the changes of x, hence the derivative δf/δxbecomes higher when increasing the activation value (Pedrycz 2010). The major limitation of sigmoid transformation function is that it converts the zero values in the FCM to 0.5. Hence, the value of inactive concepts (Ci = 0) takes values 0.5. Also, in case of missing values in large and complex FCMs, it is not able to produce reliable results.

In order to ascertain positive and negative changes in concepts after activation of input concepts during simulation process, the hyperbolic transformation function is used (Singh and Chudasama 2017), which is given below:

$$f(x) = \frac{e^{\lambda x} - e^{-\lambda x}}{e^{\lambda x} + e^{-\lambda x}}, a \in R^{+}$$

Based on the relationship between condensed concepts emerging we will use appropriate transformation function for evaluating impacts of different concepts within the system.

We developed two future scenarios; a) climate change without adaptation, i.e. business-as-usual scenario, and b) climate change with adaptation, i.e. scenario after scaling up certain adaptation interventions. These scenarios were generated to get better insight into the system's behaviour from baseline or steady state. The projected changes through simulations comparative to the baseline are explained linguistically. The first scenario was based on the hypothesis that climate change and variability continues to match long-term regional projections. All three central variables, i.e. increased summer temperature, increased winter temperature, and increased rainfall variability was increased to their maximum activation level [1]. This scenario runs simulations without scaling up adaptations; however, it considers the feedback of present adaptation practices into the system. The second scenario was based on the hypothesis that climate variability and change continues to match long-term regional projections with scaling up adaptations. Here also, all three central variables were increased to their maximum activation level [1]. Additionally, certain adaptation interventions are also scaled up in order to analyse their effectiveness in reducing impacts of climate variability and change. Every time when the second scenario is run, those adaptation interventions which are not scaled up to provide their feedback into the system (Singh et al. 2014). While running scenario, we have gone for 100 iterations in each case.

Adaptation Strategies

Elaboration of adaptation options, in view of the range of scenarios developed in the AEZ simulations, for enhancing food security and livelihood, which is primarily based on utilizing available resources. Additionally, it also assesses the current existing adaptations approaches toward climate change using the fuzzy cognitive mapping approach.

2.2.4 FCM Sampling

The below table shows general sampling plan for the areas chosen for FCM study.

Table 2.1: Overview of Sampling and Communities' Participation

Number of Districts covered	3
Number of Villages covered	25
Number of male groups interviewed	142
Number of female groups interviewed	62
Total number of community groups interviewed	204
Number of fuzzy cognitive maps drawn	358
Number of community respondents	1265 (approx.)

Total 36 fuzzy cognitive maps were obtained for summer, winter and rainfall seasons from Surendranagar district. Out of the total, 25 and 11 maps were constructed by male and female groups respectively. Total 41 fuzzy cognitive maps were obtained for summer, winter and rainfall seasons from Mahesana district to conduct a case study on water budgeting. Out of the total, 33 and 8 maps were constructed by male and female groups respectively. Total 34 fuzzy cognitive maps were obtained for summer, winter and rainfall seasons Mahesana district to conduct a case study on participatory irrigation management (PIM). Out of the total, 25 and 9 maps were constructed by male and female groups respectively. The stakeholders interviewed in Mahesana are engaged in different means of livelihoods, varying from farming to livestock rearing. From Valsad district total 95 fuzzy cognitive maps were obtained from wadi farmers, landless laborers working in the wadi, and people involved in the value chain and enterprising. The stakeholders are chiefly dependent on horticulture production like mango and cashew nut, and it's enterprising.

Table 2.2: Detailed Sampling Plan for the Study Area Districts (Climate Variability and Change)

District	Village	Number of Male Groups	Number of Female Groups	Total Number of Maps
Surendranagar	Gadh	4	1	5
	Kherana	6	1	7
	Khintala	3	4	7
	Mokasar	4	2	6
	Nagarka	5	1	6
	Vatavach	3	2	5
	Total	**25**	**11**	**36**
Mahesana	Amarpura	4	0	4
	Chansol	3	2	7
	Dalisana	3	3	9
	Dedasana	3	2	7
	Mahiyal	5	1	7
	Rasulpur	4	0	4
	Sakari	5	0	5
	Waghbadi	6	0	6
	Total	**33**	**8**	**41**
Total number of maps obtained		**58**	**19**	**77**

Table 2.3: Detailed Sampling Plan for the Study Area Districts (Climate Variability and Change)

District	Village	Number of Male Groups	Number of Female Groups	Total Number of Maps
Mahesana (PIM)	Denap	6	1	7
	Kiyadar	5	2	7
	Kansa	6	1	7
	Fudeda	3	3	6
	Dedhasan	5	2	7
	Total	**25**	**9**	**34**
Mahesana	**Wadi owners**			
	Kaprada	10	1	11
	Dhafkal	4	1	5
	Karjun	3	2	5
	Nilosi	3	2	5
	Varvat	4	2	6
	Matuniya	6	2	8
	Total	30	10	40
	landless labours working in wadi			
	Sutarpada	4	0	4
	Karjun	4	2	6
	Dixal	0	5	5
	Mandva	0	5	5
	Karchaun	4	2	6
	Total	13	18	31
	People involved in value chain and enterprising			
	NA	16	6	22
Total number of maps obtained		**84**	**43**	**127**

CHAPTER-3

Spatial and Temporal Patterns of Climatic and Bio-Physical Parameters

3.1 Spatial and Temporal Variability of Climatic Parameters

Climatic variables are prepared for the use in the AEZ Gujarat through spatial and temporal interpolation. The temporal interpolation of the gridded monthly climatic variables into daily data provides the basis for the calculation of soil water balances and agro-climatic indicators relevant to crop production.

3.1.1 Annual Mean Temperature

Reference climate and current data for temperature in Gujarat suggest that south and central Gujarat are predominantly having larger areas showing mean annual temperature, of around 27.1˚C, in Gujarat. However, Saurashtra, Kutch, and south Gujarat are having most of the region with relatively lower annual mean temperature (around 23.5˚C). The current annual mean temperature in Gujarat varies between 23.5 to 26.5˚C. Temperature data also indicates that the region along the border between south and central Gujarat are experiencing highest temperature in Gujarat in current conditions. Reference climate averaged data indicates a homogenous rise in annual mean temperature in entire Gujarat. The 30-year average annual temperature for duration 1981–2010, 1971–2000, and 1961–1990 has shown continues increase of 0.01 to 0.5˚C.

Projection using Ensemble Mean of all Models across RCPs

Temperature projection for different RCPs shows the heterogeneous rise of temperature in the different parts of Gujarat. Projection using different RCPs pathway suggests maximum rise of 1 to 2.5˚C for period 2020s (2011–2040), 1.3 to 2.7˚C for period 2050s (2041–2070), 1.3 to 4.6˚C for period 2080s (2071–2100), mostly in the region of south Gujarat and small portion of region of Kutch, and north Gujarat. Rest part of the Gujarat may experience a rise in temperature between 0.5 to 1.0˚C during the same period. The projection for period 2041–2070 suggests a maximum rise of 2 to 2.5˚C, mostly in some parts of south Gujarat, central Gujarat, and entire north Gujarat and Kutch. Remaining part may observe the rise of 1.3 to 2˚C from current temperature. During the 2050s and 2080s, the eastern part of Gujarat may experience 2 to 2.5˚C and 2.5 to 3˚C respective increase in temperature. South Gujarat, the northern part of Saurashtra, and central Gujarat may experience an increase in temperature up to 1.5˚C in the 2050s and 2080s with a slight decline in the rate of temperature increase.

The table below shows annual mean temperature for reference climate (CRUTS32: 1981–2010); and E-Mean: ensemble mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-

CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) is taken into consideration to avoid extreme variation in the result.

Table 3.1: Annual Mean Temperature (0C) for Reference Climate (1981–2010) and Temperature Change for Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	Temperature change in 2050s (°C)				Temperature change in 2080s (°C)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	27.2	1.3	1.7	1.6	2.5	1.3	2.2	2.5	4.2
North	26.7	1.4	1.8	1.8	2.7	1.4	2.4	2.6	4.6
Central	27.4	1.3	1.8	1.8	2.5	1.3	2.3	2.5	4.4
Saurashtra	27.0	1.3	1.6	1.6	2.4	1.3	2.1	2.4	4.1
South	27.3	1.3	1.7	1.6	2.4	1.3	2.2	2.4	4.2
Gujarat	27.1	1.3	1.7	1.7	2.5	1.3	2.2	2.5	4.3

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ensemble mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) is taken into consideration to avoid extreme variation in the result.

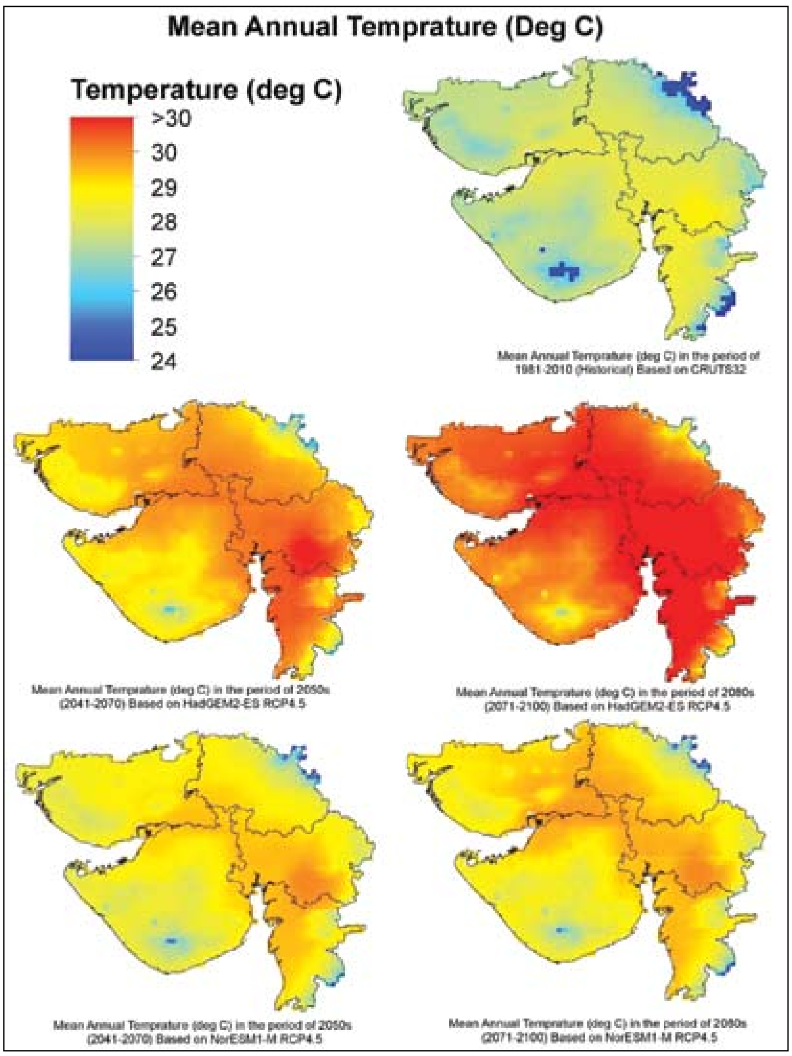

Figure 3.1: Mean Annual Temperature for Gujarat

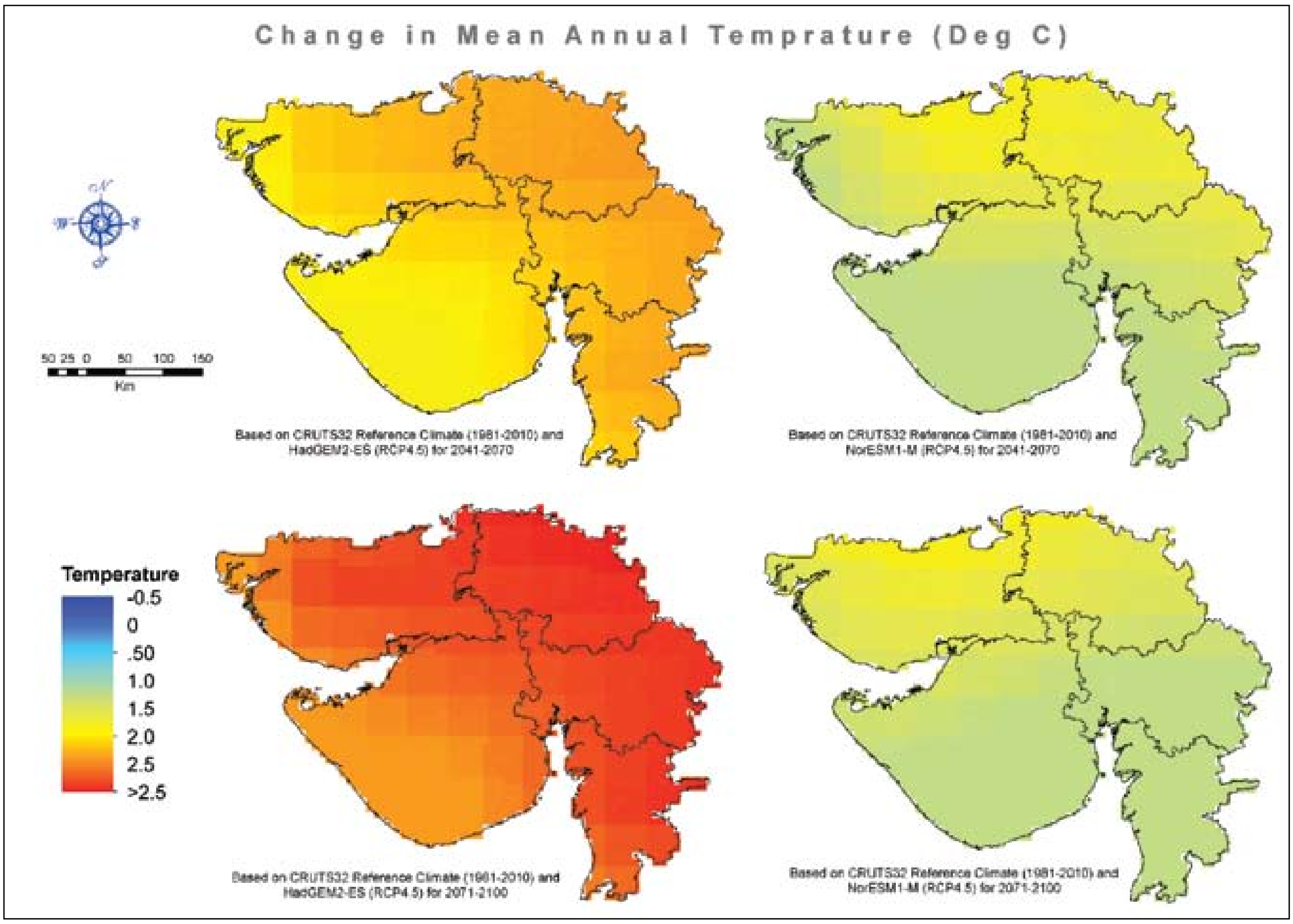

Figure 3.2: Change in Mean Annual Temperature for Gujarat

3.1.2 Annual Mean Precipitation

Observation of reference climate as well as current data on mean annual rainfall suggests South Gujarat as region receiving highest rainfall in Gujarat. Currently, it receives around 1500 mm of annual mean rainfall. However, rest of the Gujarat can be considered relatively dry with mean annual rainfall of lower than 900 mm. Kutch is observed to be highly dry among all with current rainfall of approximately 500 to 550 mm.

Projection using Ensemble Mean of all Models across RCPs

Rainfall projection using different RCPs for period 2020s, 2050s, and 2080s suggests an increase in rainfall in Gujarat except for a small region in Saurashtra and Kutch where it may decline by 78 mm (2020s) and 20 mm (2050s). Most of the region in Kutch, Saurashtra, and western part of north Gujarat may experience an increase in mean annual rainfall by 1 to 200 mm. The Southern part of south Gujarat may experience the highest increase in mean annual rainfall by 400 to 600 mm. Remaining parts of Gujarat may experience an increase in rainfall between 200 to 400 mm. During the 2050s (2041–2070), mean annual rainfall for most of the region may remain similar to 2020s (2011–2040), however, the southern region of south Gujarat may experience an additional increase in rainfall by 600 to 800 mm. It may further reach to around 3700 mm of mean annual rainfall with a change up to 600 mm, in the southern region of south Gujarat between the 2080s (2071–2100). Coastal Kutch, Saurashtra, and the northern part of south Gujarat may decline up to 100 mm in the 2050s in comparison to reference climate (1981-2010). The results suggest a significant increase in rainfall in entire Gujarat.

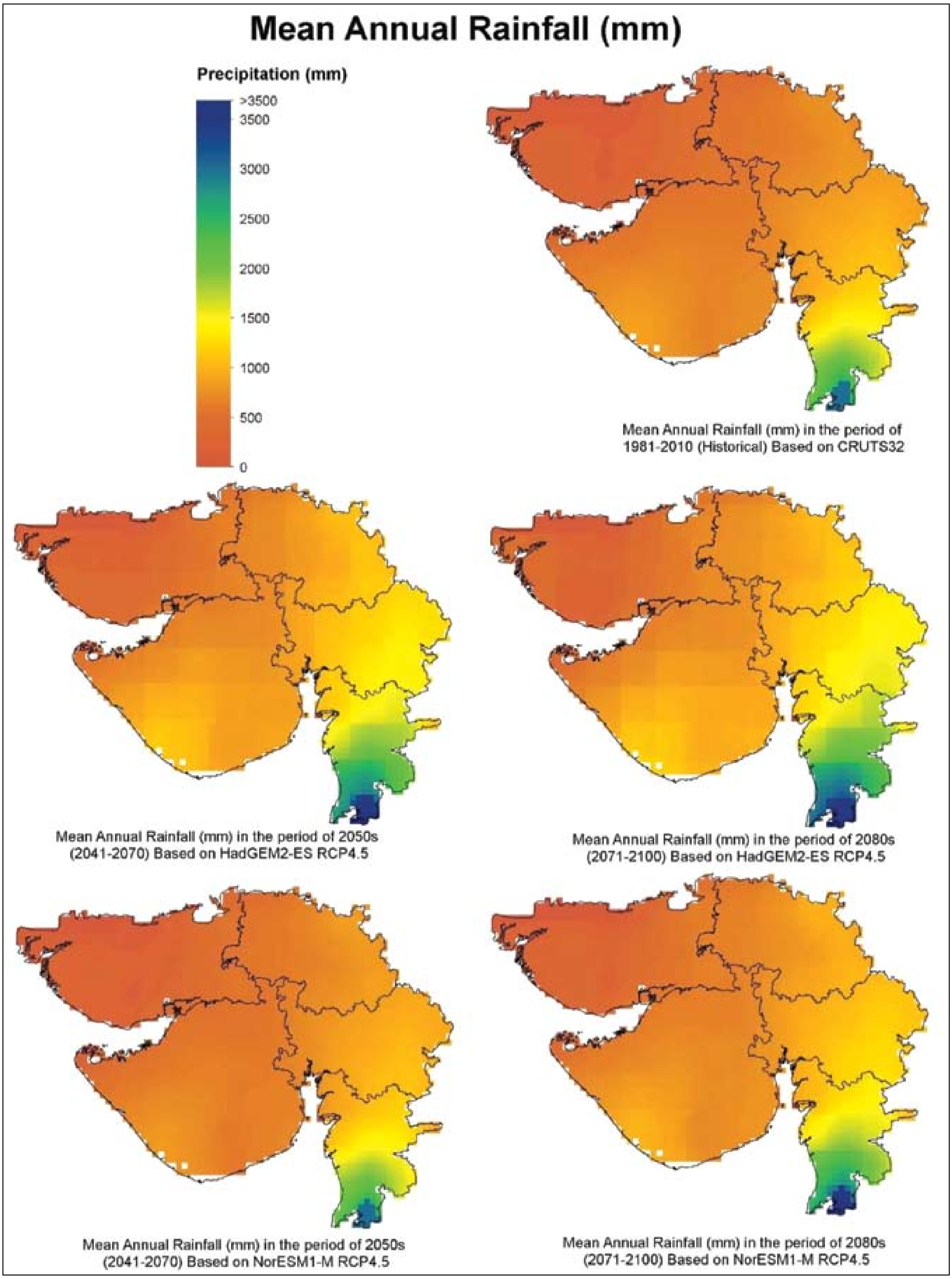

Figure 3.3: Mean Annual Precipitation for Gujarat

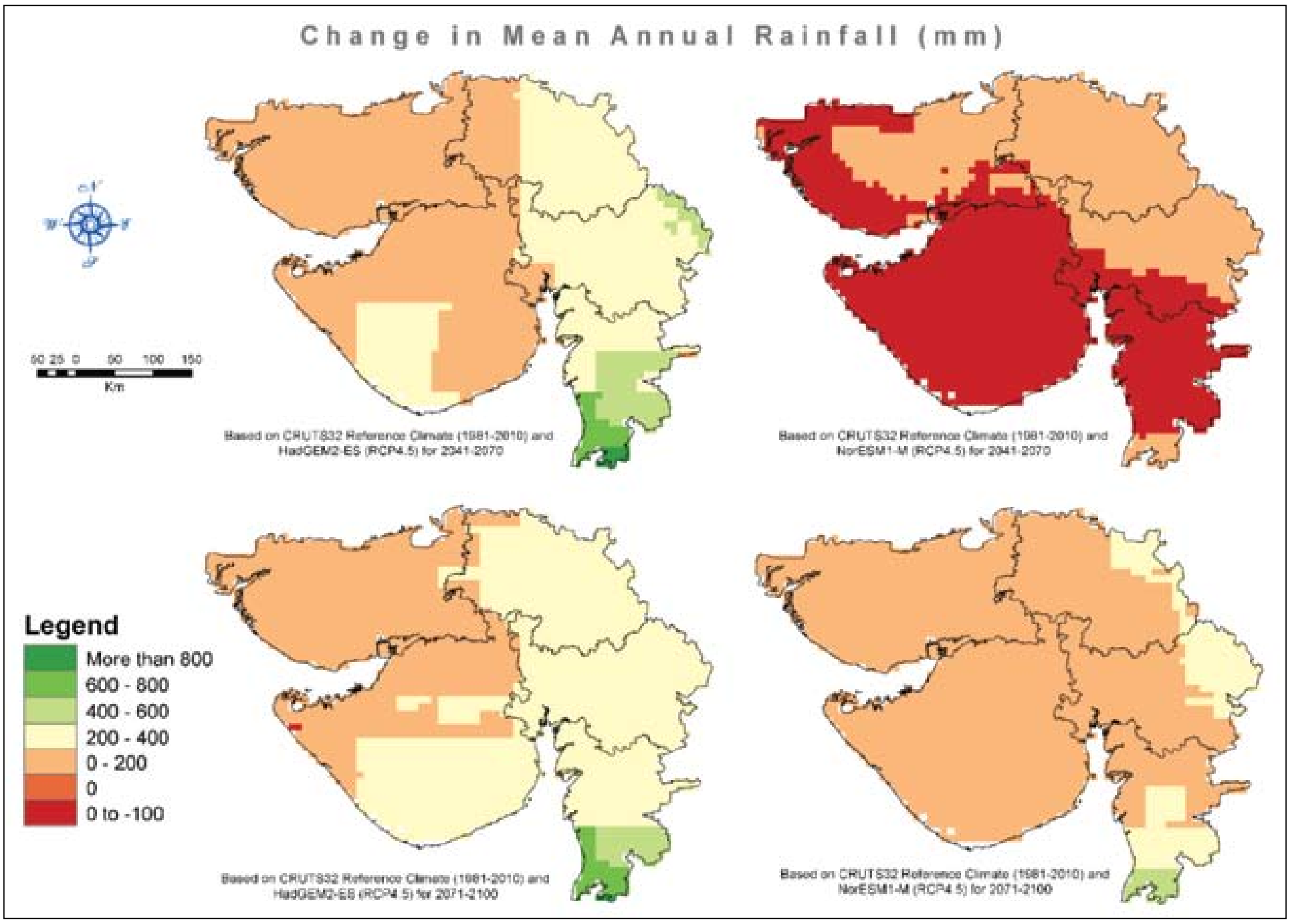

Figure 3.4: Change in Mean Annual Precipitation for Gujarat

The table below shows annual mean precipitation forreference climate (CRUTS32: 1981–2010); and E-Mean: ensemble mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) is taken into consideration to avoid extreme variation in the result.

Table 3.2: Annual Mean Precipitation (mm) for Reference Climate (1981–2010) and Precipitation Change for Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	Temperature change in 2050s (°C)				Temperature change in 2080s (°C)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	531	32	24	-3	64	30	68	74	84
North	672	121	79	77	137	120	141	173	138
Central	869	140	91	89	149	144	189	219	210
Saurashtra	667	5	6	-19	45	2	59	79	114
South	1500	98	70	47	153	78	215	233	300
Gujarat	933	76	52	35	110	70	140	162	186

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ensemble mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) is taken into consideration to avoid extreme variation in the result.

3.1.3 Total Number of Rainy Days

Observation of reference climate as well as current data on the total number of rainy days suggests south Gujarat experience the longest period of the rainy day in Gujarat. Currently, it receives rainfall around 120 to 160 days, however, rest of the Gujarat receive precipitation relatively less number of days. Kutch is observed to be less than 40 rainy days. Eastern part of south Gujarat, central Gujarat, and north Gujarat receive precipitation from 80 to 120 days; however, part of north Gujarat, the eastern part of central Gujarat, and middle Saurashtra could receive precipitation for lesser (40 to 80) days.

Projection using Ensemble Mean of all Models across RCPs

The number of rainy days projected using different RCPs for the period the 2050s and 2080s suggests a decrease in the number of rainy days in most parts of Gujarat except for small parts of Gujarat, where it

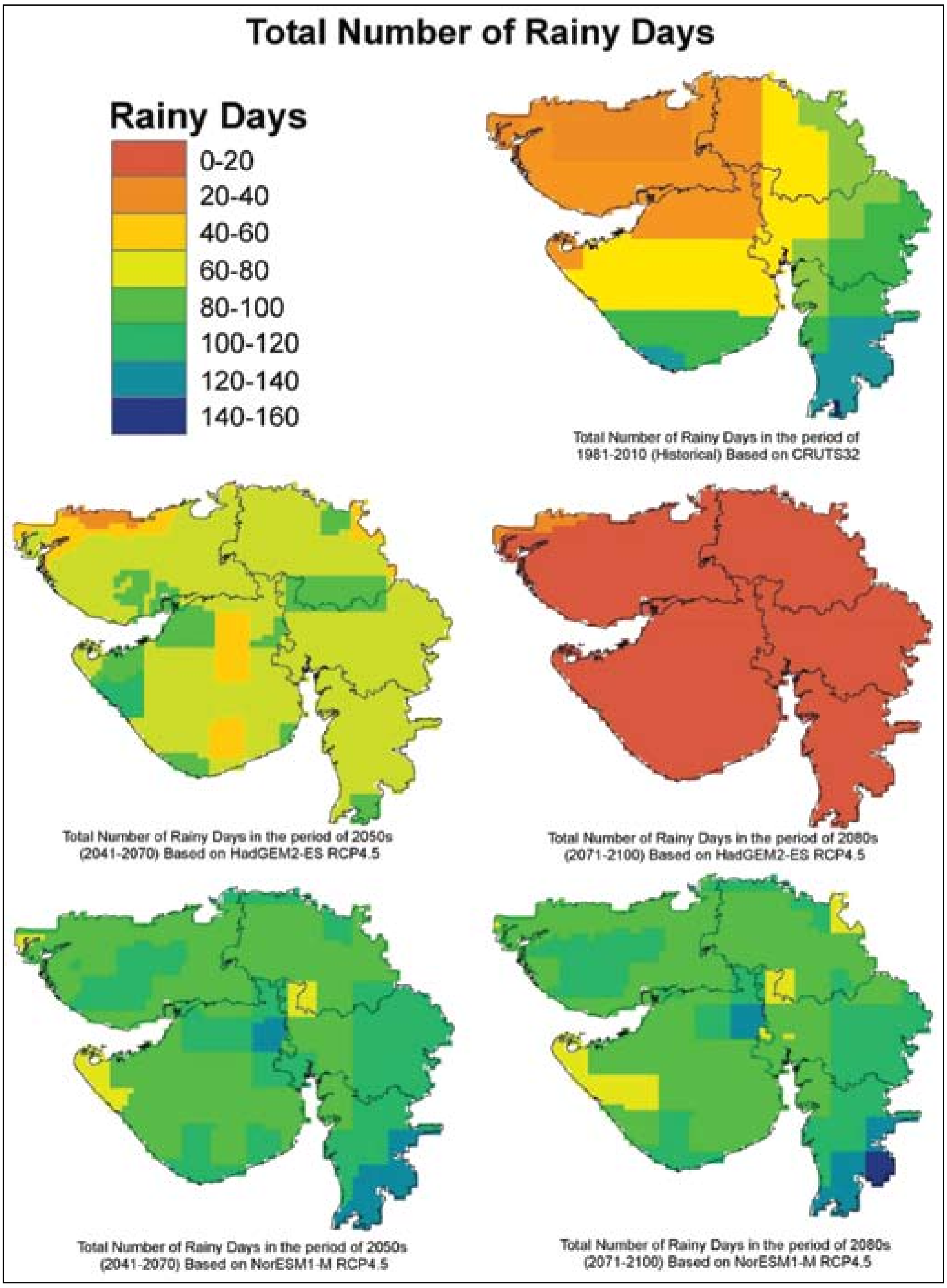

Figure 3.5: Total Number of Rainy Days

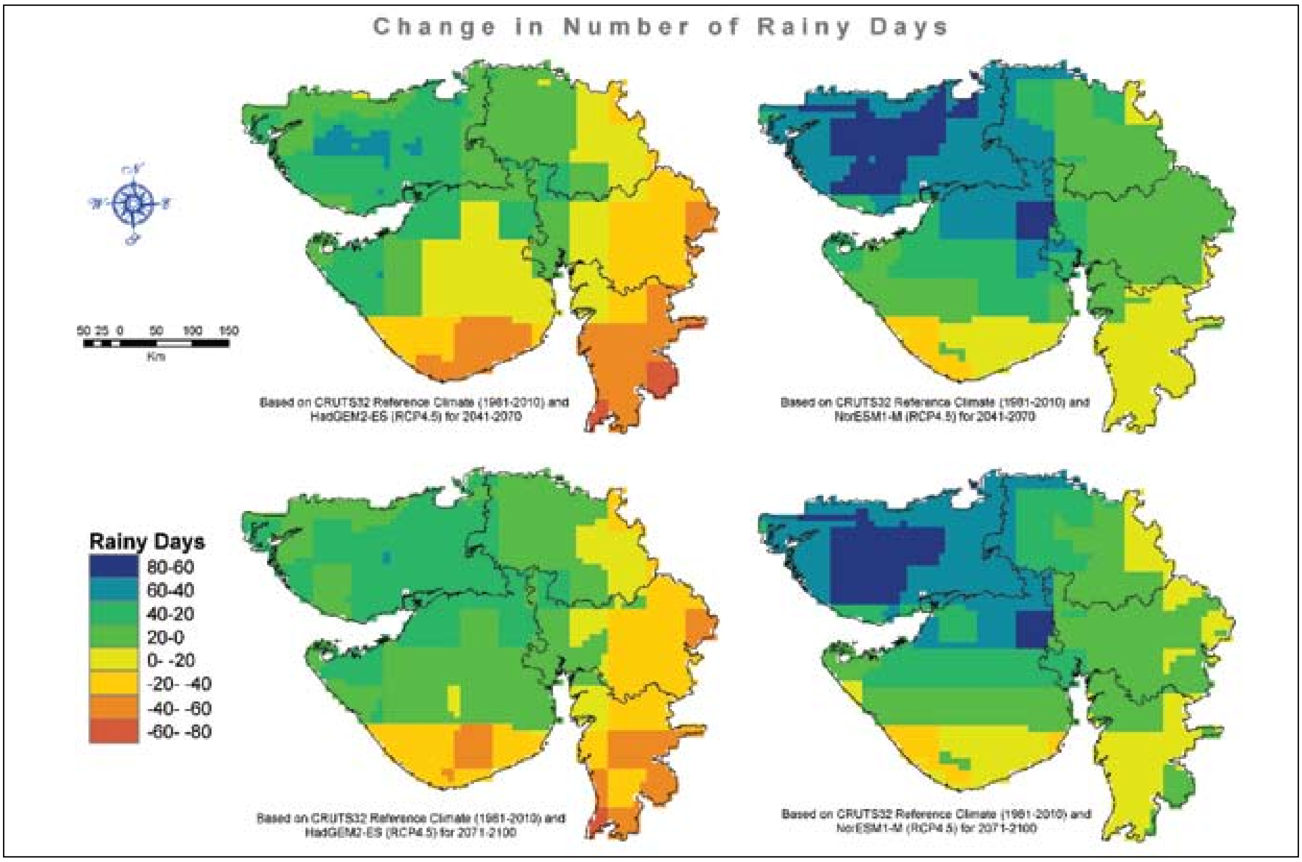

Figure 3.6: Change in Total Number of Rainy Days

may increase by 80 to 100 days (2050s). Based on HadGEM2-ES most of the state may receive precipitation for 60 to 80 days during the 2050s and about 20 days during the 2080s, whereas, based on NorESM1-M most of the state may receive precipitation for 80 to 120 days and south Gujarat may receive 120 to 140 days during the 2050s and during 2080s number of rainy days may have almost same pattern of spatial distribution of 2050s. Kutch, most of the region in Saurashtra, and north Gujarat may experience an increase in the number of rainy days during the 2050s and 2080s. The southern part of south Gujarat may experience the highest decrease in numbers of rainy days by 60 to 80 days. South Gujarat, south Saurashtra, and eastern part of central Gujarat can face a decline in the number of rainy days by 20 to 60 days in the 2050s and 2080s. As a whole, it can be said eastern and southern part of Gujarat can face a decline in the number of rainy days, whereas, the northern part will receive larger numbers of rainy days.

3.1.4 Number of Consecutive Dry Days (During Rainy Season)

Observation of reference climate as well as current data on the total number of dry days suggests less than 10 consecutive dry periods during rainy days except for some part of Kutch, north and eastern part of north Gujarat, and extreme north of Saurashtra have. Extreme northern part of Kutch shows a longest consecutive dry period of 20 to 30 days.

Projection using Ensemble Mean of all Models across RCPs

The number of consecutive dry period projected using different RCPs for the period the 2050s and 2080s suggests an increase in the number of consecutive dry days in Gujarat except for small parts of Gujarat. The consecutive dry period during the 2050s and 2080s follow the similar pattern of up to 10 and 20 days increase in consecutive dry days in most parts of central Gujarat, south Gujarat, and Saurashtra. Part of Kutch and part of Saurashtra shows 10 days decrease in consecutive dry days during the 2050s and 20 days decrease in consecutive dry days during 2080s.

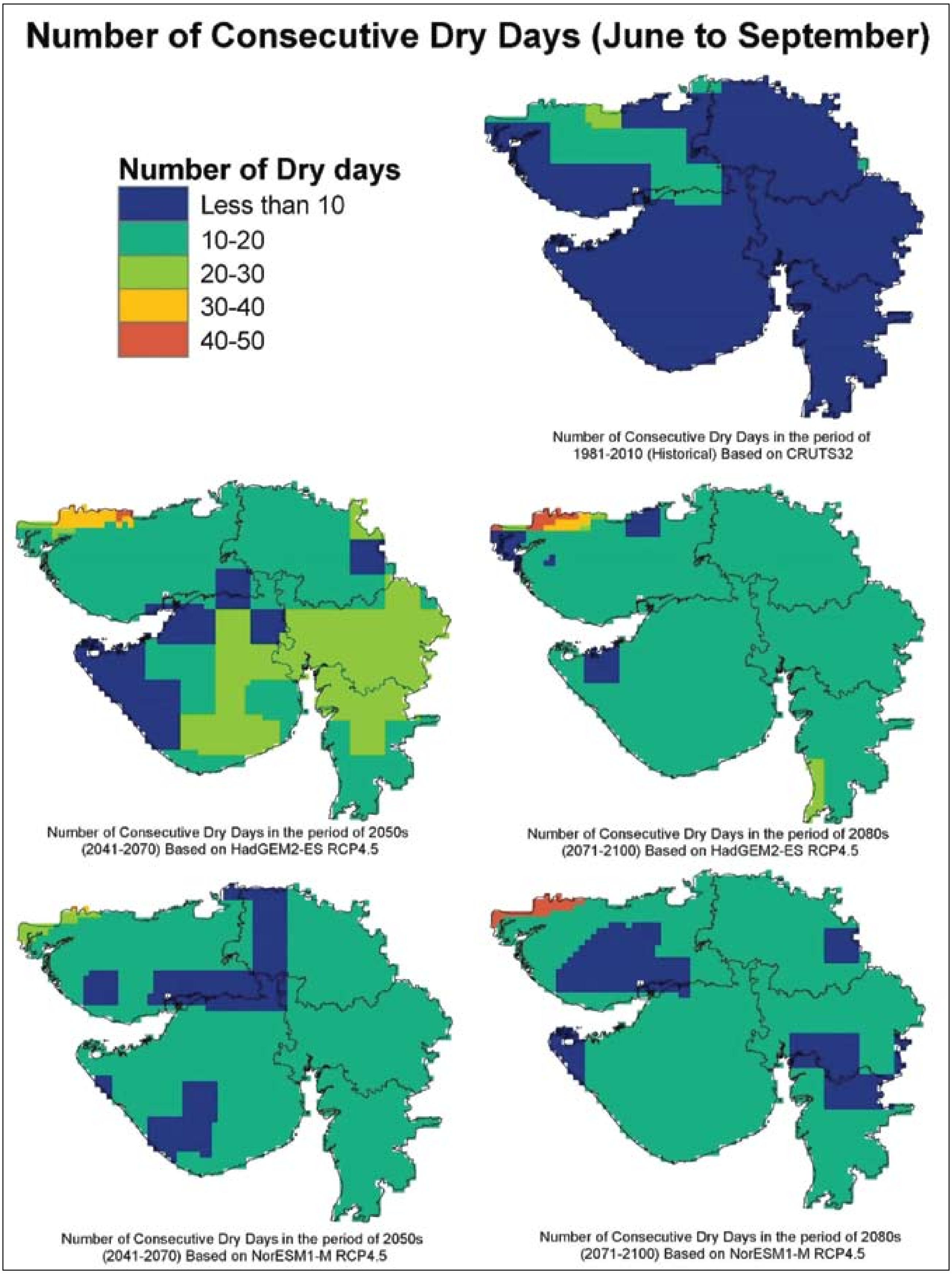

Figure 3.7: Number of Consecutive Dry Days (During Rainy Season)

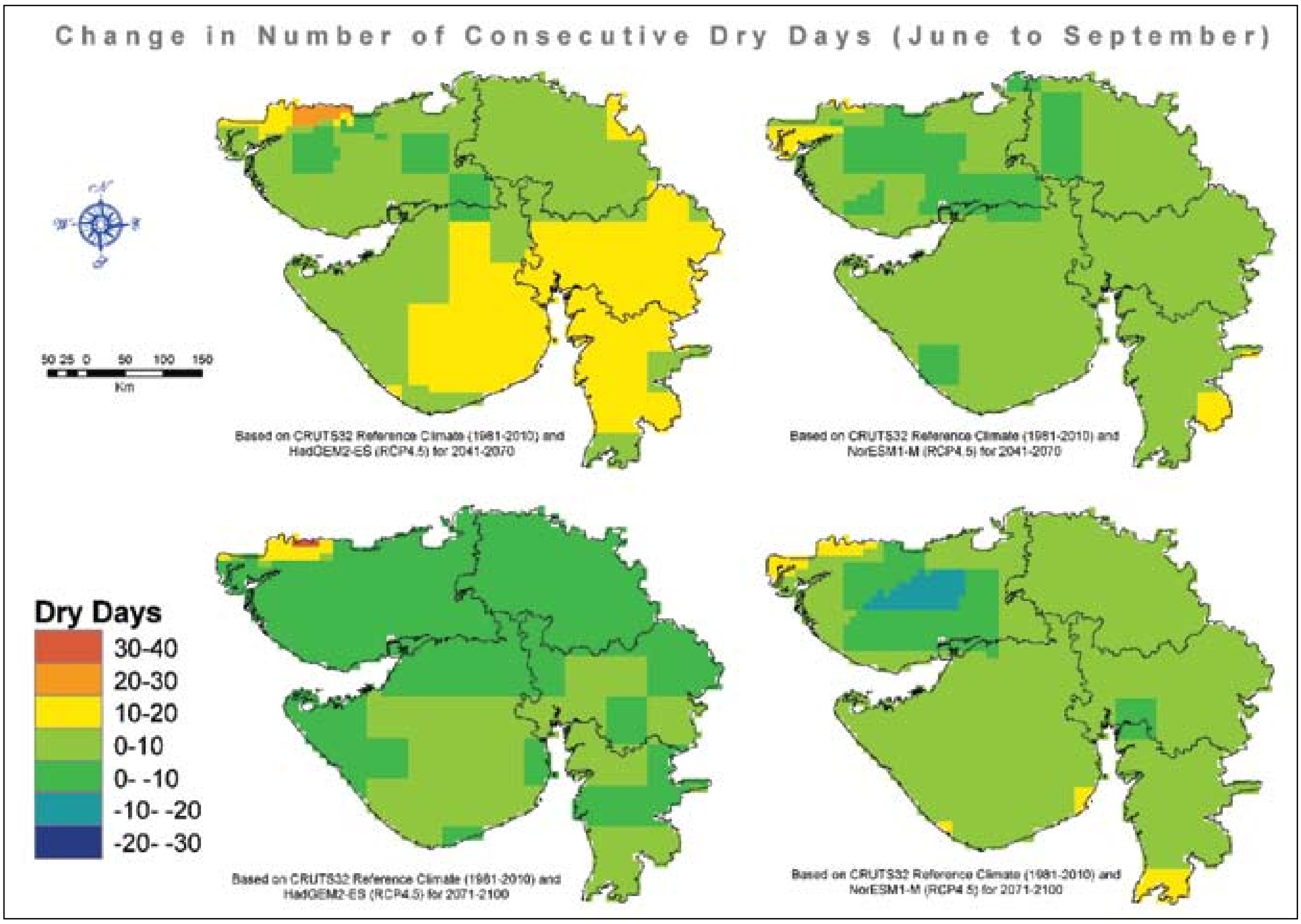

Figure 3.8: Change in Number of Consecutive Dry Days (During Rainy Season)

3.2 Spatial Patterns of Bio-Physical Parameters

3.2.1 Spatial Patterns of Soil

The soil is the outermost layer of the surface of the Earth on which the plants grow. It consists of eroded rock, mineral nutrients, decaying plants and animal matter, water, and air. This abiotic factor is equally important in agriculture and is treated under the heading of adaptation to soil and climatic or crop requirements. Most plants are terrestrial in that they are anchored to the ground through their roots, with which they absorb water and nutrients. But epiphytes and floating hydrophills do not need soil to live. Variations in the physical, chemical, and biological properties of the soil have different effects on the growth and development of the plants, depending on the natural adaptation. There are two soil properties that have pronounced direct effects on plant growth and crop production: physical and chemical properties. There are also biological factors or living organisms in the soil such as earthworms, insects, nematodes, and microorganisms such as bacteria, fungi, actinomycetes, algae, and protozoa. These organisms help in improving soil structure, tilth, aeration, water permeability, and availability of soil nutrients. The physical and chemical properties of the soil are called edaphic factors of the plant medium. Physical properties include soil texture, soil structure, and bulk density that affect the soil's ability to retain and supply water, while chemical properties consist of soil pH and cation exchange capacity that determines its capacity to supply nutrients. It is now known that this abiotic factor (soil) is not essential for the growth of plants. Rather, it is the nutrient elements that are present in the soil that makes the plants grow and allow them to complete their life cycle.

Soil is one of the basic components supporting agriculture. It is the main raw materials from which food is produced (Simpson 1983). Unlike raw materials of most industries, it can be used again for year after year, century after century. Soils have more meaning for humankinds than as a habitat for growing crops (Braddy 1970). The foundations of house, factories, and great structures depend upon the underneath of the soil on which it is constructed. They are used as beds for roads and highways and have influence on the length and life of these structures. In rural areas soils are often used to absorb domestic wastes through septic sewage systems. Soil also plays an important part in carbon sequestration.

Climate Change and Soil

The increase in the concentration of greenhouse gases in the atmosphere and its effects on global warming is currently one of the most debated issues. Reduction of atmospheric carbon dioxide (CO_2) can be done by decreasing emissions or by removing CO_2 from the atmosphere. One of the key strategies for reduction of the concentration of greenhouse gases in the atmosphere is the application of terrestrial ecosystems as a carbon sink. The soil is the second largest carbon store, or 'sink', after the oceans. Depending on the local conditions, the soil is at the same time a source and a sink of greenhouse gases. This balance between sink and source function is very delicate. Depending on the region, climate change might result in more carbon being stored in plants and soil due to vegetation growth, or more carbon being released into the atmosphere. Soil not only contains worldwide twice as much carbon as the atmosphere, the flux of CO_2 between soil and the atmosphere is also large and estimated at ten times the flux of carbon dioxide from fossil fuels. Waterlogged and permafrost soil types hold major stocks of carbon but also are important emitters of methane (CH_4) and nitrous oxide (N_2O). After all, when plants photosynthesize, they draw carbon out of the atmosphere. But atmospheric carbon also affects the soil, because carbon that is not used for above-ground plant growth is distributed through the roots of a plant, which deposit carbon in the soil. If undisturbed, this carbon can become stable, and remain for thousands of years. Healthy soils can thus mitigate climate change. Sustainable use of the soil and restoring key ecosystems can help us to mitigate and adapt to climate change.

Climate change is often seen as something that occurs in the atmosphere. Increase in temperatures may lead to more vegetation growth and more carbon stored in the soil. However, higher temperatures could also increase decomposition and mineralisation of the organic matter in the soil, reducing organic carbon content. In other areas, the carbon-containing organic matter in stable peat lands is prevented from decomposing due to the low levels of oxygen in the water. If such areas dry out, the organic matter can quickly break down, releasing carbon dioxide (CO_2) into the atmosphere. The increase in concentration of carbon dioxide in atmosphere may cause the microbes in the soil to work faster to break down organic matter, potentially releasing even more carbon dioxide. Though it is not clear what the overall effect will be, as different regions absorb and emit different levels of greenhouse gases. But there is a clear risk that a warming climate can lead the soil to release more greenhouse gases, which can further heat the climate in a self-reinforcing spiral. If managed correctly, soil can help us to reduce greenhouse gases and adapt to the worst effects of climate change. But if we fail to care for the soil, we may quickly exacerbate the problems connected to climate change.

I. Soil Texture

Soil texture is one of the most important physical properties of soils. Soil texture is related to a number of important soil characteristics such as water holding capacity, soil drainage, and soil fertility. A large part of the soil in south Gujarat consists of clay with exception to some portion of south-eastern Gujarat, where sandy clay loam and clay loam found. The central part of Gujarat contains sandy loam, sandy clay loam, silty clay and sandy clay. Clay soil is the major soil in Saurashtra, whereas, sandy clay loam, clay loam, confined mainly to the coastal region of Saurashtra. The northern part of Gujarat contains sandy loam, sandy clay loam, clay loam soil, and sand. The Kutch region consists of sandy loam, sandy clay loam, sand, silt clay, loam, and clay.

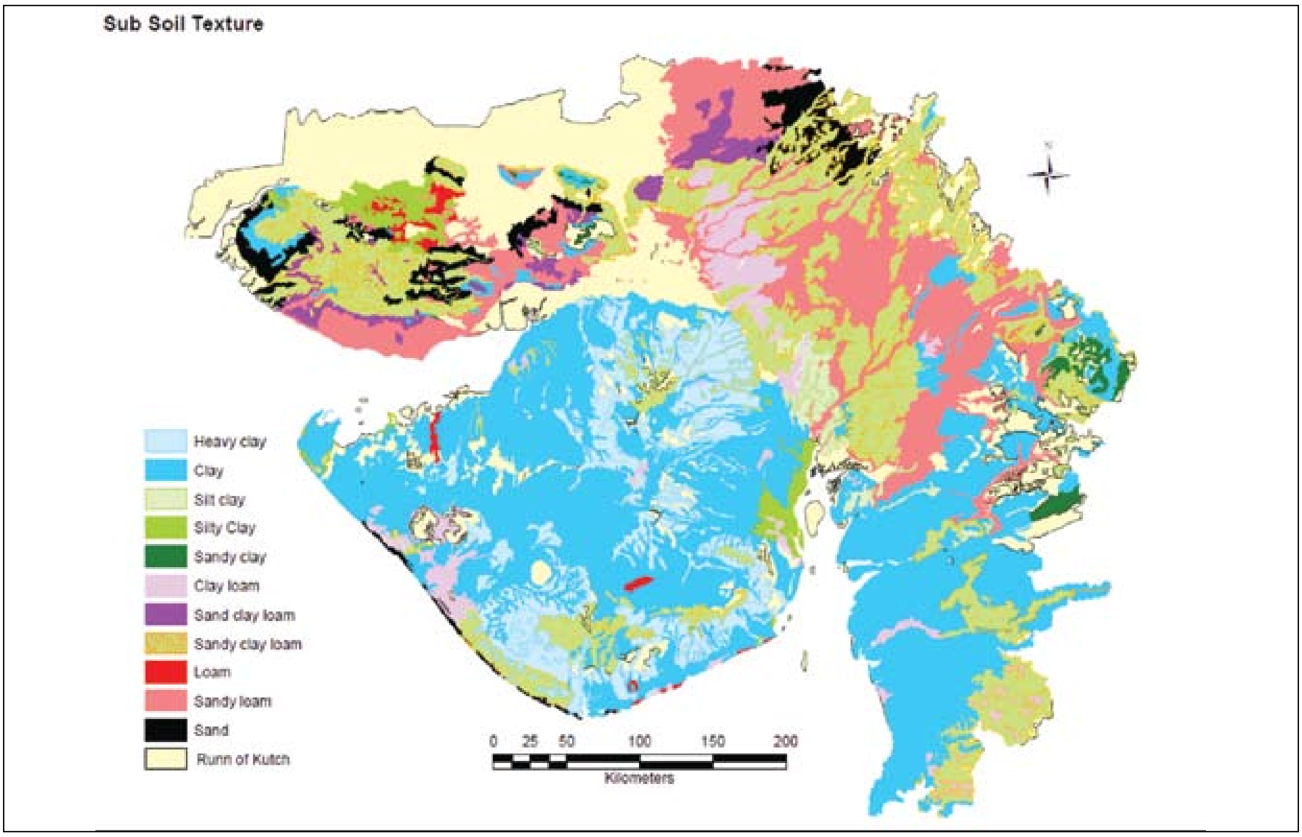

Figure 3.9: Soil Texture Map of Gujarat

II. Top Soil Organic Carbon

Kutch region of Gujarat consists of run of Kutch has lowest soil organic carbon of 0 to 0.1%. Major regions of Kutch have a soil organic content varied between 0.1 and 0.3%, which in some region it has been found

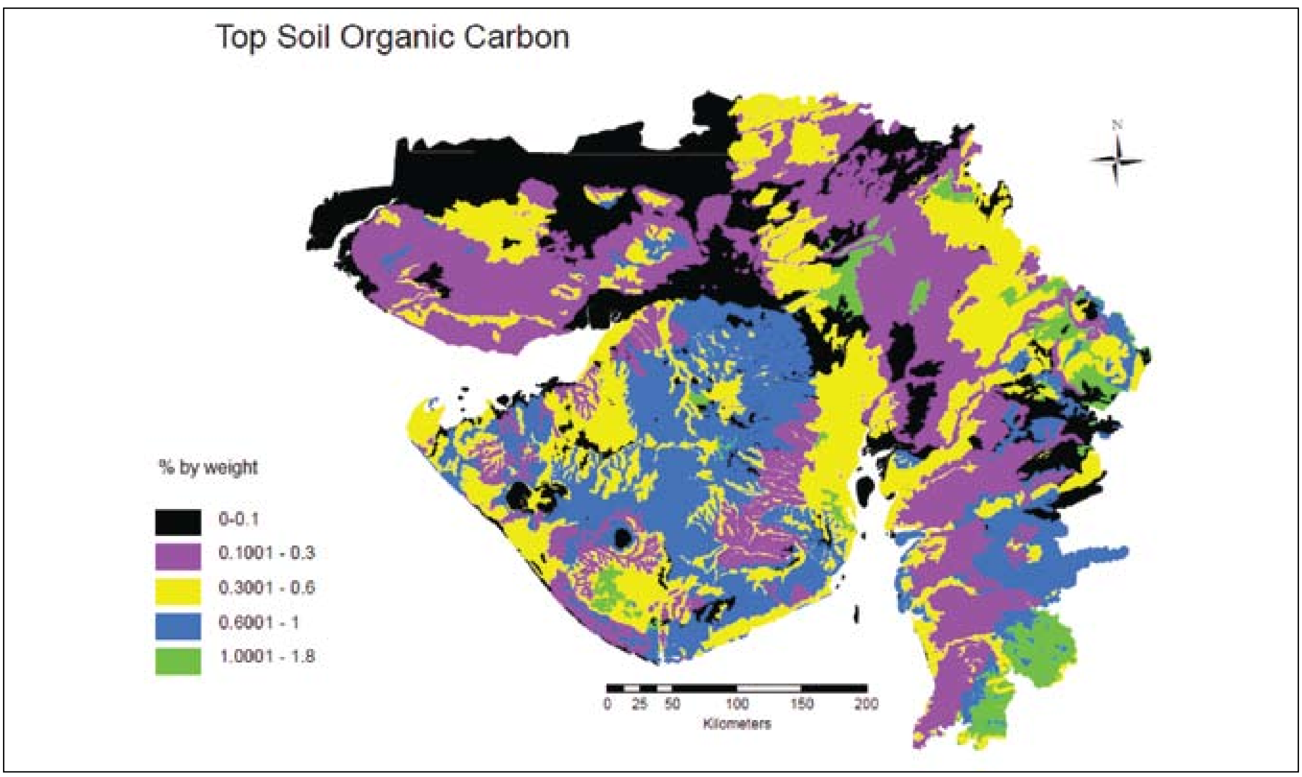

Figure 3.10: Soil Organic Carbon Map of Gujarat

to be 0.3 to 0.6%. Soil organic content of northern Gujarat varied between 0.1 to 0.6%. Sizable portion of central Gujarat has a soil organic carbon content of 0.1 to 0.3%, while western part of central Gujarat has a soil organic carbon of 0.3 to 0.6% and higher SOC content of 0.6% to higher confine to very small regions in western part of central Gujarat. Saurashtra has a considerable amount of soil organic carbon content of 0.6 to 1%, while the soil organic carbon content of coastal region of Saurashtra varied between 0.1 to 0.6% by weight.

III. FAO'90 Soil Units

Saurashtra contains a major area of calcaro-vertic cambisols and small area of eutric cambisol, calcaric cambisol and vertic cambisol. All these fall under the soil group of cambisol. It is a brown colored soil and the horizon starting between 25 and 100 cm below the soil surface. Cambisols are medium textured and have a good structural stability, high porosity, good water holding capacity, and good internal damage (FAO 2001). It is suitable for the production of food and oil crops. The major crops cultivated in these soils are groundnut, cotton, wheat, and sesame. The north Gujarat contains a major area of calcaric cambisols and a small area of eutriccambisols, vertic cambisols, calcaric regosols. The major crops suitable for this area are groundnut, cotton, wheat, mustard, castor, pearl millet, and maize. The central Gujarat contains eutric fluvisols, calcaric cambisols, calcaro-vertic cambisols, calcaric fluvisols. Fluvisols are the soil developed in periodically flooded areas of the alluvial plain. They are highly fertile soil. It is generally found along the Mahi River floodplain in central Gujarat. Major crops suitable for these crops are rice, wheat, maize, cotton, tobacco, millet, lents, and gram.

Eutric cambisols is the dominant soil in the southern Gujarat followed by eutric vertisols. Other types of soil which are present in small areas are calcaric fluvisols, vertic cambisols, calcaric cambisols, and calcaro-vertic cambisols. Vertisols are the products of rock weathering that have the characteristics of

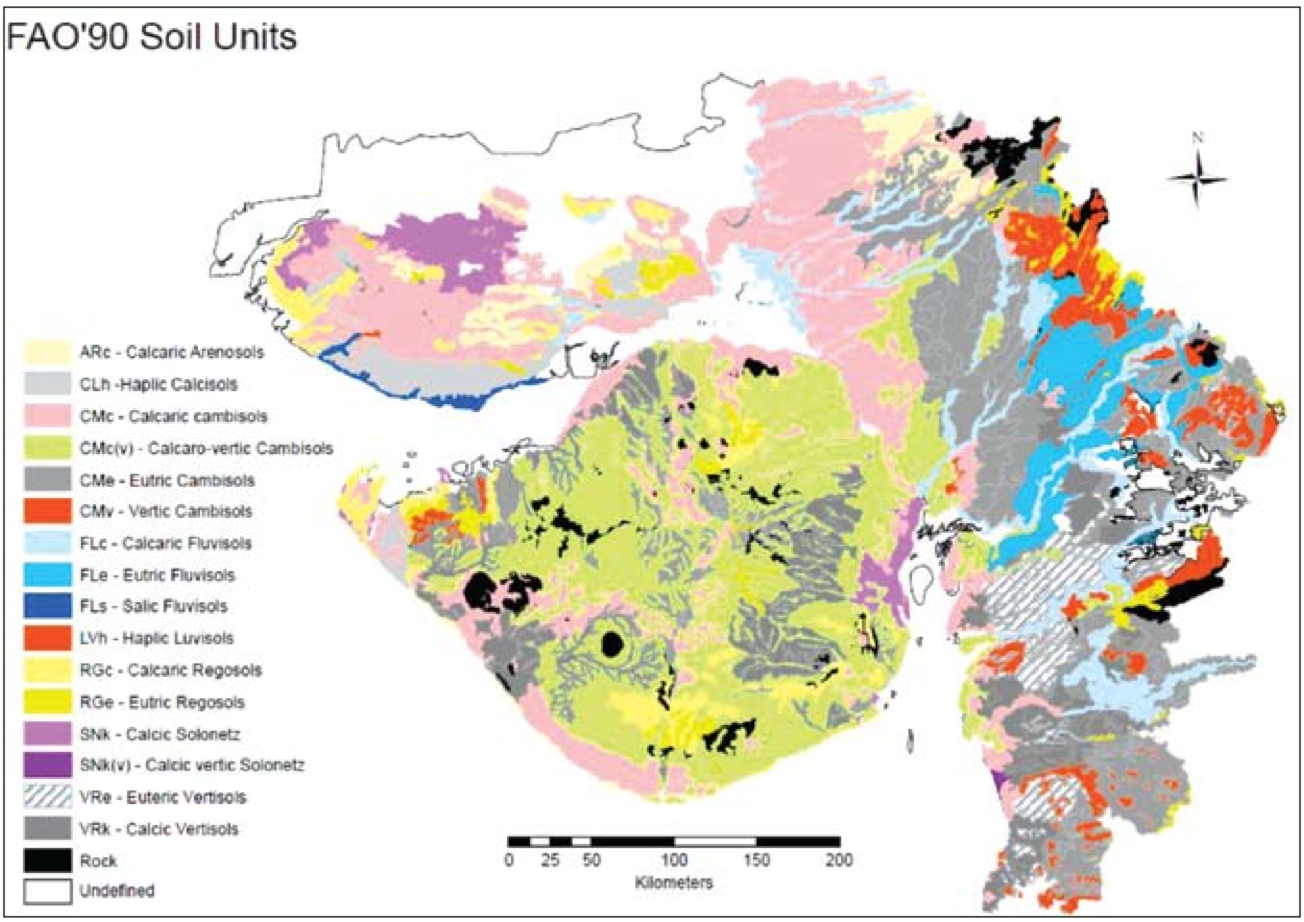

Figure 3.11: FAO'90 Soil Units Map of Gujarat

smectitic clay. It is very hard in dry season and is sticky in wet season. Tillage is difficult in this soil. Vertisole can be productive if managed well. Crops suitable for these soils are cotton, rice, sugarcane and groundnut. Kutch region contains large area under calcaric cambisols. Other soils like calcic vertic solonetz, eutric cambisols, and calcaric regosols are found in small areas in Kutch. Crops like cotton, groundnut, green gram, and castor are suitable for these soils.

IV. Soil Salinity

Soil salinity is an important factor affecting the soil health and crop productivity. Saline soils are mainly found on land which is subject to tidal flooding with salt water for part or whole of the year and on land where the groundwater is to some extent saline. Majority of the saline soils are present in western Kutch, western and eastern part of Saurashtra, and coastal region of southern Gujarat, eastern part of central and northern Gujarat. Inadequate drainage resulting in water logging and rise in water tables as a consequence of canal irrigation is the main cause of inland salinity of the soil in the deltaic areas along the west and south Saurashtra coast, Mahi command in central Gujarat and eastern region of southern Gujarat. Saline water intrusion and improper drainage also affects the salinity of the soil in the coastal districts of Surat, Bharuch, and Valsad.

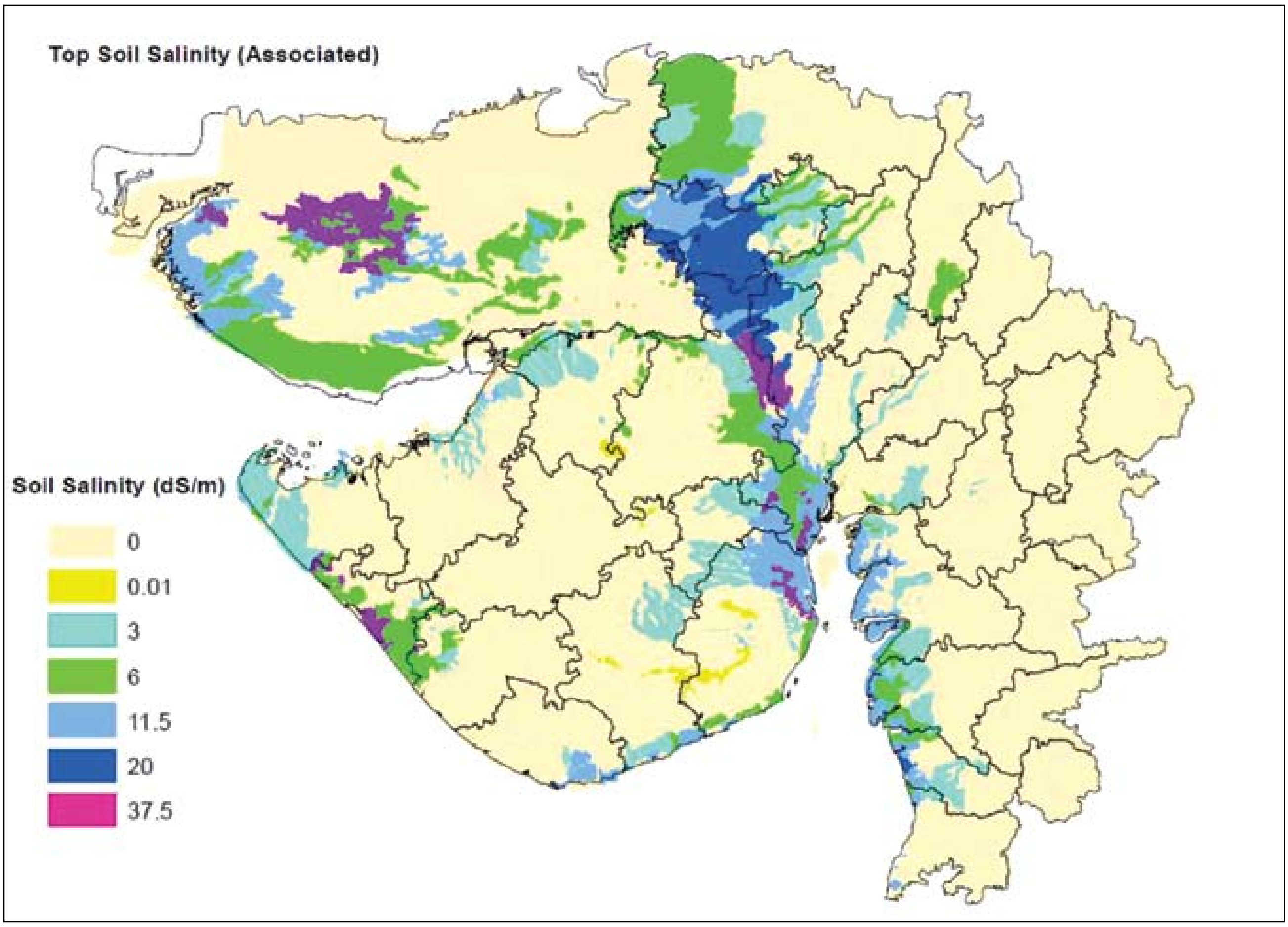

Figure 3.12: Soil Salinity Map of Gujarat

V. Soil Depth

Soil depth plays a pivotal role in the crop performance of annual as well as perennial crops, plant growth and yield. The effective depth of a soil for plant growth is the vertical distance into the soil from the surface to a layer that essentially stops the downward growth of plant roots. The barrier layer may be rock, sand, gravel, heavy clay, or a cemented layer (e.g. caliche).

Deep soils can hold more plant nutrients and water than can shallow soils with similar textures. Depth of soil and its capacity for nutrients and water frequently determine the yield of a crop, particularly annual crops that are grown with little or no irrigation. Plants growing on shallow soils also have less mechanical support than those growing in deep soils. Trees growing in shallow soils are more susceptible to blown over by wind than those are growing in deep soils. Soil depth having deep to very deep are the predominant soil in both north and south Gujarat with some exception in eastern region of north and south Gujarat. In Kutch, deep soils are found in coastal region. In rain fed agriculture, deep to very deep soil plays a major role, since it has better moisture storage ability. This soil type supports medium to deep rooted crops. Long duration crops favor this soil. Shallow soil is confined in Eastern region of both northern and southern Gujarat, central region of Saurashtra, where, it is predominant soil, and eastern region of Kutch. The crops with shallow root system and short duration harvesting time are favored in this soil. Some forage crops may be grown in shallow soils, as their root depth is shallow.

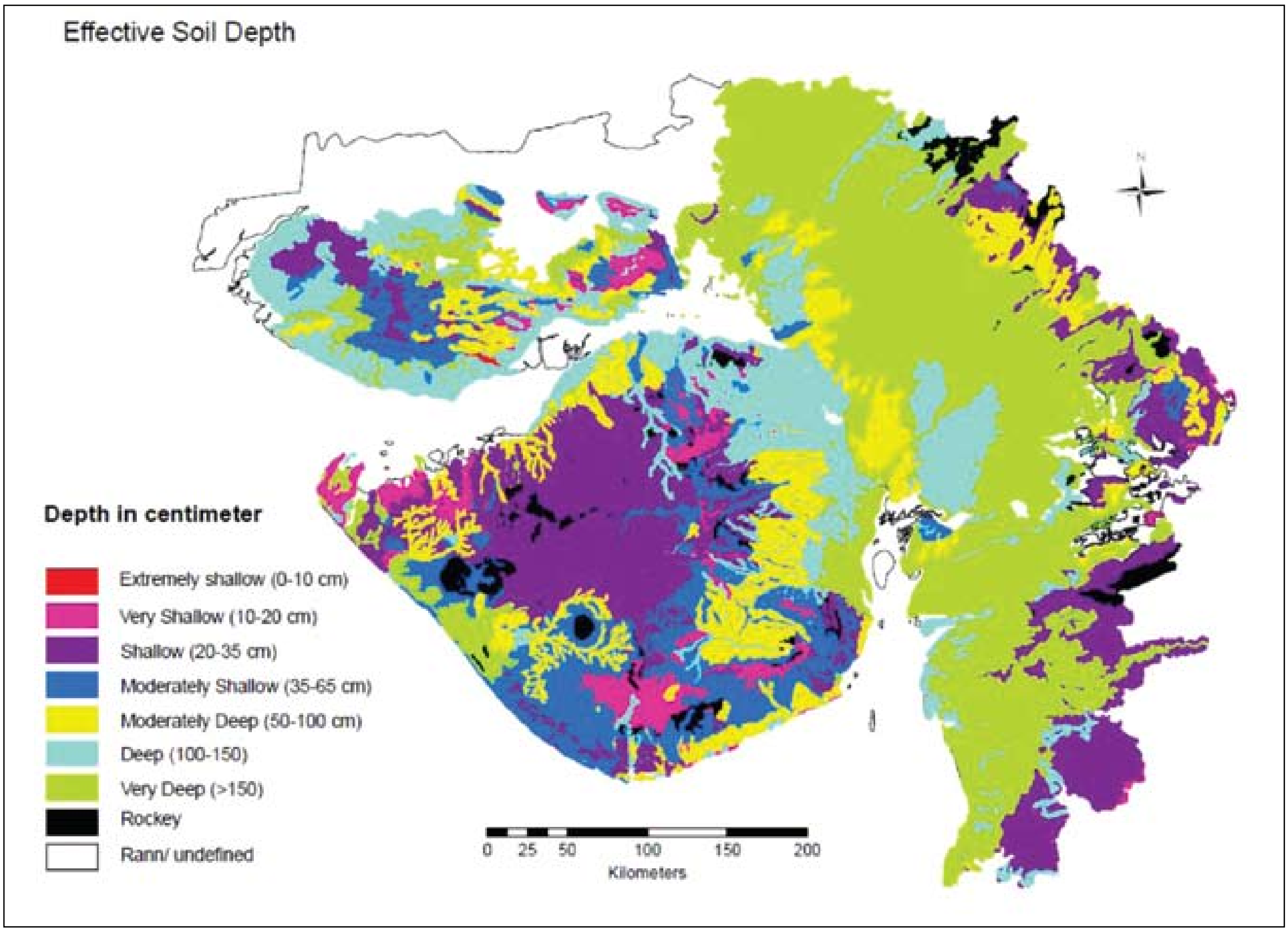

Figure 3.13: Soil Depth Map of Gujarat

VI. Soil pH

Soil pH is a measure of soil acidity, neutrality or basicity. Soil pH values of Gujarat ranges from 6 to 10. Both extremes pose some limitations to crop production. Extremes of soil pH release substances from soils that can be toxic to plants. Acid soils may dissolve toxic amounts of metals like aluminum and manganese. Alkaline soils may accumulate salts and sodium carbonates in toxic concentrations that can alter soil structure, which make it difficult for plant roots to grow. Stunted root systems have difficulties, while taking up adequate water and nutrients. Toxic metals in acid soils or subsoil are responsible for nutrient depletion. Clay pans also stunt root growth. Slightly acidic soils (pH of 6.5) are considered most favorable for overall nutrient uptake. Such soils are also optimal for nitrogen-fixing legumes and nitrogen-fixing soil bacteria. Some plants are adapted to acidic or basic soils due to natural selection of species in these conditions. Potatoes grow well in soils with pH <5.5 while cotton, garden pea, and many kinds of grass grow well in alkaline soil (>7.5). Soil pH also affects the soil in other ways. For example, soil microbe activity; particularly nitrogen-fixing bacteria may be reduced in acid soil. The sodic soil (>8.5 pH) confines mostly in the coastal region of Kutch and central Kutch, north and eastern part of north Gujarat, some area of the central and eastern part of central Gujarat, eastern and western part of southern Gujarat, and central Saurashtra. Acidic soils are found in south Gujarat, the central part of Kutch region, and western part of central Gujarat. Soil having pH between 7 and 8 are predominant in Gujarat.

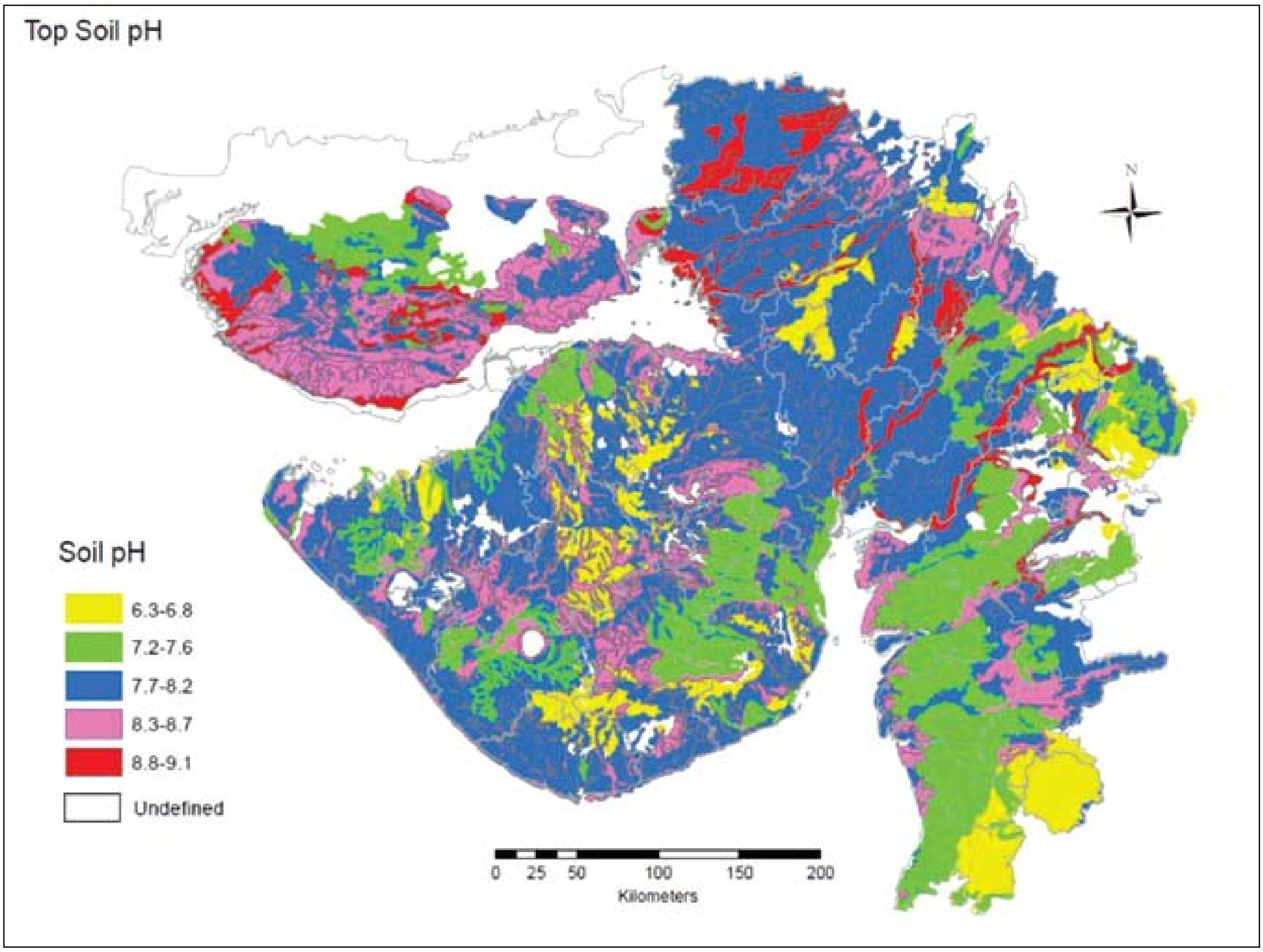

Figure 3.14: Soil pH Map of Gujarat

VII. Top Soil Texture

Top soil texture is an important soil feature that could influence water retention capacity, aeration, drainage, and susceptibility to erosion, which drives crop production and management. The textural class of the soil is determined by the percentage of sand, silt and clay. Soils can be classified into one of the four major texture classes including sand, silt, clays and clays. Generally speaking, three kinds of texture are identified in the state. Clay and clay types are predominant in the state under fine and medium texture soils. The soil texture of the Kutch region belongs to the sandy class. Soils found in southern Gujarat and Saurashtra are predominantly clayey. In the central of Gujarat, it is the sandy loam to clay or clay loam to clay in the central region, the alluvial plains and the coastal salt area. The predominant soil texture of northern Gujarat is sandy to loamy-sandy.

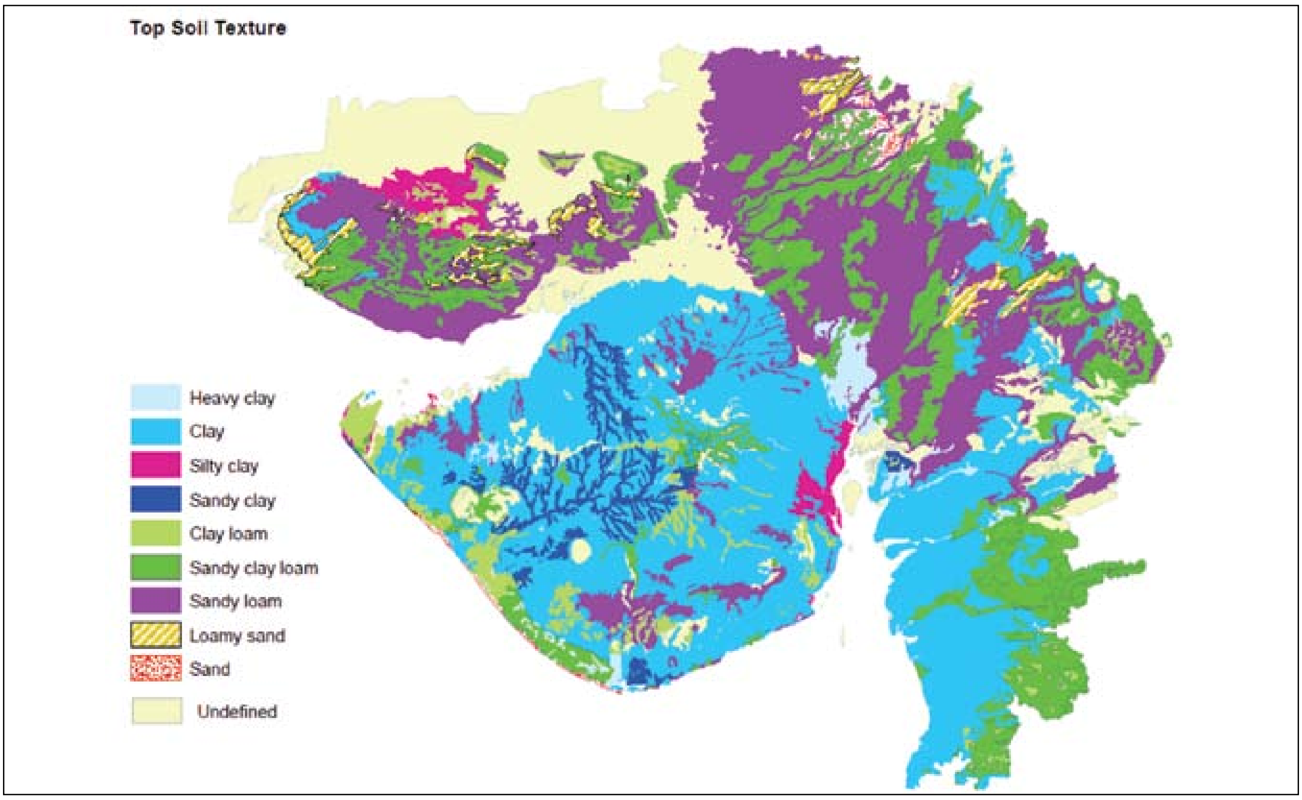

Figure 3.15: Top Soil Texture Map of Gujarat

VIII. Soil Erosion

Soil erosion caused by water and wind is a major problem in Gujarat. There are slight to moderate soil erosion occurs in Saurashtra, Kutch, southern Gujarat, central Gujarat, and northern Gujarat. Severe

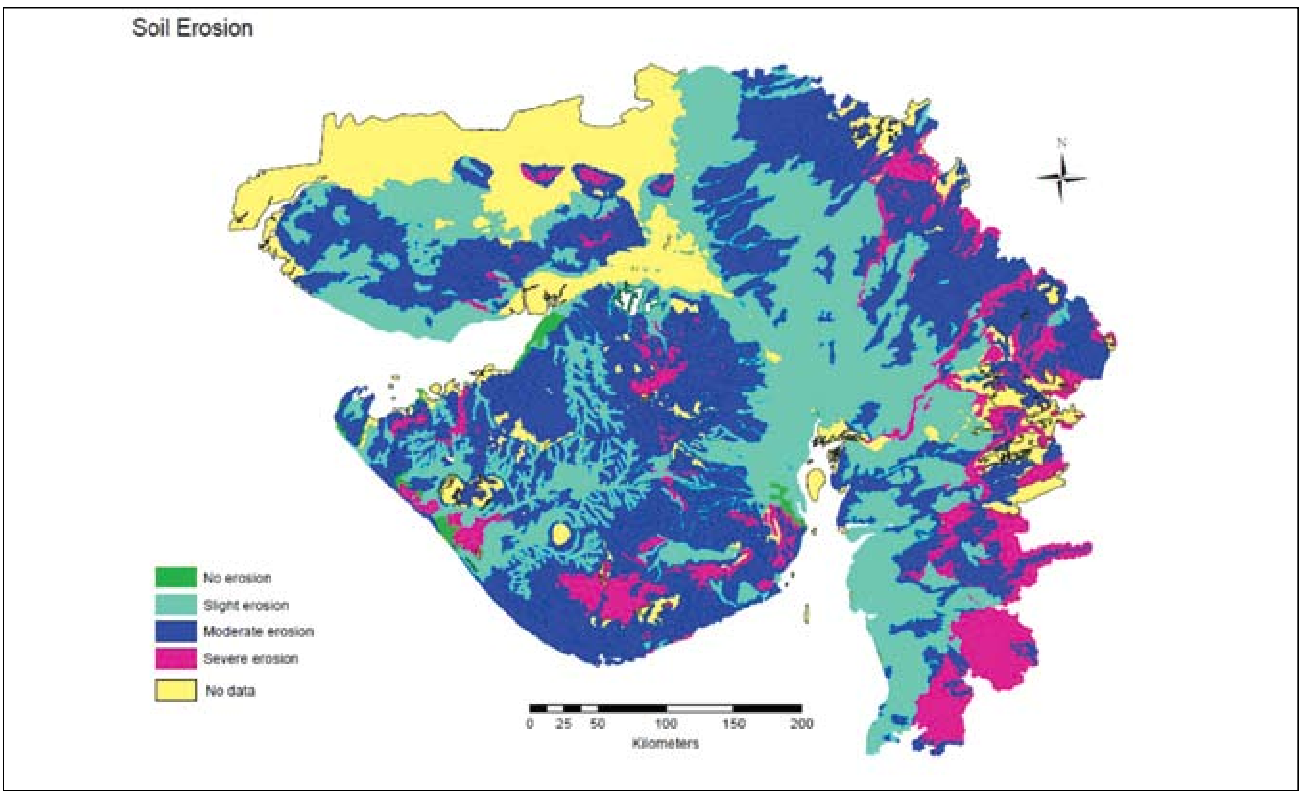

Figure 3.16: Soil Erosion Map of Gujarat

soil erosion confined in eastern part of south, north, and central Gujarat and in some central region in Saurashtra. These areas suffer from severe erosion because the terrain is "undulating" and the soil is loose, the situation further worsened by rainwater which loosened the soil and it get washed away because of sloppy terrain.

IX. Drainage

Drainage refers to the swift and extent, that the water is discharged from a soil by surface runoff, underground water flow through the soil. Drainage also refers to soil drainage status the frequency and duration with which soil is waterlogged. Majority of soils in Gujarat are well drained. Soil drainage at extreme level creates problems for crops. Excessively drained soils do not provide most crops with adequate water and nutrients, and the structure of the soil limits root growth. Somewhat excessively to excessively is found in eastern part of Kutch, northern and southern parts of north Gujarat, coastal, and central parts of Saurashtra.

Poor to very poor drainage system confines to the eastern coastal part of southern Gujarat: covering districts of Navsari, Surat, Bharuch, central part of Kutch, some coastal part of Saurashtra. Water and nutrient availability are also limited in poorly drained soils because oxygen deficiency limits the ability of roots to take up adequate water and nutrients. With water-logging, decaying occurs when partially decomposed organic matter accumulates, clogging soil pores and blocking root growth and the drainage of water through soil. Decaying forms toxic substances: reduced nitrogen, sulfur, metals, and organic fermentation products. Furthermore, it produces methane; which is a greenhouse gas.

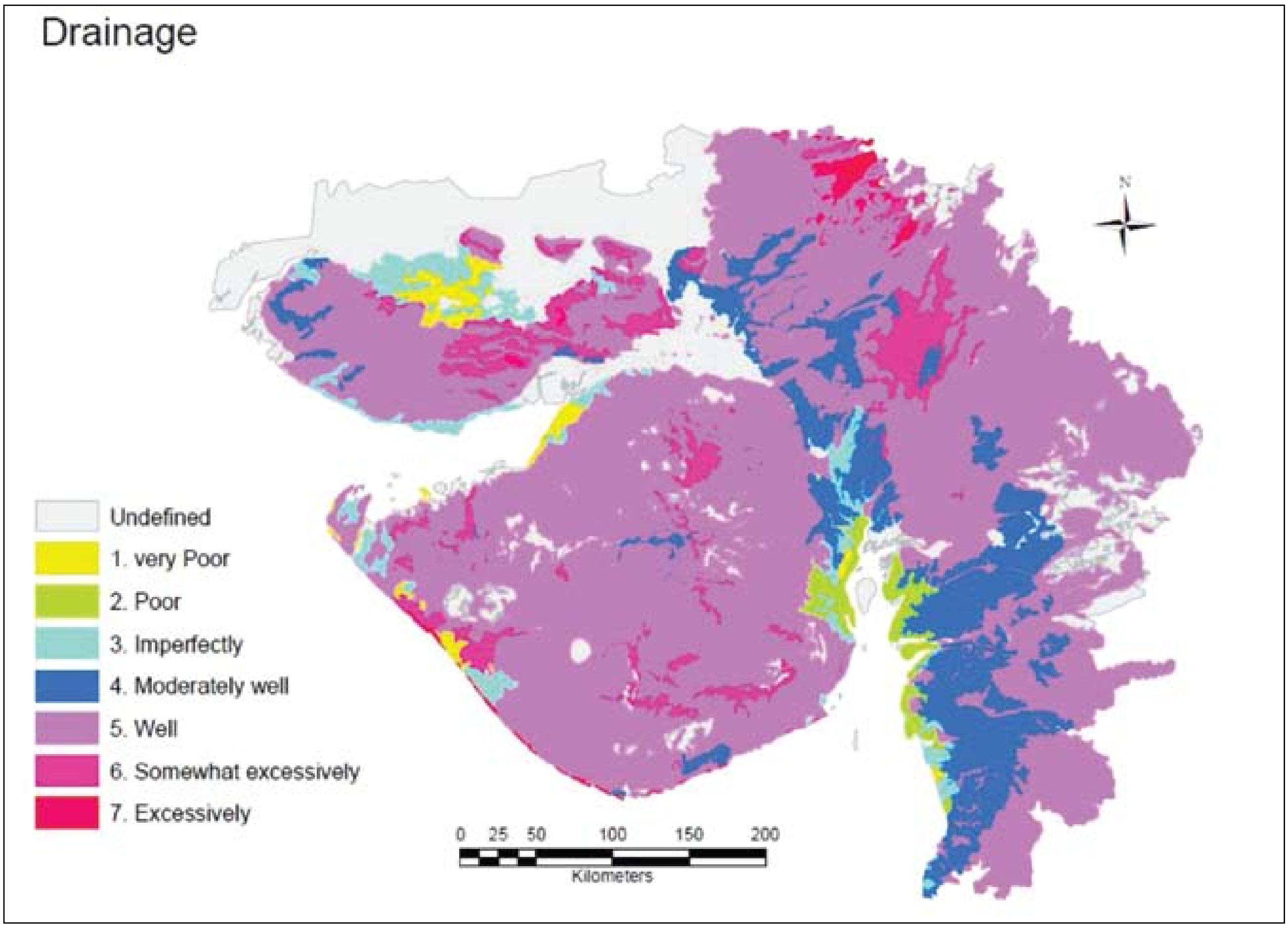

Figure 3.17: Soil Drainage Map of Gujarat

X. Calcium Carbonate of the Top Soil

Calcium carbonate of top soil having 0 to 1% by weight is predominant in Kutch region, whereas, $CaCO_3$ content of top soil is in the range between 8 and 16 confines in the coastal region of Kutch and some areas in central Kutch. The top soils of central region of Kutch mainly consist of $CaCO_3$ that varies between 1 and 8% by weight. Calcium carbonate of top soil having 0 to 1% by weight is dominant soil in rest of Gujarat as well Gujarat. It is the major soil found in the north, central and south Gujarat, and Kutch region. Soil containing $CaCO_3$ of 8 to 16% by weight confined in coastal area of Kutch, central region of Saurashtra, western part of central Gujarat, and eastern part of southern Gujarat.

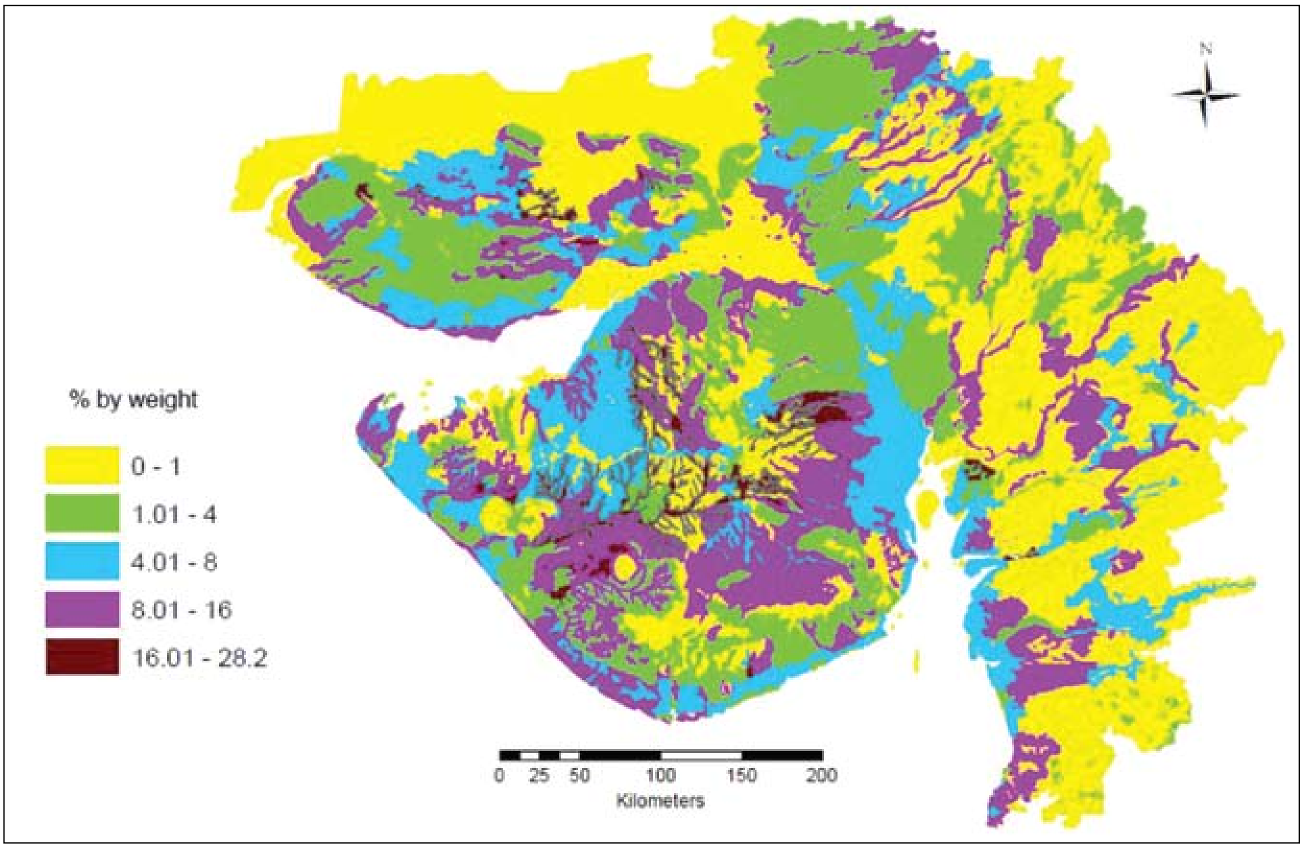

Figure 3.18: Calcium Carbonate of the Top Soil Map of Gujarat

3.2.2 Spatial Patterns of Land

A. Physiographical Parameters

I. Topography

Topography includes the physical characteristics of the Earth, such as, elevation of land, slope, terrain, ridges, and water bodies. The slope of a land is the percentage change in its elevation over a certain distance. It is measured by dividing the vertical distance between the foot and the top of the earth by the horizontal distance between those points, multiplied by 100. An elevation angle of 45-degrees is equivalent to 100% slope. The inclination of a slope affects the growth of the plant through the differential incidence of solar radiation, wind speed, and soil type. A steep slope is susceptible to rapid surface runoff and soil erosion that cause soil degradation. The land elevation with respect to the sea level influences the growth and development of the plant mainly through the effect of the temperature.

The relation of the topography to the temperature is like the distance between the Equator and the Arctic poles. According to Stiling (1999), the temperature decreases by 1˚C per 100 meters of altitude in dry air. The effect of the elevation of the earth on the growth and development of the plants is evident when exploring a high mountain. The dominance of certain types of plants varies with elevation. With changes in altitude from sea level up to 4,876.8 meters from the foot to the top of a mountain in the Peruvian Andes or New Guinea, temperatures change from tropical to sub-tropical, temperate and sub-arctic to arctic Also, the influence of the topography on the growth and distribution of the plants is appreciated. There is a change of tropical vegetation in the coastal base for the oak forest, then conifers, and finally a tundra scene with resistant grasses, mosses and dwarf shrubs. At the top of the Arctic, only occasional lichens are found on exposed rocks. In the tropics, the timber line on which no more tree grows can be found between 3,962 to 4,267 masl (Went and The Editors of Life 1963).

Topography is an important concern in the selection of crops and/ or suitable sites for more productive agriculture. The coconut prefers an elevation not exceeding 600 meters above sea level (masl) (PCARRD 1982); for better quality, the tea is cultivated better than 1000 masl while the rubber does not require more than 500 masl because at higher elevation the latex flow is restricted (Abellanosa and Pava 1987); the seasonality of ripening of various fruit crops, e.g. durian, is modified when they are planted in different elevations.

II. Elevation

With the increase in altitude, temperature goes down. With this elevation and temperature are inversely proportional. In higher altitude crop requires longer growth cycle. Hence, potato and wheat can be grown at 2,500 masl up to 3,800 masl. Similarly, maize can be grown below 2,500 masl.

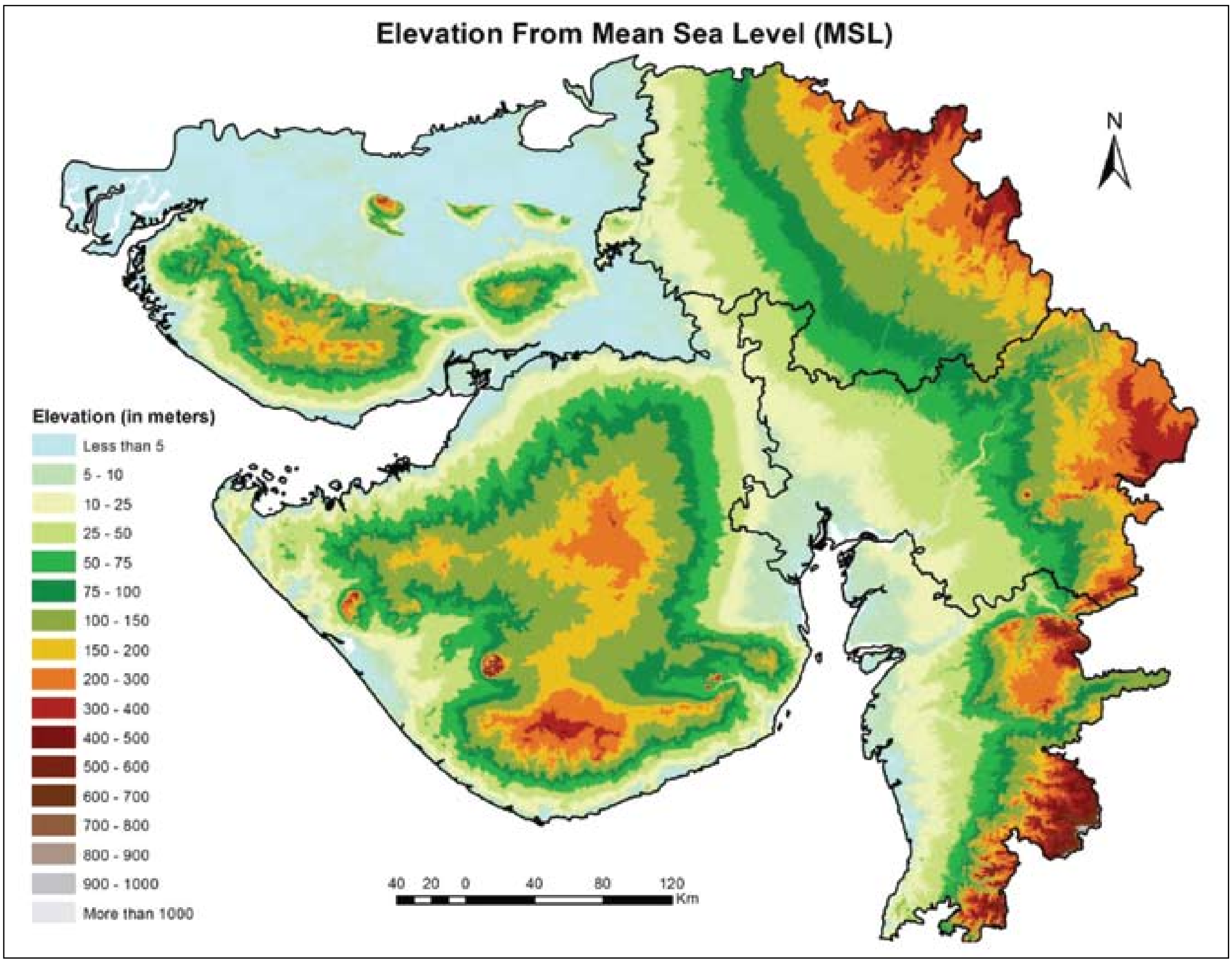

Figure 3.19: Elevation from Mean Sea Level (MSL) for Gujarat

Table 3.3: Elevation by Area (Area in %)

Elevation (meter)	Kutch	North	Central	Saurashtra	South	Total
0	0.47	0.00	0.12	0.20	0.23	1.03
0 to 5	12.56	0.08	0.33	1.28	0.66	14.90
5 to 10	2.36	0.38	1.03	2.03	1.22	7.02
10 to 25	1.76	1.37	2.28	4.23	2.14	11.78
25 to 50	1.97	2.11	3.76	4.91	1.66	14.41
50 to 100	2.50	3.89	2.96	7.95	1.79	19.09
100 to 200	1.95	5.49	3.20	9.53	2.01	22.18
200 to 300	0.12	2.01	1.44	1.68	1.04	6.28
300 to 800	0.01	0.92	0.79	0.29	1.27	3.28
More than 800	0.00	0.00	0.00	0.00	0.03	0.03
Total	23.70	16.24	15.91	32.11	12.04	100.00

III. Slope

The slope tables provide an area in terms of the square kilometer and percentage of total land area with their respective slopes. Areas with the slope less than 5% can be used for agricultural purposes and as per the data, it is 92.3% which is 175,153 km^2 out of the total area of 189,774 km^2.

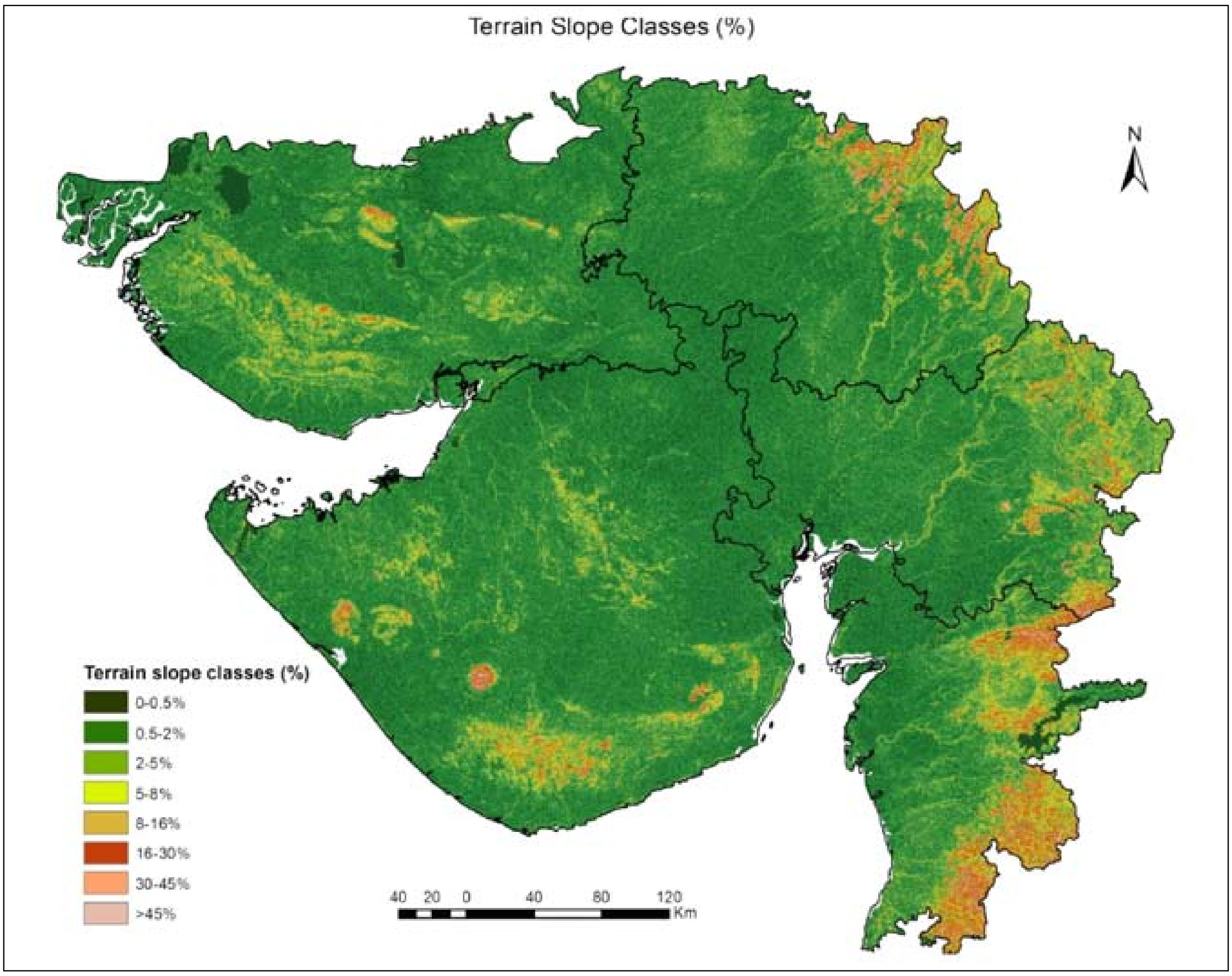

Figure 3.20: Terrain Slope of Gujarat

Table 3.4: Slope by Area (Area in %)

Regions	Categories							Total area (%)
	0.0-0.5%	0.5-2%	2-8%	8-16%	16-30%	30-45%	>45%	
Kutch	3.81	14.99	3.62	0.23	0.06	0.01	0.00	23.70
North	1.94	10.26	2.70	0.44	0.32	0.14	0.06	16.24
Central	1.93	9.29	3.22	0.46	0.25	0.07	0.01	15.91
Saurashtra	1.39	5.25	2.30	1.01	0.82	0.28	0.07	12.04
South	4.61	21.64	4.26	0.49	0.19	0.05	0.01	32.11
Total area	13.67	61.43	16.10	2.63	1.65	0.56	0.15	100.00

i. Mainland Gujarat

The *Aravali* range enters Gujarat near the *Abu* and after zigzagging all along the north-eastern and eastern part of the State up to *Shivrajpur* merges into Vindhyas hills. The Aravali owes its origin to uplift in the Earth's crust and is thus a "Tectonic mountain". The ranges are with steep slopes and without any plateau at the top. They are mainly composed of Quartzites, phyllites, schists, calcgneisses, granites, etc. These hill-range follow flexures of the fold. In the Palanpur Danta-Idar area, the *Aravali* range is broken into long and narrow hills. In Mehsana, the hills are known as the *Taranga* Hills; on one of the peaks, there are beautiful *Jain* Temples. Across the Tapi lie the ranges of the *Sahyadri*, the Western Ghats, which also are of 'relict' type. Among the hilly tract of Gujarat, the *Sahyadri* receives higher rainfall, and thus many rivers rise on its western slopes, which are covered with dense forests, like the one of The Dangs; these areas are known for their scenic beauty. Many hills in the Narmada and Tapi valley are unlike the trap hills with step-like scenery; these have hog-back shaped features as those are composed of large barriers intruded into the traps.

ii. Peninsular Gujarat: Saurashtra

The highest peak in this area is *Guru Goraknath* 1,117 masl, while other peaks are *Dattatraya* and *Ambaji*. The hills are more elevated in the south and west, while in the north and east they are low. Along with its group of hills, it covers about 166 km^2 area. Most of the rivers in Saurashtra rise from this central tableland. The terrain very gently slopes outwards, i.e. towards, coastal plains. Thus, drainage in this region is typically radial.

iii. Kutch

The trend of hill ranges in the east-west direction with steep slopes in the north and gentle slopes south owe their origin to faults running in the east-west direction.

B. Land Use Land Cover (LULC)

Land use is the form and extent to which land is used. Land use is the modification of the natural environment in settlements, roads, rail networks, other infrastructures, agriculture, forests, wetlands, wastelands, etc. It has also been defined as the arrangements, activities and inputs that people perform on a given land type of cover to produce, change or maintain (Gregorio and Jansen 1998). To maintain the balance between the environment and development planners must have knowledge about the existing land use and trends over the years. People discuss how the earth has changed over time. Sometimes there are conflicts over land use. Therefore, there is a need for proper land assessment and classification. Since several land categories are within the scope of different departments, there are inconsistencies in land use classes. There is a need to have a standard land use classification, which can be applied to the entire state. The classification of land use should be detailed and each kind of land needs to be defined to reduce the darkness. In addition, many scholars have highlighted the need for a systematic database to assess changes in land use. Gujarat's land use area is 196,024 km², which includes constructed area, agriculture, forest, wasteland, water and wetlands. Agriculture is dominant among all categories of land use, which is 60.4% of the total area of Gujarat with an area of 118,440 km².

Table 3.5: Shares of Major Land Use/Cover Classes by District

Regions	Built-up %	Agriculture %	Forest %	Wasteland %	Water %	Wetlands %	Total Area (km²)
Central	4.95	35.24	17.61	7.29	5.16	2.47	253092.42
North	2.22	19.13	6.10	4.09	1.88	1.11	449116.42
Saurashtra	3.69	28.70	18.22	7.07	4.74	1.87	947807.65
South	2.17	16.62	8.39	3.69	2.36	1.09	1650016.49
Kutch	5.77	32.58	26.68	21.53	4.49	8.95	23954.36
Total	6.15	60.42	12.91	13.18	4.26	3.08	196024.00

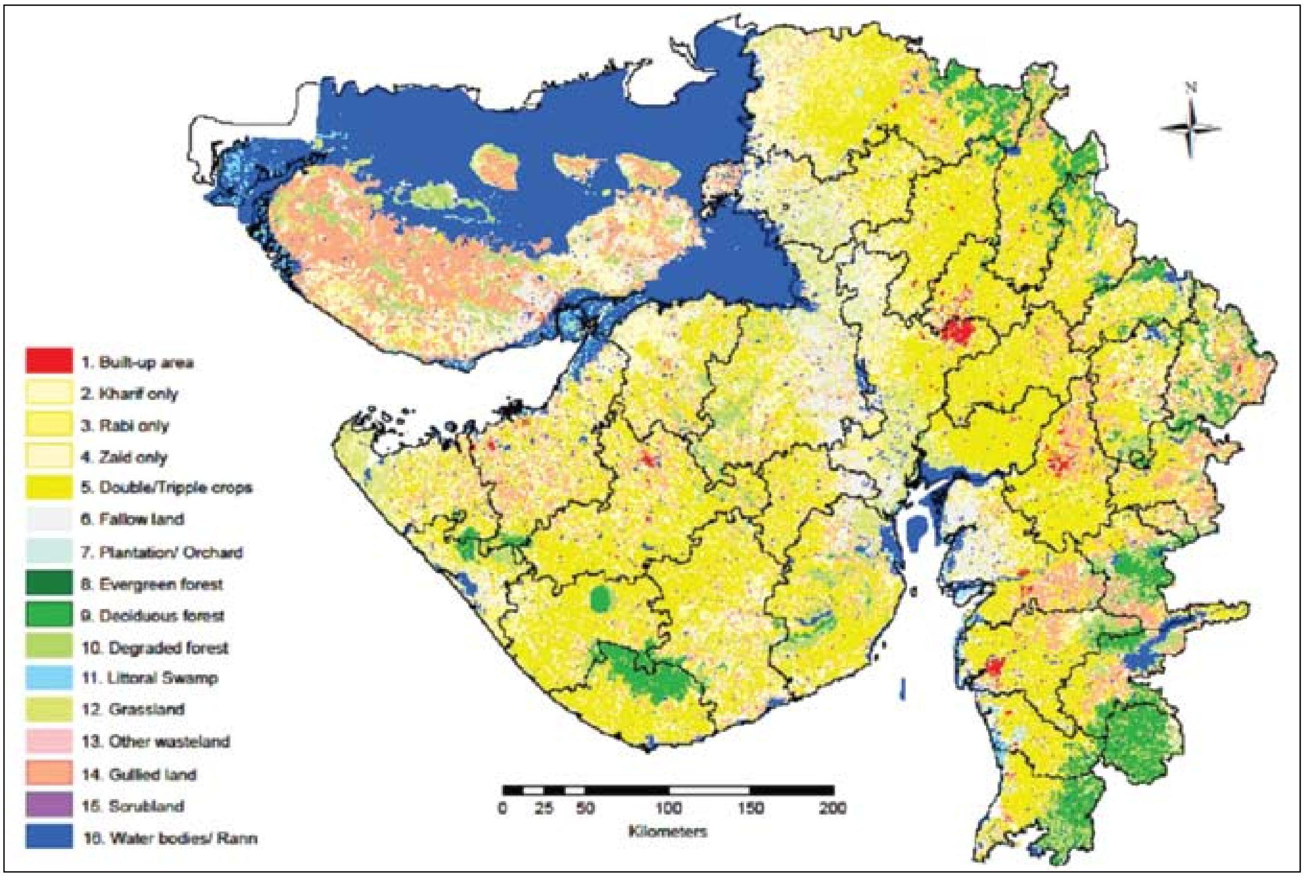

Figure 3.21: Land use Land Cover Map of Gujarat for 2007–2008

According to the GIS data base used in this study, Gujarat has a total land surface area of 196,024 km². The land under agriculture is 118,434 km², or 60% of the total area of the state. Around 6.2% is occupied by built-up areas. The remaining land consists of forests (13%), wastelands (13.2%), wetlands (3%), and water (4.3%).

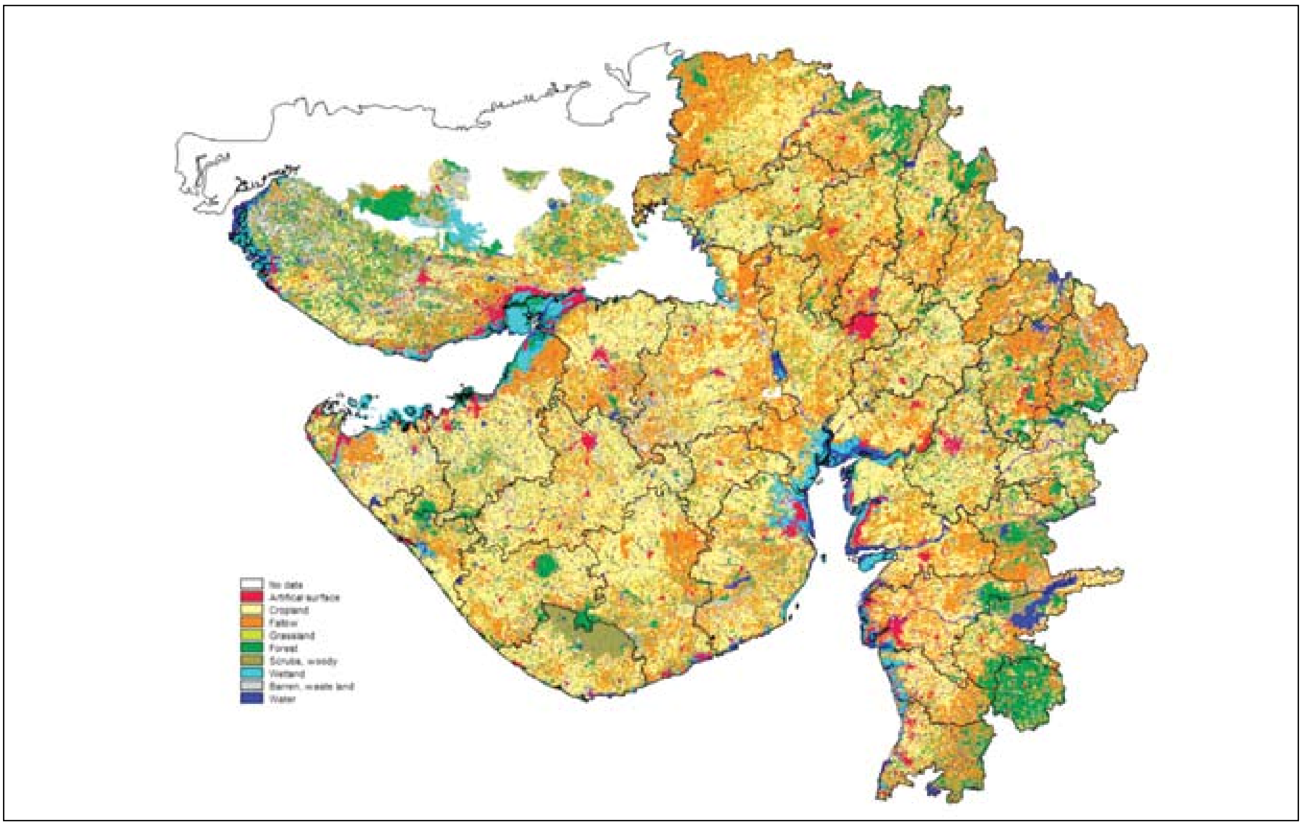

Figure 3.22: Land use Land Cover Map of Gujarat for 2011–2012

For use in AEZ Gujarat, three layers of GIS were combined, which contained information on (i) land use/ land cover, (ii) irrigated areas, and (iii) inland water bodies. The six categories of land use/ land cover that are used for land accounting and to characterize each of the three cells in the network of arches are: (i) irrigated cultivated land; (ii) rain-fed cultivated land; (iii) forest land; (iv) scrub and other vegetation; (v) settlements; and (vi) water bodies.

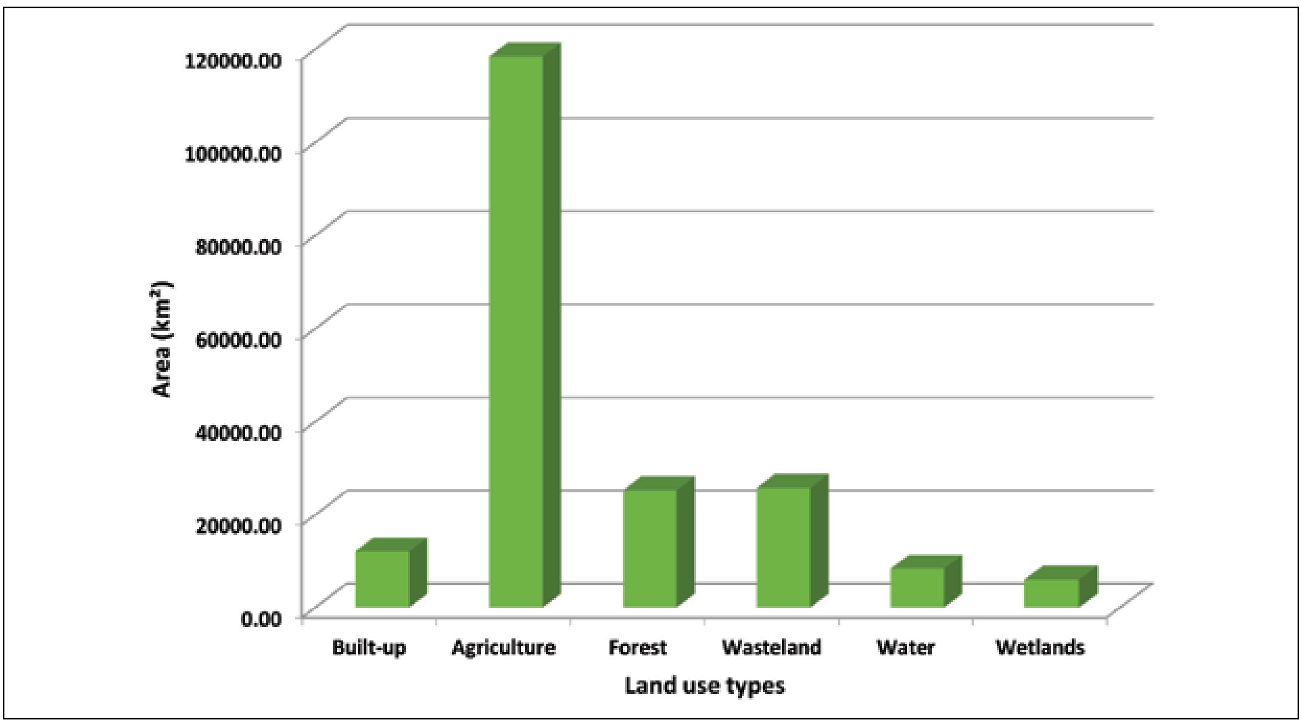

Figure 3.23: Different Types of Land use in Gujarat

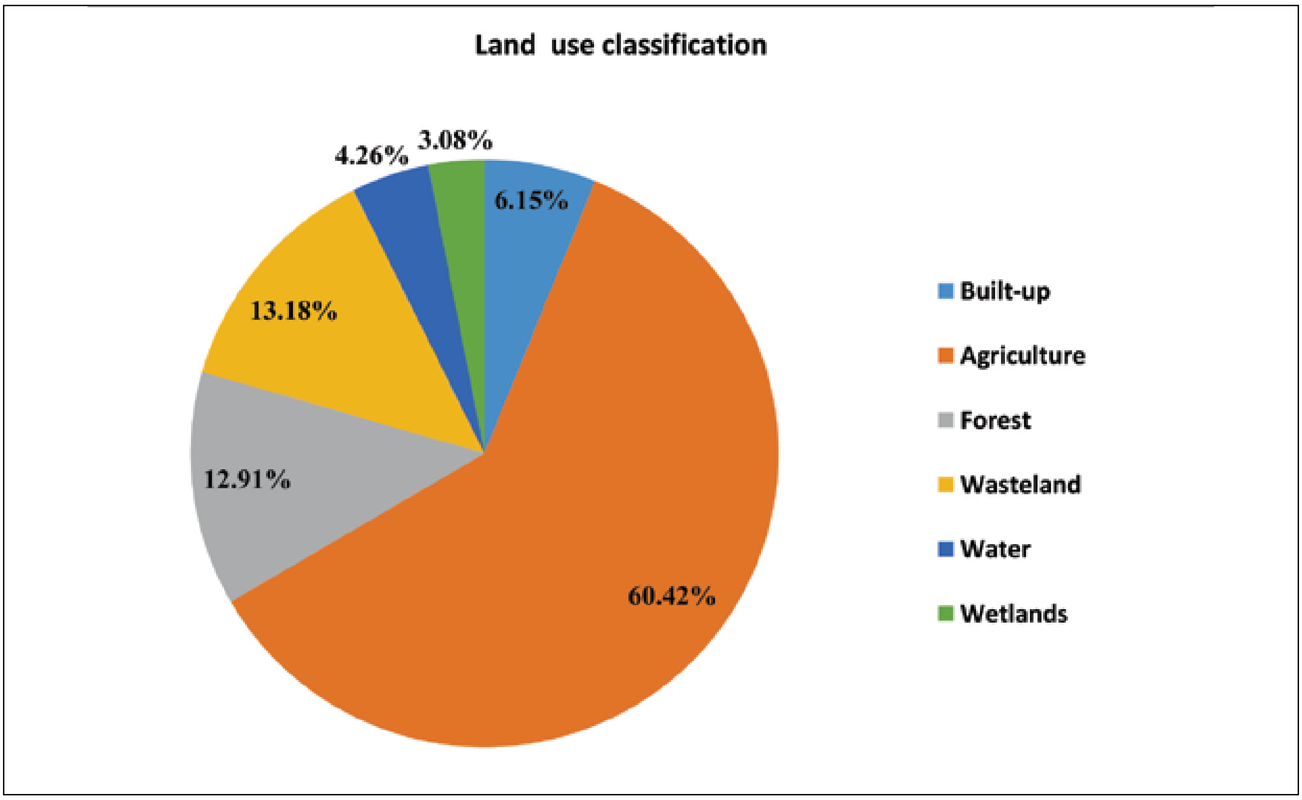

Figure 3.24: Percentage of Land use to Total Area of Gujarat

I. Built-Up

Built-up area consists of urban and rural area. Urban area consists of residential area, industrial area, commercial area, recreational area, public and semi-public area and transportation, while rural area consists of settlement and open spaces.

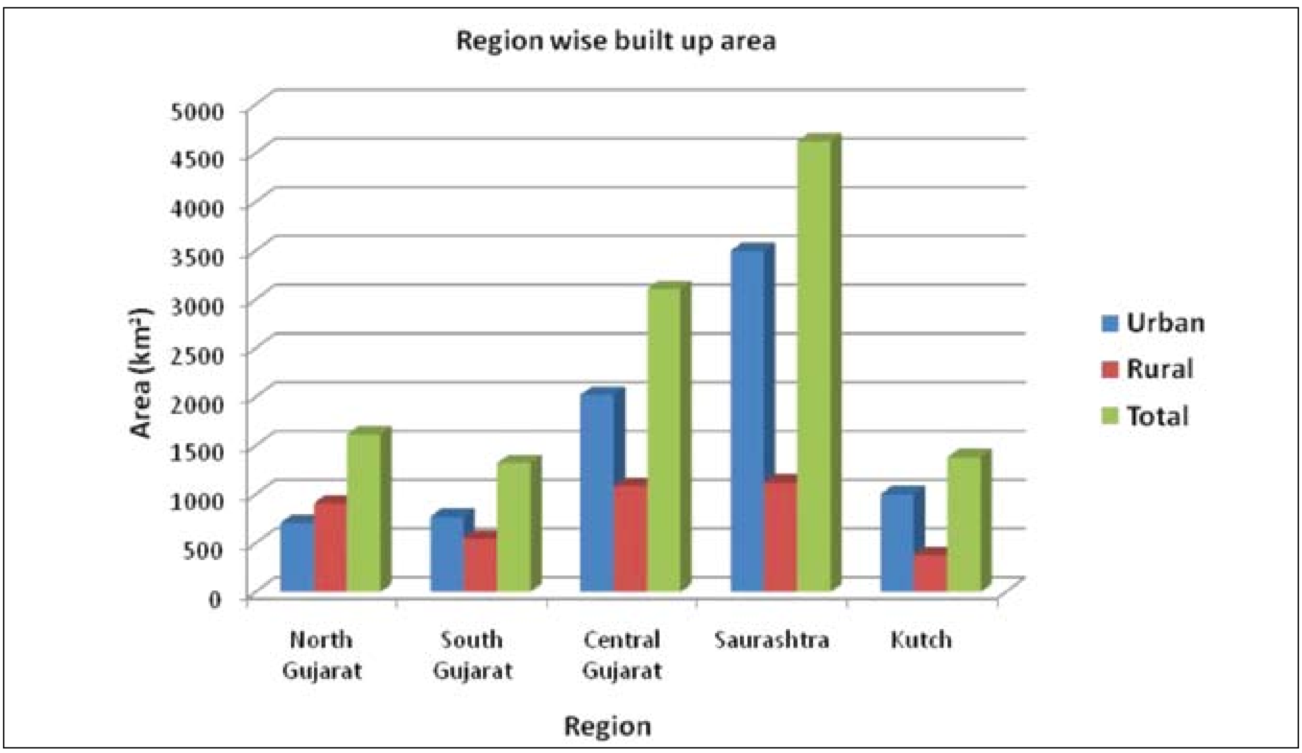

Figure 3.25: Region Wise Built up Area of Gujarat

II. Agriculture

Agricultural land holds 60.5% of the total land use area in Gujarat. Agricultural practice differs across regions of Gujarat. Agriculture land in Gujarat comprises of crop land, fallow land, riverbed cultivation and plantation.

III. Crop Land

Various types of crops are grown in Gujarat, i.e. Kharif, Rabi, Zaid (summer crops), and more than two crops. Saurashtra has maximum agricultural land covered under crop area (30,010 km^2) followed by central Gujarat, north Gujarat, Kutch, and south Gujarat.

IV. Fallow Land

Land that is left inactive periodically to recover is fallow land. This represents the cultivated area that remains fallow during the respective year. The current fallow lands remain uncultivated for one or less than one agricultural year (Department of Agriculture and Cooperation, GoG 2012). Central Gujarat has the largest amount of fallow land (13,646 km^2) followed by the centre of Gujarat, the north of Gujarat, the south of Gujarat, and Kutch.

V. Plantation

South Gujarat is the leading region in area under plantation (882 km^2) followed by Saurashtra, north Gujarat, central Gujarat, and Kutch.

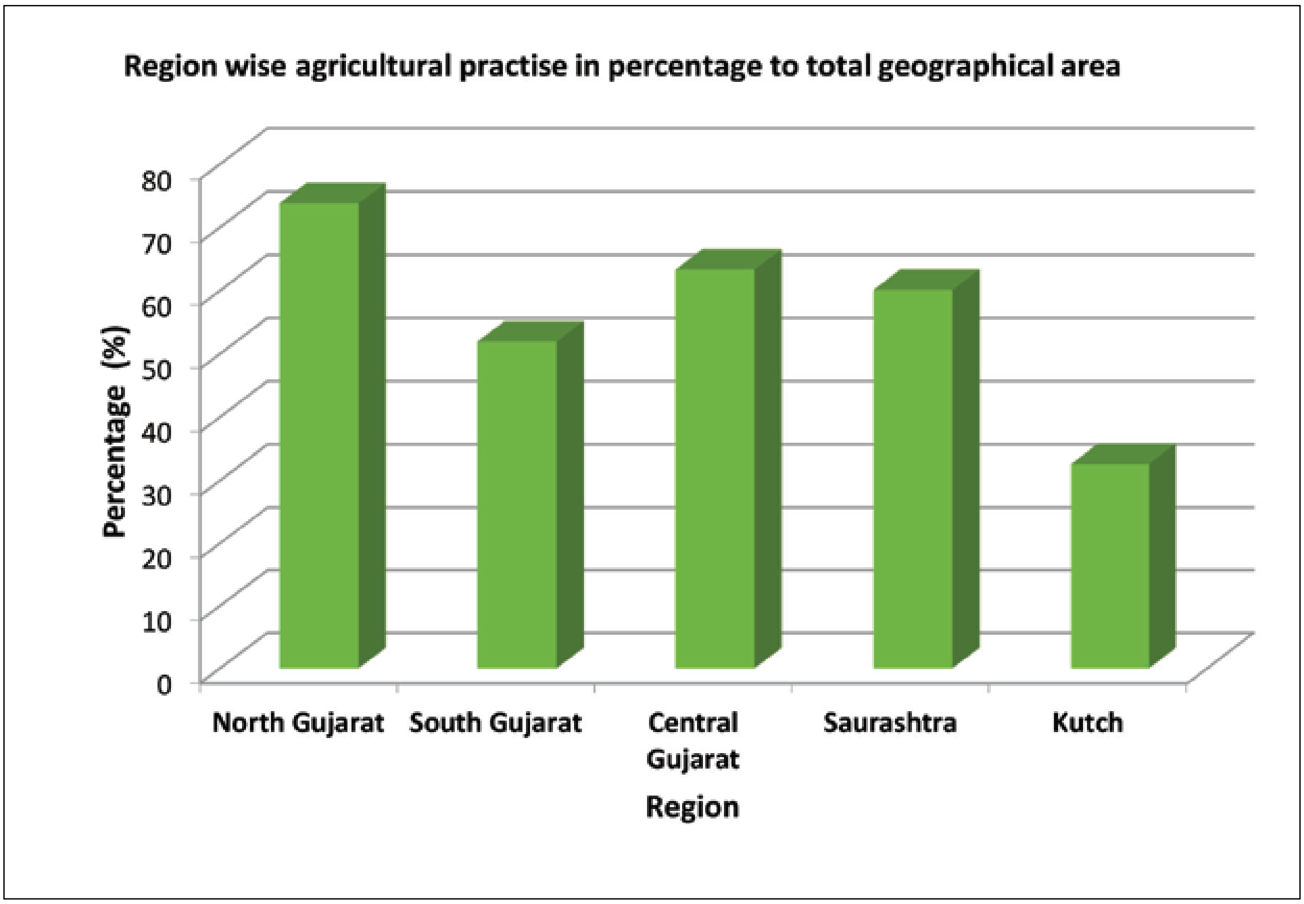

Figure 3.26: Region Wise Agricultural Practices in Percentage to Total Geographical Area

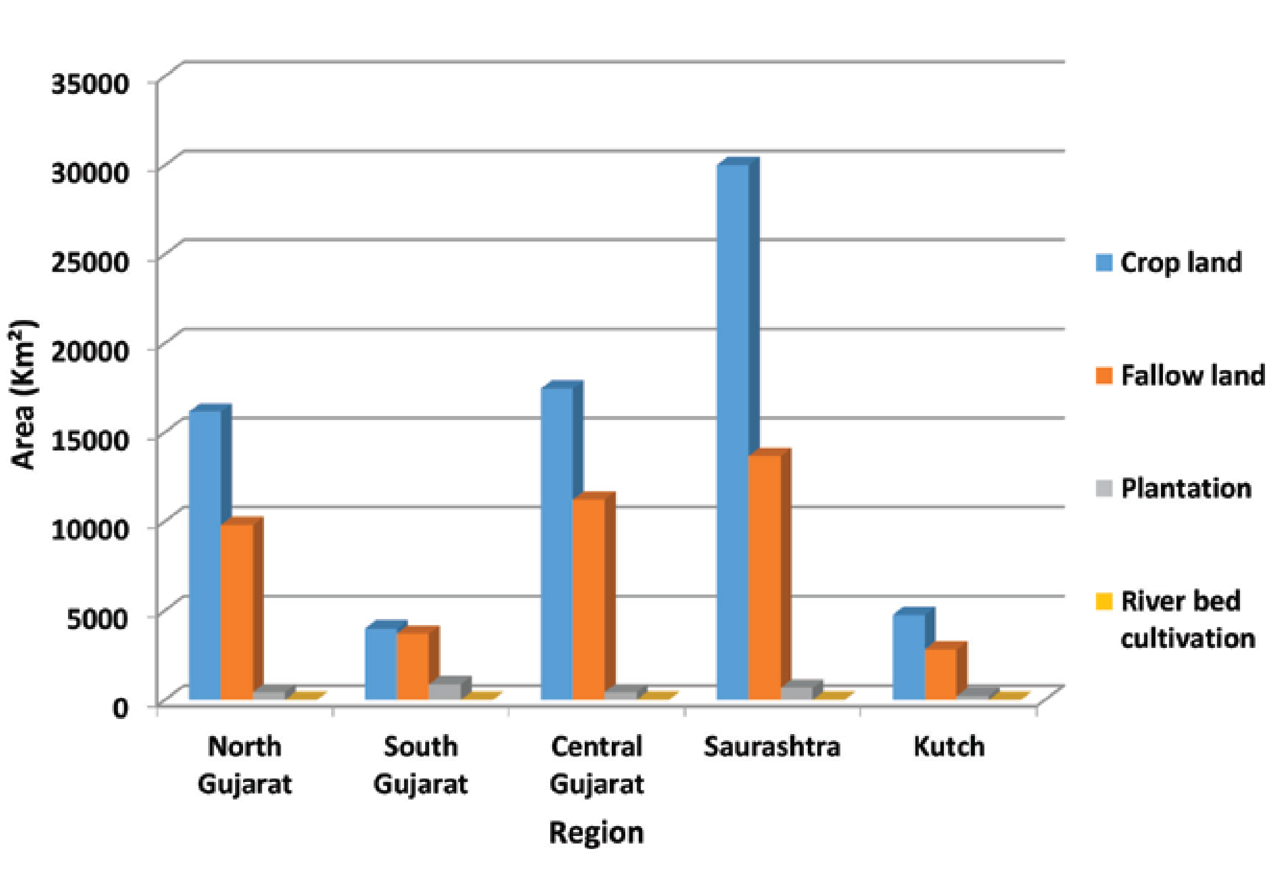

Figure 3.27: Region Wise Different Agricultural Practices

3.2.3 Spatial Patterns of Forest

The forest cover includes all lands with a tree crown of more than 10%. The Indian Forest Survey (FSI 2011) has classified forest cover under very dense forests with a canopy cover of 70% and more, moderate dense forest with 40-70% canopy cover and open canopy cover forests between 10 and 40%. The forest and tree cover of the state according to the assessment in 2013 is 24,317 km^2, which is equivalent to 12.41% of the geographical area. The state's forest cover has shown an overall increase since 1991 when forest cover was 11,907 km^2 and increased to a maximum of 15,152 km^2 in 2001. In 2011, the total forest area of Gujarat was estimated at 14,619 km^2 (FSI 2011). This increase has been due to management interventions such as regeneration and departmental plantations. However, according to data provided by the Directorate of Economics and Statistics, the forest area in Gujarat is 19,130 km^2. In order to analyze the regional variations of forests and forest cover, we used the data available in the FSI reports. The variation in the forest coverage data of different agencies is due to the different scale and resolution of the surveys adopted. The table below shows the distribution of forests and tree cover in Gujarat.

Gujarat's tree cover outside the forest area is about 10,459 km^2, which is 5.3% of geographical area in comparison to only 2.8% in India. The tree outside the forest area is the second highest amongst the states of India (Forest Department, Gujarat 2011). For forest resources to be valuable and productive in terms of providing ecosystem services, it is essential that the dense forest cover increases. The region wise forest covers of Gujarat is given in below figures. Kutch has highest forest cover among all the region of Gujarat, which holds 25.2% of total forest, followed by Saurashtra (23.6%), central Gujarat (18.7%), north Gujarat (18.5%), and south Gujarat (14%). Kutch has 26.7% of its area falls under forest cover, which is highest among the entire region followed by south Gujarat (21.4%), north Gujarat (13.1%), central Gujarat (10.3%), and Saurashtra (8.1%). Kutch holds 6,390 km^2 of forest resources followed by Saurashtra (5964 km^2), central Gujarat (4730 km^2), north Gujarat (4,682 km^2), and south Gujarat (3548 km^2).

Table 3.6: Forest Resources of Gujarat

Class	**Area (km^2)**	**Percentage of geographical area (%)**
Very dense (> 70%)	3396.46	1.73
Dense (40-70%)	2987.71	1.53
Open (10-40%)	3940.25	2.01
Scrub forest (< 10%)	3533.94	1.8
Tree cover (Outside forest)	10459.12	5.34
Mangroves	706.16	0.36
Crop land in forest	257.68	0.13
Forest plantation	34.05	0.01
Total	25315.38	12.91

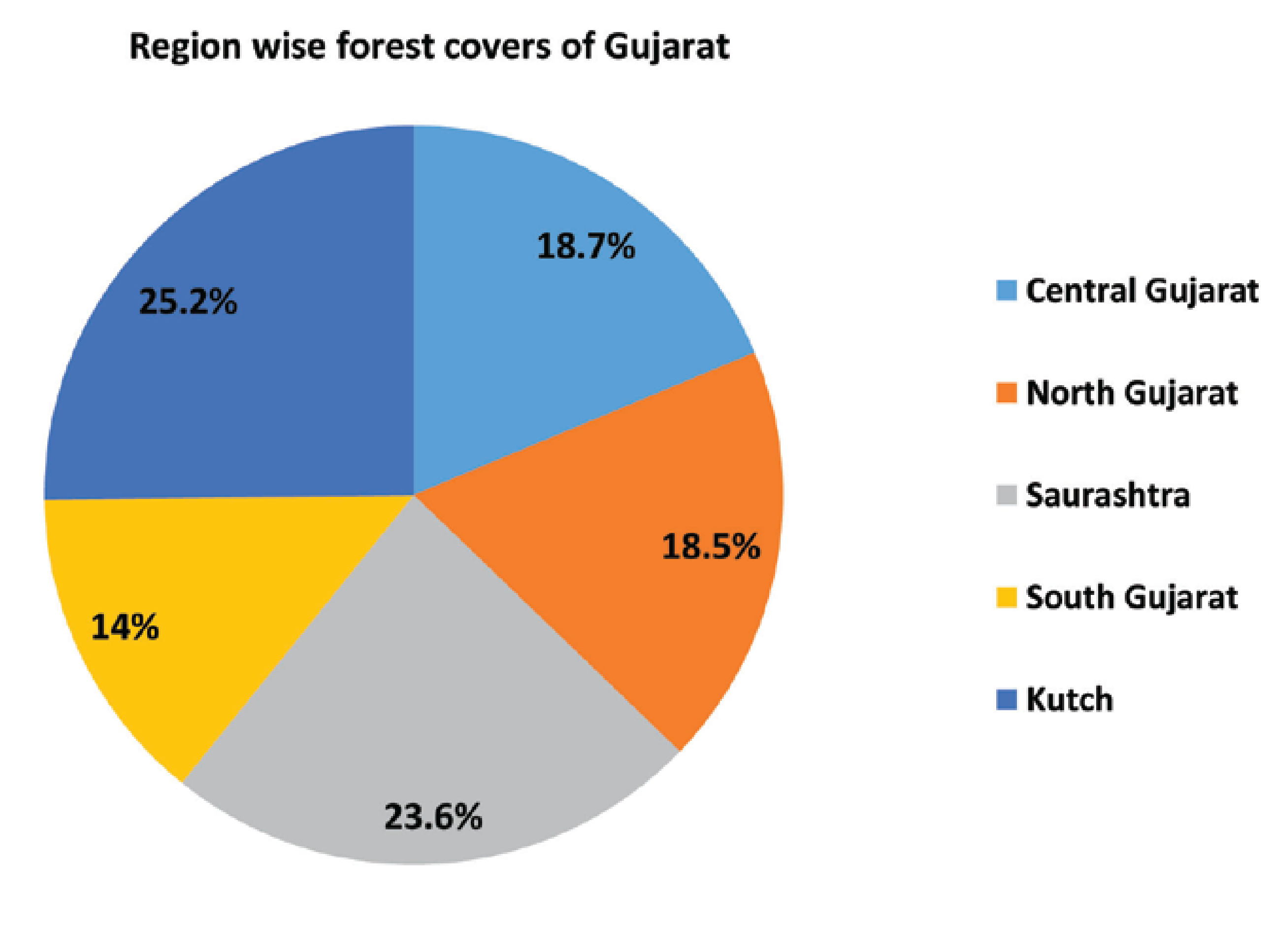

Figure 3.28: Region Wise Forest Covers to Total Forest Area

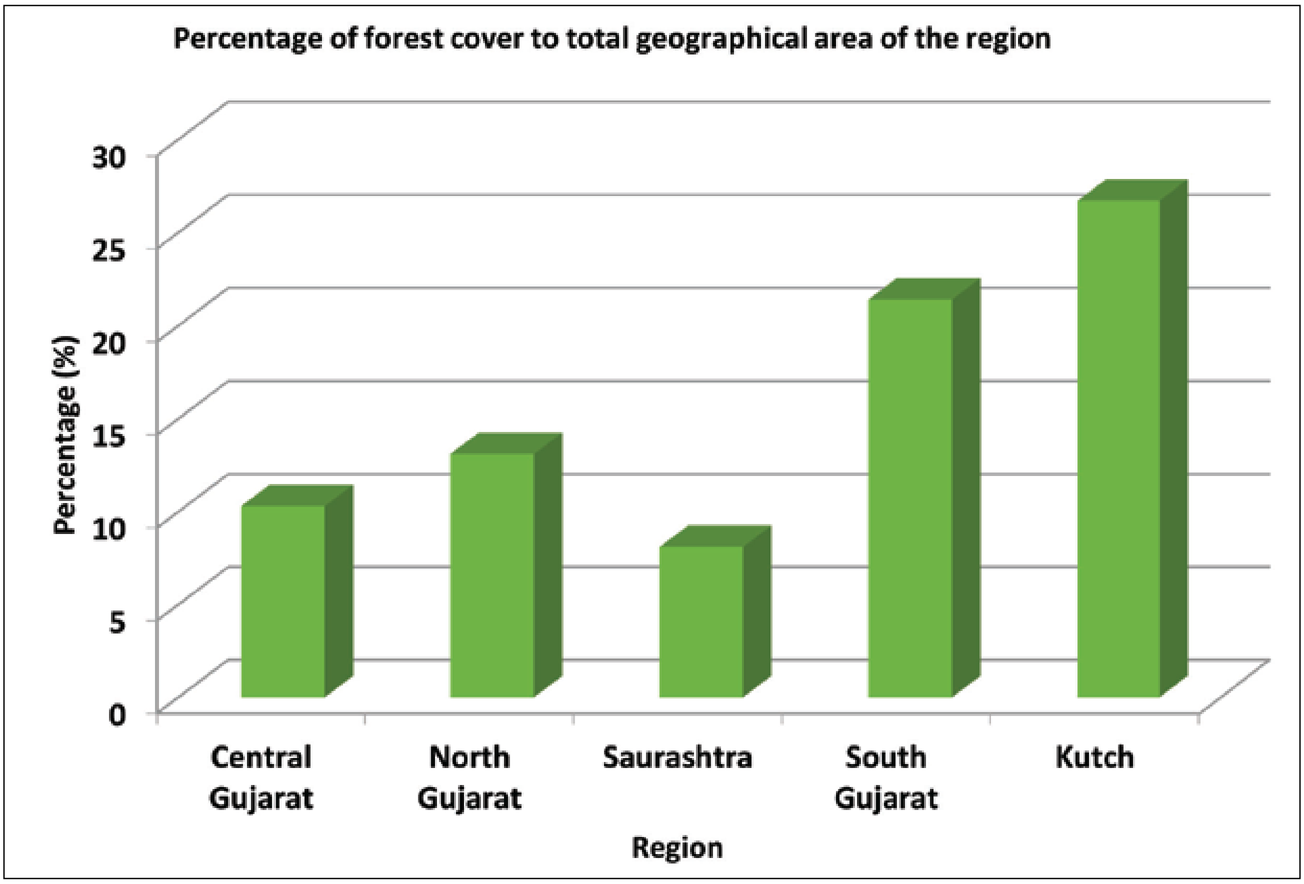

Figure 3.29: Percentage of Forest Cover to Total Geographical Area of the Region

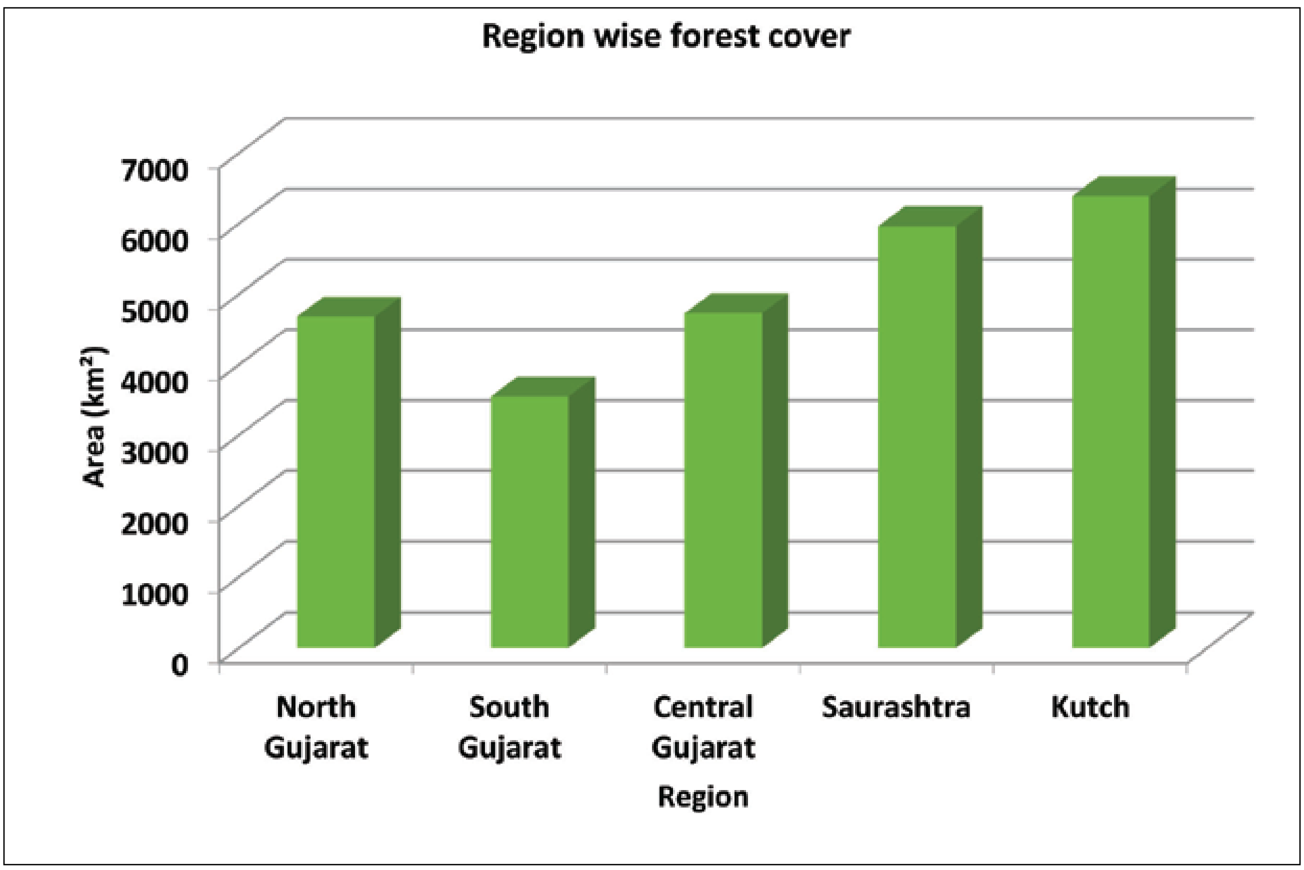

Figure 3.30: Region Wise Forest Covers of Gujarat

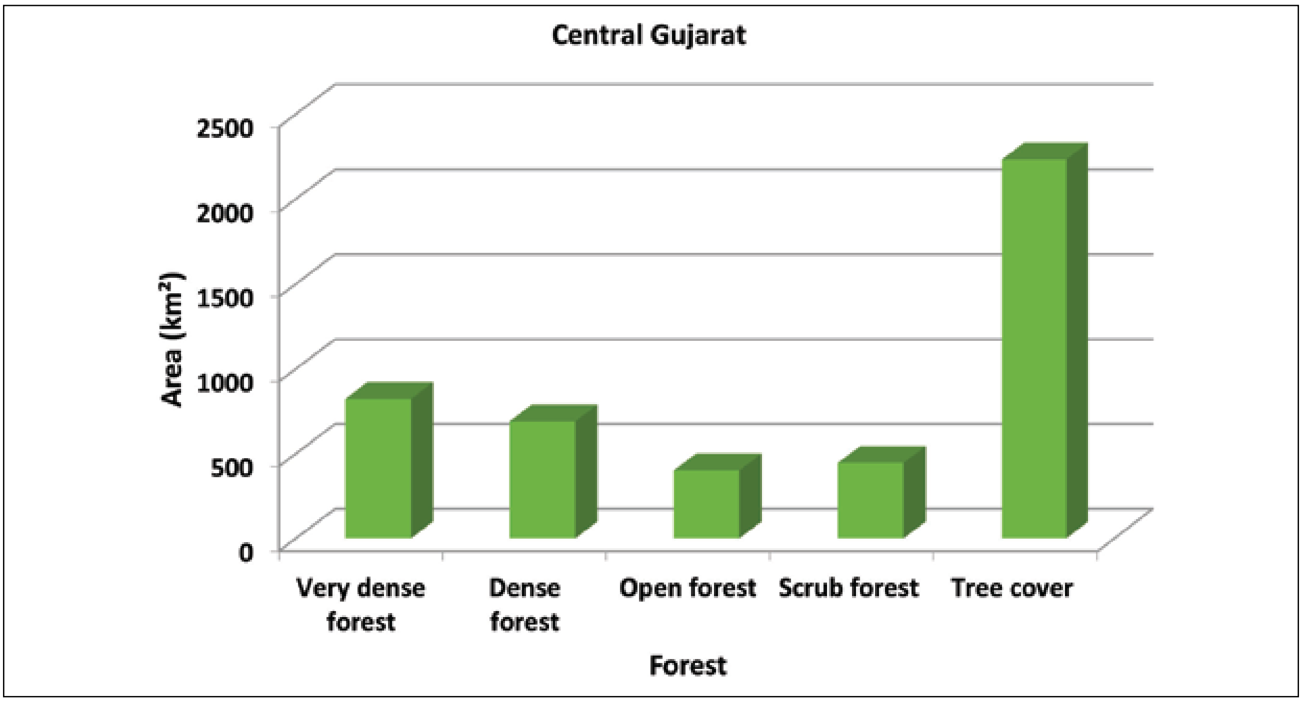

Figure 3.31: Forest Resources of Central Gujarat

Central Gujarat: Central Gujarat contains 823 km^2 of very dense forest, 690 km^2 of dense forest, 401 km^2 of open forest, 445 km^2 of scrub forest and 2232 km^2 of tree cover. Narmada district has 801 km^2 of area falls under forest resources. Other major districts of forest resources are Chhotaudepur, Dahod, and Panchmahal.

North Gujarat: North Gujarat contains 725 km^2 of very dense forest, 575 km^2 of dense forest, 595 km^2 of open forest, 610 km^2 of scrub forest and 2449 km^2 of tree cover. Banashkantha district has covers an area of 1820 km^2 under forest resources. Sabarkantha, Patan, and Mehsana are the major district of forest resources.

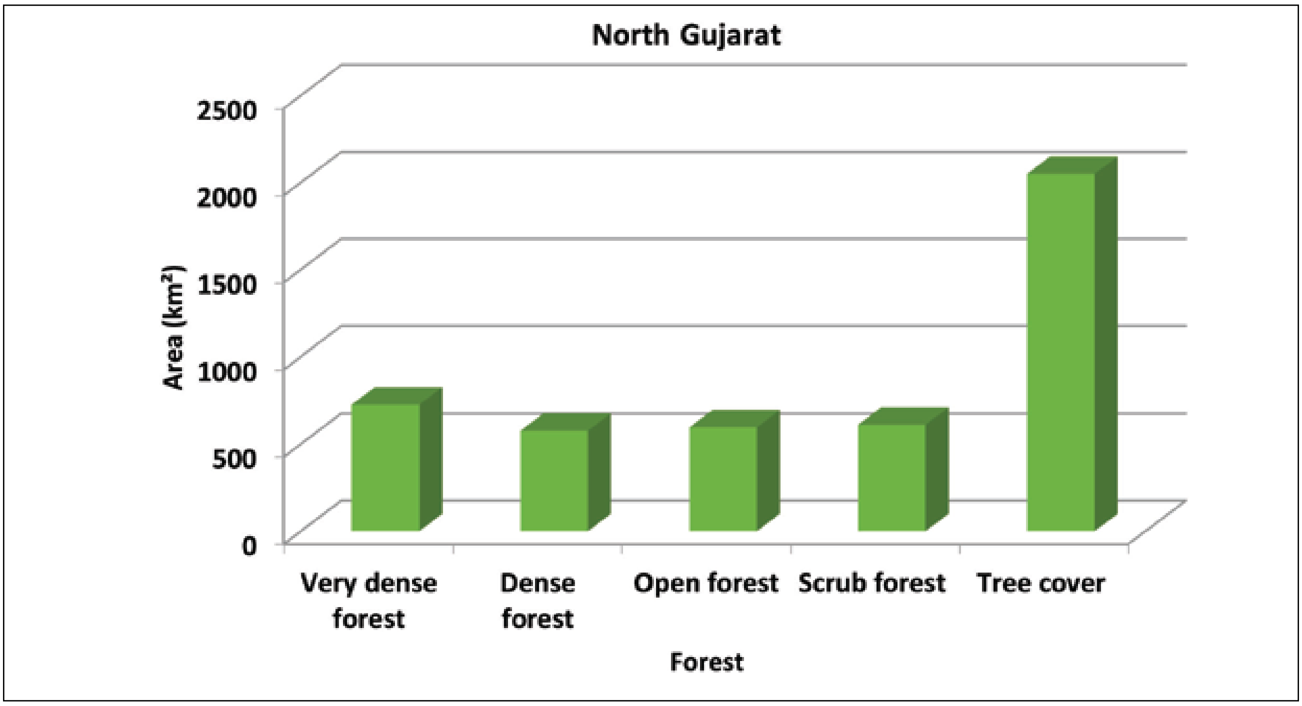

Figure 3.32: Forest Resources of North Gujarat

Saurashtra: Saurashtra contains 422 km^2 of very dense forest, 509 km^2 of dense forest, 1561 km^2 of open forest, 499 km^2 of scrub forest and 2644 km^2 of tree cover. Gir Somanath district has 1392 km^2 of area falls under forest resources. Other major districts of forest resources are Junagadh, and Amrelli.

South Gujarat: South Gujarat contains 570 km^2 of very dense forest, 440 km^2 of dense forest, 298 km^2 of open forest, 397 km^2 of scrub forest and 1806 km^2 of tree cover. The Dangs, Tapi, and Valsad are the major districts having forest resources in south Gujarat.

Kutch: Kutch contains 856 km^2 of very dense forest, 773 km^2 of dense forest, 1086 km^2 of open forest, 1584 km^2 of scrub forest, and 1728 km^2 of tree cover.

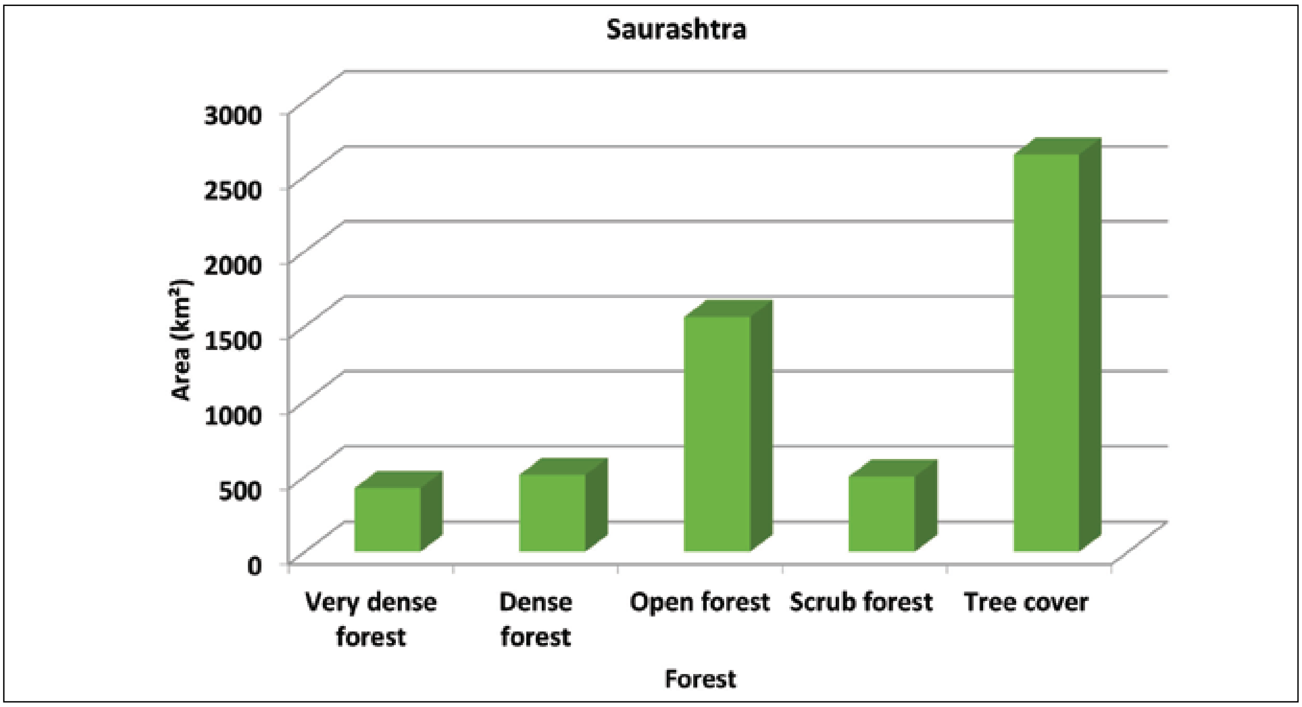

Figure 3.33: Forest Resources of Saurashtra

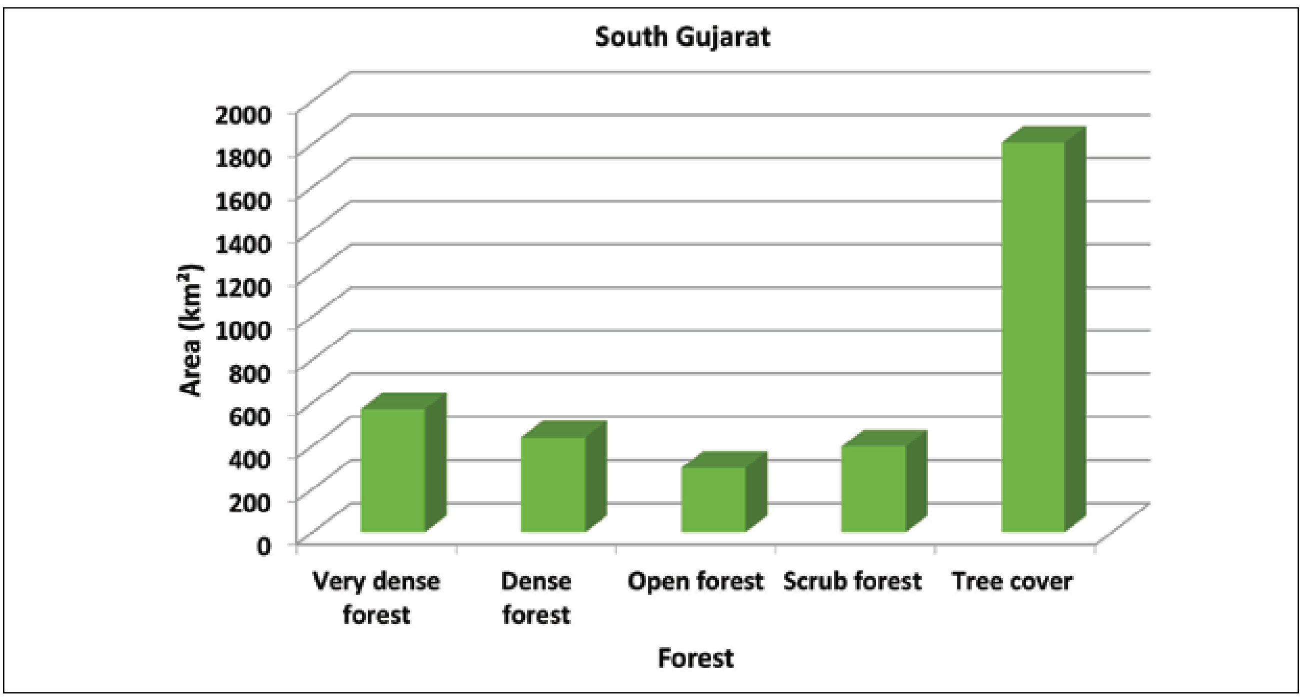

Figure 3.34: Forest Resources of South Gujarat

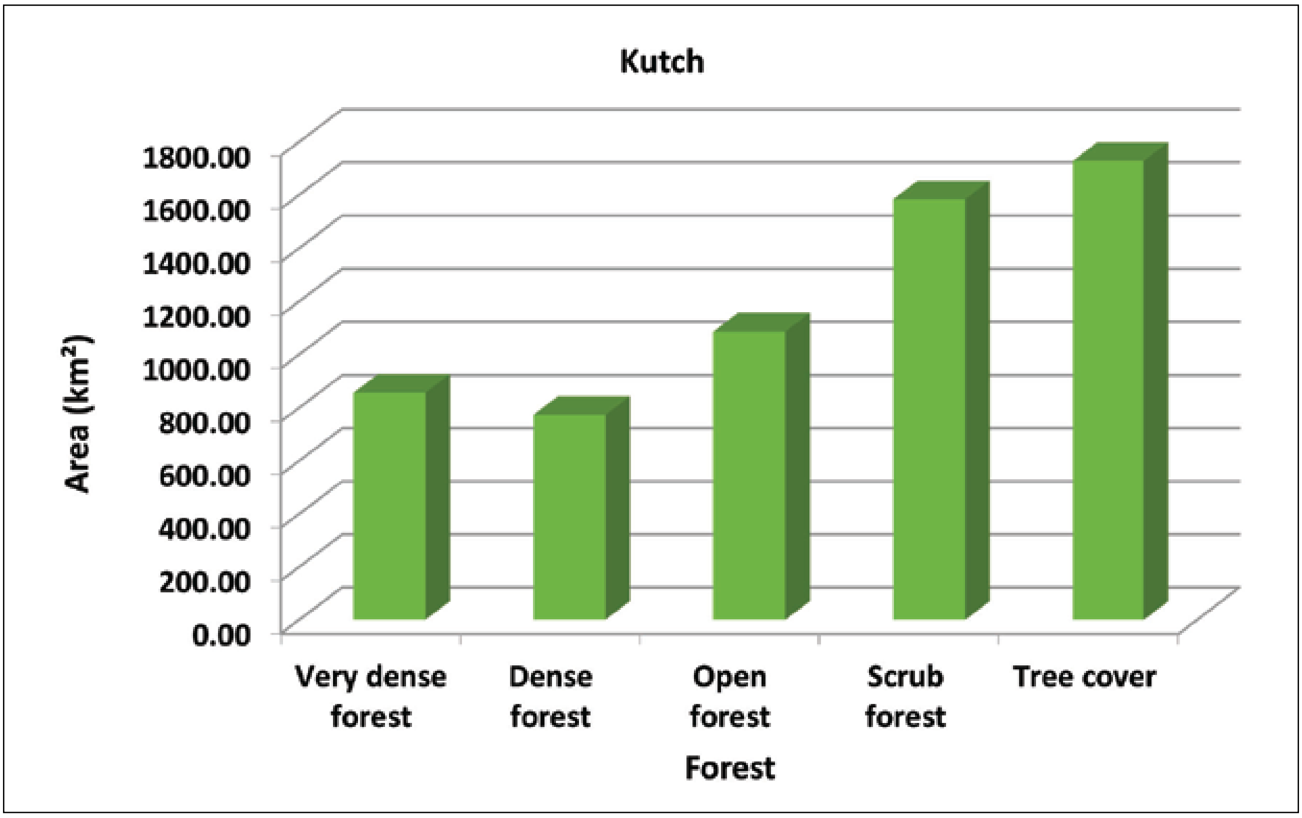

Figure 3.35: Forest Resources of Kutch

I. Mangroves

The mangroves are salt-tolerant plant communities rich in biodiversity, both terrestrial and aquatic. They offer a range of ecological services and play a key role in protecting coastal areas against erosion and rising

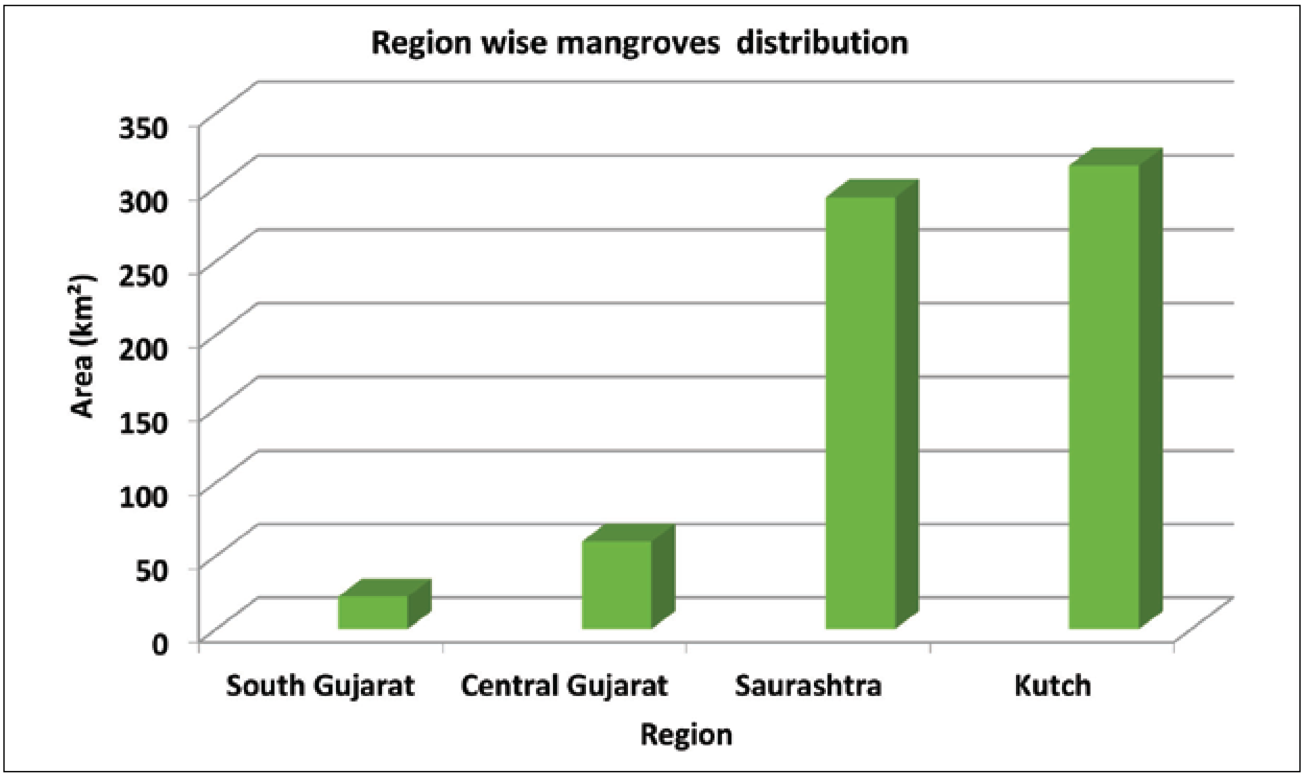

Figure 3.36: Region Wise Mangroves Distribution

sea levels and act as a shield against cyclones, ecological disasters, and as a protector of the coasts. They are also beneficial for the accumulation of the earth, as they trap particles of fine particles. The mangroves create a buffer zone between land and sea. They host a variety of life forms such as invertebrates, fish, amphibians, reptiles, birds, and mammals. The mangroves are also the main source of income for coastal communities such as fishermen. They are also a good source of wood, fuel, and fodder. They also act as a potential source for recreation and tourism.

The highest mangrove cover in Gujarat is found in Kutch district, which possess an area of 314 km^2 followed by Jamnagar (218 km^2) and Bharuch (47 km^2). The mangroves in various districts are under three main categories: very dense (canopy density of more than 70%), moderately dense (canopy density between 40 to 70%), and open mangrove (canopy density is between 10 to 40%). Mangroves, as said earlier, provide a variety of ecological services. There is, however, a lack of dense mangrove cover with most mangroves in the open forest category hence they provide lower ecosystem services. Efforts need to be scaled up to ensure a significant increase in dense mangrove cover for the ecosystem to be productive of natural resources and protect the coastal communities and infrastructure against mighty cyclones.

II. Waste Land

Waste land is a land that is deteriorating due to lack of proper management of water and soil or natural causes, and can be brought under vegetation cover with reasonable effort and is currently underutilized. According to the National Earth Atlas, uncultivated lands have been classified as follows: i) Gullied and/ or ravenous land; ii) Gullied and/ or ravinous land; iii) Land with dense Scrub; iv) Land with open scrub; v) Waterlogged and Marshy land-Permanent; vi) Waterlogged and Marshy-Seasonal land; vii) Land affected by salinity/ alkalinity; vii) Underutilised/ degraded notified forest land-Scrub dominated; ix) Underutilised/ degraded notified forest land-Agriculture; x) Degraded pastures/ grazing land; xi) Degraded land under plantation crops; xii) Sands-Coastal; xiii) Mining waste land; and xiv) Barren rocky area. The classification by the National Wasteland Atlas cannot be compared in two periods of time due to non-uniform classification systems.

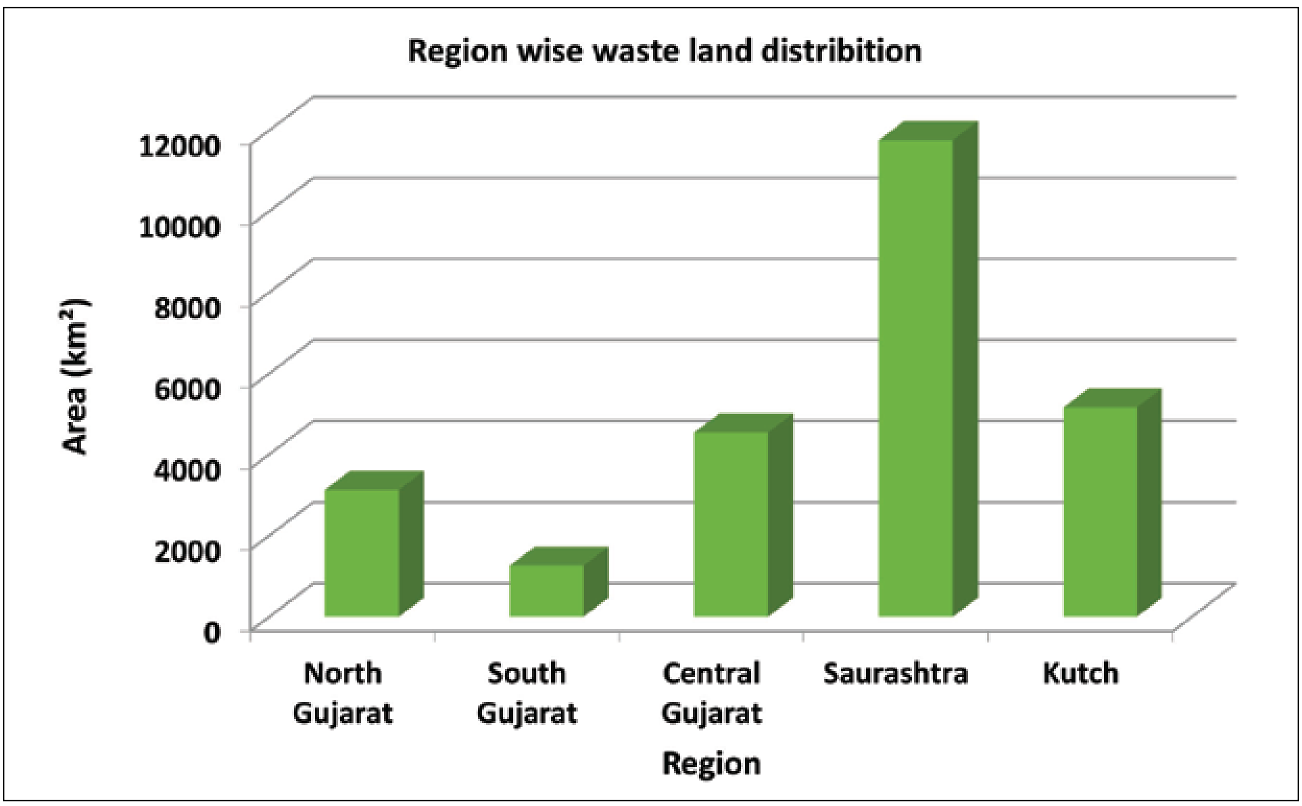

Figure 3.37: Region Wise Waste Land Distribution

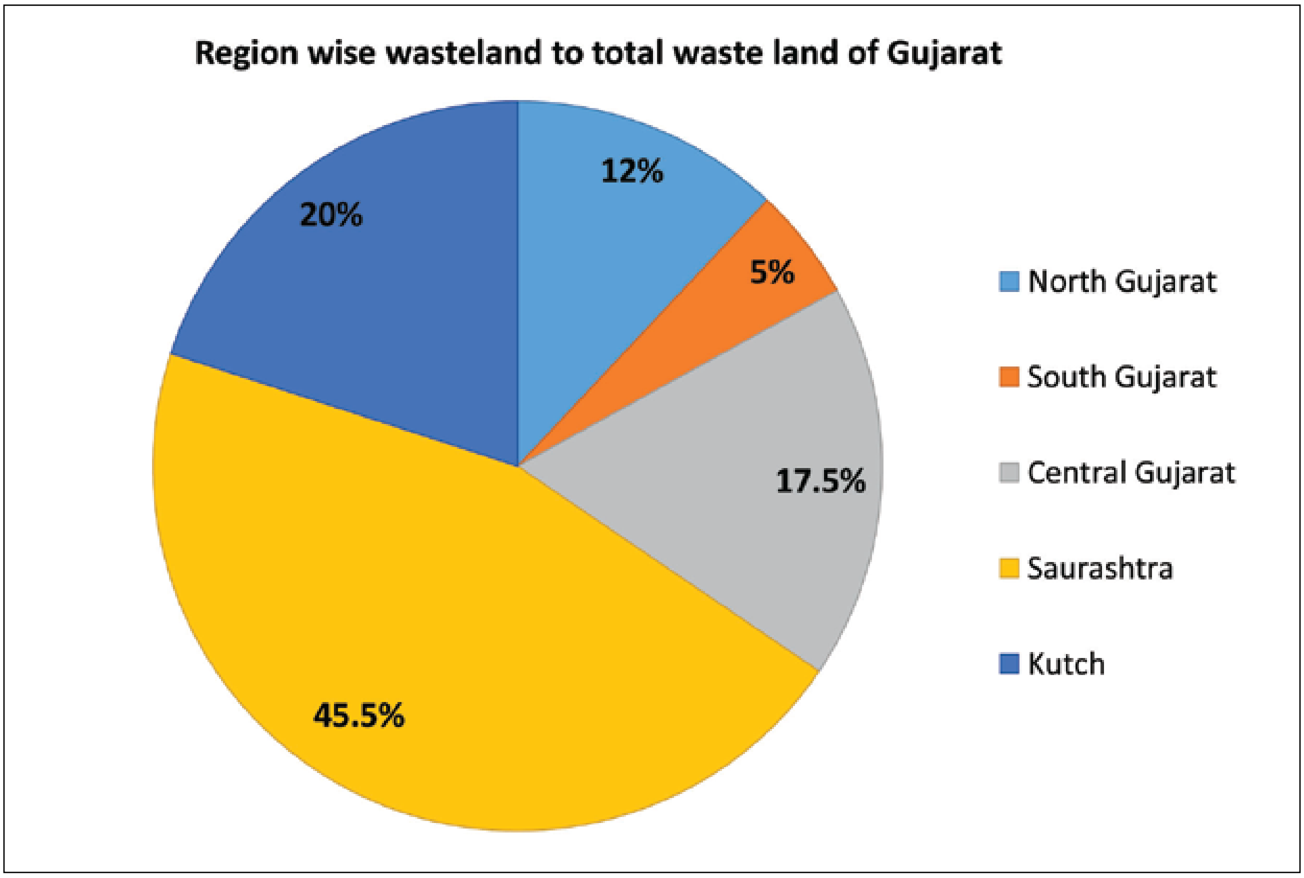

Figure 3.38: Region Wise Waste Land Distributions in Gujarat

Saurashtra has an area of 11,758 km^2 wasteland, which is 45% of its geographical area and highest among the entire region followed by Kutch (5,156 km^2), central Gujarat (4,537 km^2), north Gujarat (3,124 km^2), and south Gujarat (1,254 km^2). In Saurashtra, the Surendranagar district accounts for the largest wasteland area extending up to 2,806 km^2 in the region and second largest in the state after Kutch. In north Gujarat, most of the wastelands are concentrated in the Banaskantha (930 km^2) and Aravali (628 km^2) districts. Narmada (704 km^2) and Dahod (720 km^2) are the major district holding wasteland in ventral Gujarat. Most of the wastelands are concentrated in Surat (341 km^2) and Valsad (314 km^2) district in south Gujarat.

III. Wetlands

The wetlands are areas where water is the key factor in controlling the environment and allied flora and fauna. They occur where the water table is at or near the surface of the Earth. They are among the most productive environments in the world in terms of aquatic biodiversity. Many plant and animal species depend on wetlands for their survival. Wetlands have been described as "the kidneys of the landscape" due to the functions they perform during hydrological and chemical cycles and as "biological supermarkets" because of the extensive food webs and the rich biodiversity they support (Mitschand Gosselink 1993). The following figure shows the region-wise distribution of the wetland in Gujarat. Kutch has the highest proportion of wetlands (35.5%), followed by Saurashtra (28.5%), central Gujarat (26.2%), south Gujarat (6.3%) and north Gujarat. The distribution of the different types of wetlands in Gujarat is shown below.

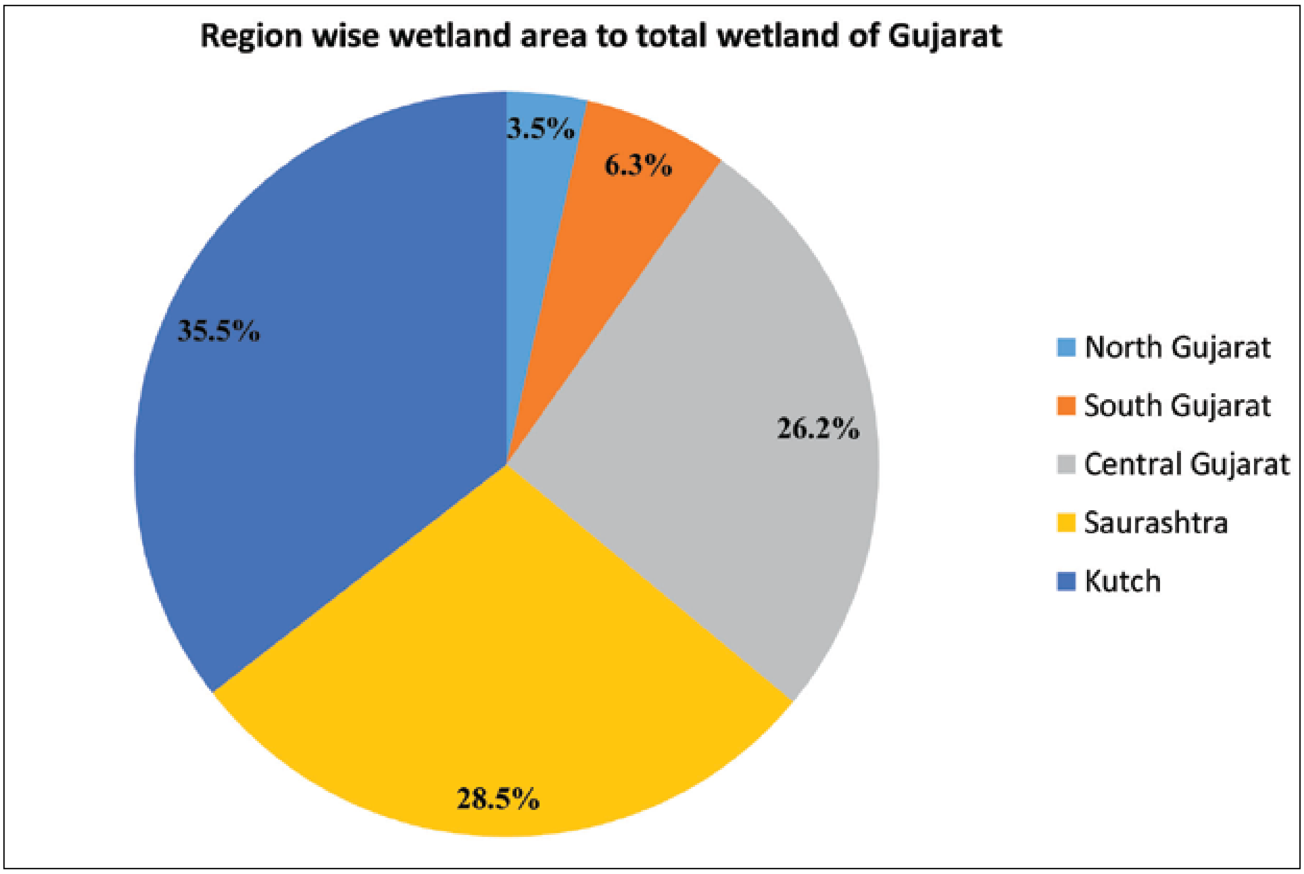

Figure 3.39: Region Wise Distribution of Wetland in Gujarat

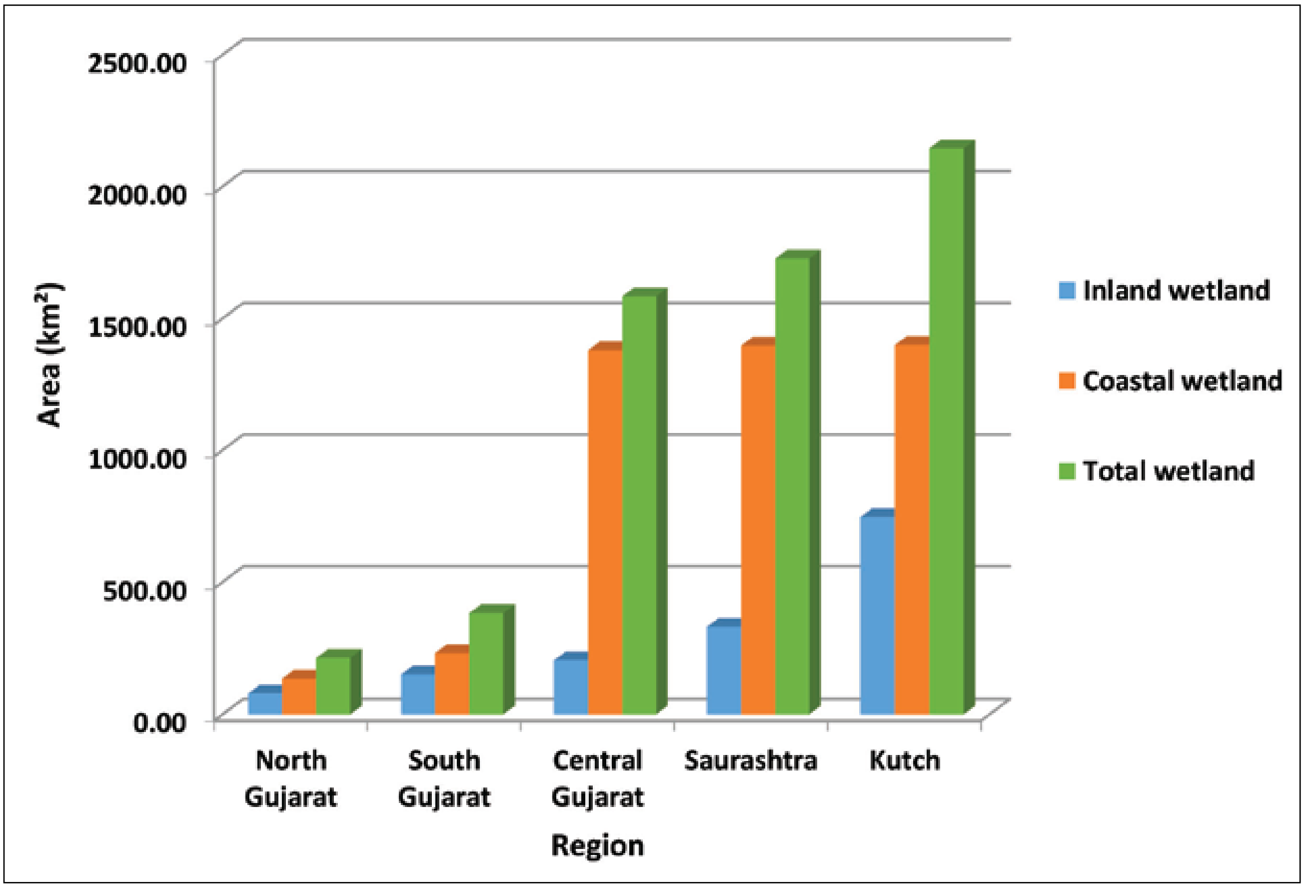

Figure 3.40: Distribution of Different Types of Wetlands in Gujarat

The wetland plants trap sediment suspended in water leading to improved water quality. In the riparian areas, its roots keep the soil together at the river banks, reducing soil erosion. Nitrogen and phosphorus enter groundwater; surface runoff and effluent removal and wetland vegetation uses some of these nutrients for growth. Bacteria that live in wetland soils absorb and break down nitrogen from runoff and leaching, which also helps to improve water quality. It is estimated that about 50% of the Earth's wetland area has disappeared over the last hundred years through conversion to industrial, agricultural and residential developments (Wetlands Report 2010). They are highly valued by local communities for their educational, scientific, aesthetic, spiritual and cultural value. People use the wetland soil for agriculture and extract wood and firewood from wetlands (Barbier et al. 1997). There are two main categories of wetlands, coastal wetlands (natural and artificial) and continental wetlands (natural and artificial).

a) **Inland Wetlands—**exist along rivers and streams (sometimes called riparian wetlands) and in some low-lying areas where precipitation saturates the soil as in bogs. The inland wetlands include lakes, ponds, water logged areas, rivers/streams, reservoirs, tanks, salt pans, etc. (Ornes 2012). Unlike the coastal wetlands, the inland wetlands always contain freshwater.

b) **Coastal Wetlands—**exist along the coastlines of mid to high latitude areas. They form estuaries and are prone to different levels of salinity and water levels because of tidal action. They include lagoons, creeks, sand/beach, inter-tidal mud flats, salt marshes, mangroves, coral reefs, salt pans, and aquaculture ponds (Briney 2012).

Kutch has an area of 2,145 km^2 of wetland, which consisted of 1,399 km^2 of inland wetland and 2144 km^2 of coastal wetlands. Saurashtra holds 1727 km^2 of wetlands, out of which 330 km^2 of inland wetland and 1,397 km^2 coastal wetlands. Central Gujarat has an area of 204 km^2 of inland wetland and 1379 km^2 coastal wetlands. South Gujarat holds an area of 382 km^2 of wetlands, which consisted of 151 km^2 of inland wetlands and 231 km^2 of coastal wetlands. North Gujarat has an area of 213 km^2 of wetlands.

3.2.4 Spatial Patterns of Water

The water that is central to human life is obvious that the change in the state of water has implications for human existence. It was along the banks of major river systems where human civilizations flourished. Many civilizations have disappeared due to droughts and/ or floods. In a sense, the consumption of water and the management of floods and droughts have existed since time immemorial. Modern development and lifestyles have the potential to change the pattern not only of water use but also of the very nature of water, and this is often due to demographic change, urbanization, industrialization, and water pollution.

The water resources in Gujarat are characterized by colossal regional variation in the context of wealth and scarcity. The state's water resources are concentrated mainly in its southern and central regions. The coastal wetlands are mainly concentrated around the Gulf of Khambat, Gulf of Kutch, and the two Ranns. The Saurashtra, Kutch, and northern Gujarat regions have limited surface and groundwater resources. Gujarat experiences an irregular distribution of precipitation ranging from 400 to 2000 mm. 71% of its total area is deficient in water. Only 29% of the south and the centre of Gujarat have surplus water. The inadequacy of surface water has led to massive over-exploitation of groundwater, which has been a source of concern for a long time. Although much of Saurashtra and southern Gujarat is safe, most of the northern region of Gujarat and some parts of southern Kutch are considered overexploited; the northern talukas of north Gujarat and some southern regions of Kutch are categorized as critical. Gujarat has a total of 50.1 billion cubic meters of water including surface water, groundwater, and storage capacity of reservoirs (excluding Sardar Sarovar). Surface water resources contribute 38.1 billion cubic meters, while groundwater contributes 12 billion cubic meters.

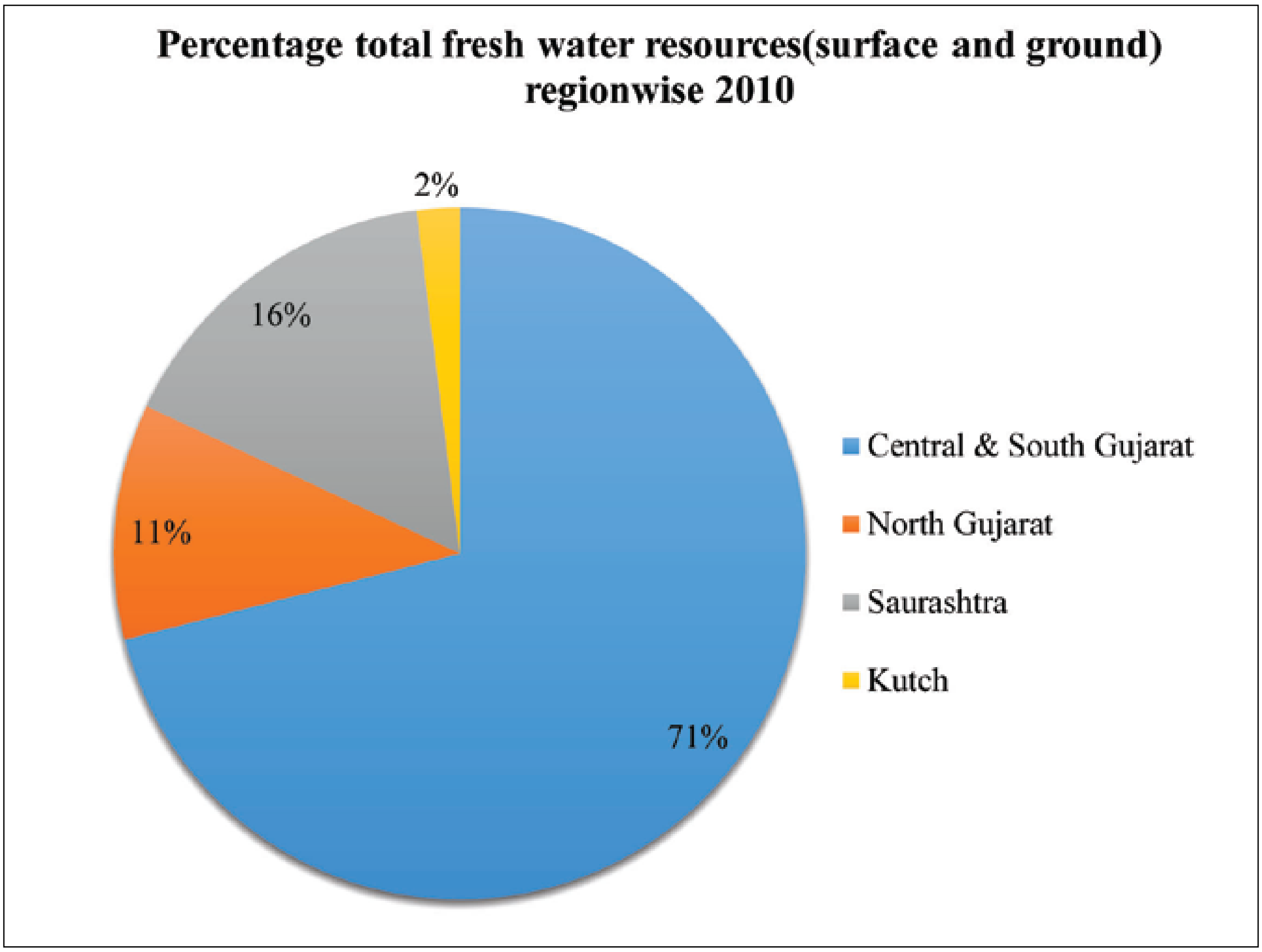

Figure 3.41: Total Fresh Water in Different Regions of Gujarat

Source: Based on data from NWRWS 2010

A. Water Resources of Gujarat

The water resources in Gujarat are characterized by many regional variations in terms of their wealth and scarcity. The state's water resources are concentrated mainly in the southern and central parts of the state. Saurashtra, Kutch, and the northern regions of Gujarat have limited surface and groundwater resources. Geological and geo-hydrological situations such as rocky terrain, deserts, and a 1600 km long coastline and water quality problems have added to the complexities of the water sector in Gujarat. The following table represents the detail of the water resources in Gujarat. The surface and underground water resources have dynamic and static facets with implications for the availability and quality of water in the state. Measuring the dynamic nature of water in terms of flows has been significant for most development needs. The static nature of the length and area of bodies of water has been vital for actions such as fishing, navigation, watershed development, etc.

It is known that Gujarat experiences irregular rains that vary regionally between 400 and 2000 mm over 196,024 km^2 of the total geographic area. 71% of its total area is deficient in water. 29% of the southern and central Gujarat areas have leftover water, which needs to be diverted to the sparse northern regions of Gujarat, Saurashtra, and Kutch. While surface water availability is only two percent of the country's total water availability, the population is 5% of the country's total population. Due to insufficient surface water, there is massive over-exploitation of groundwater.

Table 3.7: Details of Water Resource of Gujarat

Area	Total Water Quota (10^6 m^3)	Surface Water (10^6 m^3)	Underground Water (10^6 m^3)	Storage capacity of existing reservoirs (Except Sardar Sarovar) (10^6 m^3)	% of Water Resources	% of area
Central & South Gujarat	38105	31750	6355	10400	69	25
North Gujarat	6342	2100	4242	2100	11	20
Saurashtra	9723	3600	6123	2250	17	33
Kutch	1438	650	788	250	3	22
Total	55608	38100	17508	15000	100	100

Source: Narmada, water resource, water supply, and Kalpasar department

I. Surface Water

This section broadly covers the discussion on various facets of Gujarat's surface water resources. It mainly covers rainfall, availability of surface water and bodies of water, watershed potential, etc.

i. ***Precipitations:*** Many parts of the state are extremely susceptible to drought conditions due to the erratic pattern of precipitation in Gujarat. Saurashtra has a limited number of bodies of water with precipitations that normally vary between 400 and 800 mm. The average annual rainfall is approximately 775 mm with a standard deviation of 75.1 mm. The mainland of Gujarat, comprising the south, central and northern Gujarat, has a maximum water concentration due to rainfall normally ranging between 800 and 2000 mm. The rainfall trend for the monsoon season in five Gujarat regions is presented in figures over the last two decades. These figures suggest that rainfall in Gujarat has been reasonably high during the decade 2001-2010 compared to 1991-2000. Most parts of the state including the drier regions of Kutch, north Gujarat, and Saurashtra have benefited from this.

ii. ***Area under Surface Water Bodies:*** Gujarat surface water bodies constitute major and minor rivers, channels, reservoirs, tanks, lakes, ponds and bodies of brackish water. The trend has remained the same throughout this period with southern and central Gujarat covered by the largest area under the water masses followed by Saurashtra, northern Gujarat, and Kutch. A similar trend has been observed for the availability of fresh water in the four regions of Gujarat. South and central Gujarat have maximum availability at 71%, while Kutch has the minimum availability of two percent. In the Kutch district, no data were available for the Ranns. The remaining parts of Kutch and the districts of Banaskantha, Mehsana, Ahmedabad, Bhavnagar, Amreli, Junagadh, and The Dangs are covered by bodies of water in the range of 0 to 2% of their total area. On the other hand, districts that have 2 to 4% of their area under water bodies are Patan, Surendranagar, Rajkot, Jamnagar, Gandhinagar, Sabarkantha, Kheda, Anand, Vadodara, Dahod, Bharuch, Surat, Navsari, and Valsad. Only three districts of Panchmahals, Narmada, and Porbandar have 4 to 6% of their geographical area under bodies of water of several types. The Tapi district has the highest area under water bodies falling in the range of 8 to 10%.

iii. ***River Basin Potential:*** Gujarat river systems can be divided according to the regions of the state. Generally speaking, there are three main groups of rivers flowing in different directions. Narmada, Sabarmati and Mahi are the main rivers of central and northern Gujarat while the Mithi, Khari, Bhadar, Shetrunji, and Bhogavo rivers flow into the Saurashtra region. The main river systems of South Gujarat are formed by Narmada, Tapi, Purna, Ambika, Auranga, and Damanganga. Three rivers are perennial, namely, Narmada, Tapi, and Mahi. The natural runoff of these rivers has created enormous water potential in the state, however the inconsistent distribution of resources along with topographic factors has led to a partial use of this potential. To combat this problem, the State has presented several major and minor projects, which add to the surface storage capacity of these rivers.

Table 3.8: Per Capita Availability of Water in Major River Basins of Gujarat

River Basin	Average water Resources Potential (BCM)	Estimate Population in 2010 (Millions)	Per Capita availability of water in 2010 (cubic metres)
Mahi	11.2	14.64	765
Sabarmati	3.81	14.64	260
Narmada	45.64	20.50	2226
Tapi	14.88	20.64	721

Source: Water planning and project wing, central water commission (CWC)

iv. ***Surface Water Distribution:*** A total of 50.1 billion cubic meters of water, including surface water, groundwater, and reservoir storage capacity (excluding Sardar Sarovar), along with surface water resources, contribute to 38.1 billion cubic meters of water. The following figure represents the regional distribution of surface water resources in Gujarat. The centre and south of Gujarat have a maximum surface water availability of 31.75 billion cubic meters followed by Saurashtra, northern Gujarat, and Kutch with 3600, 2100, and 650 million cubic meters respectively (NWRWS 2010).

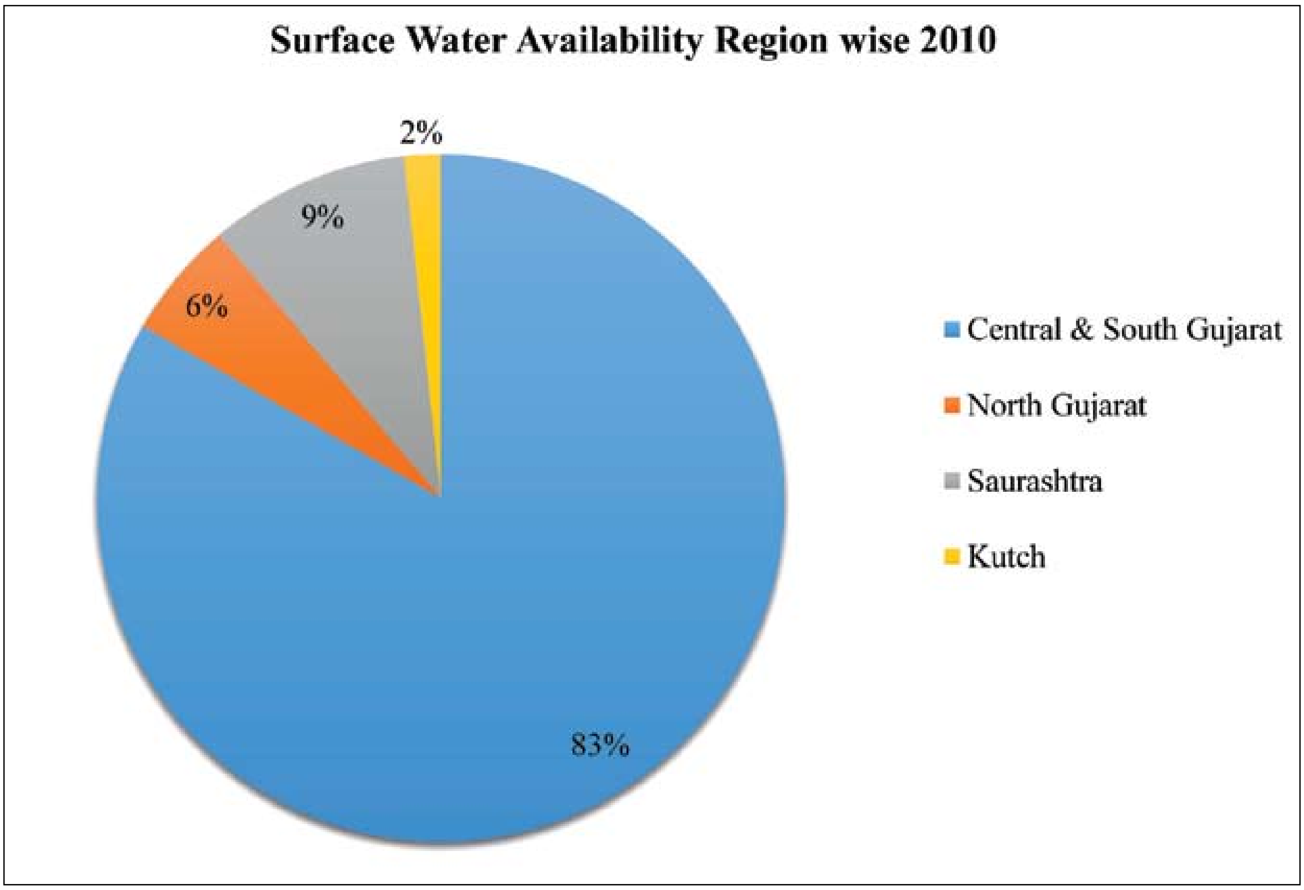

Figure 3.42: Region Wise Surface Water Availability in Gujarat

Source: NWRWS

II. Ground Water

The various terrain conditions have led to different groundwater situations in the state. Rock formations ranging from the age of Archaic to recent include gneisses, schists, phyllites, intrusive, medium grain to coarse grain, basalts, and recent alluviums. The high relief area in the eastern and northeastern part occupied by Archaean and Deccan Trap has steep slopes that allow high runoff and therefore have little potential for groundwater. The yield of the wells in these formations ranges between 5 and $10m^3.h^{-1}$. The yield in sandstones varies from 50 to $170m^3.h^{-1}$. The yield of wells touching quaternary alluvium in the Cambay basin ranges from 75 to $150m^3.h^{-1}$. There are five major aquifers in alluvial sediments of which the upper one has dried due to overexploitation.

The regional distribution of 12 billion cubic meters of groundwater resources in Gujarat is shown in the following figure. The standard for the availability of groundwater is not the same as for surface water. Saurashtra has a maximum groundwater availability of 4300 million cubic meters, followed by the south of Gujarat, the central Gujarat, the north Gujarat, and Kutch with 3950, 3300, and 450 million cubic meters respectively (NWRWS 2010).

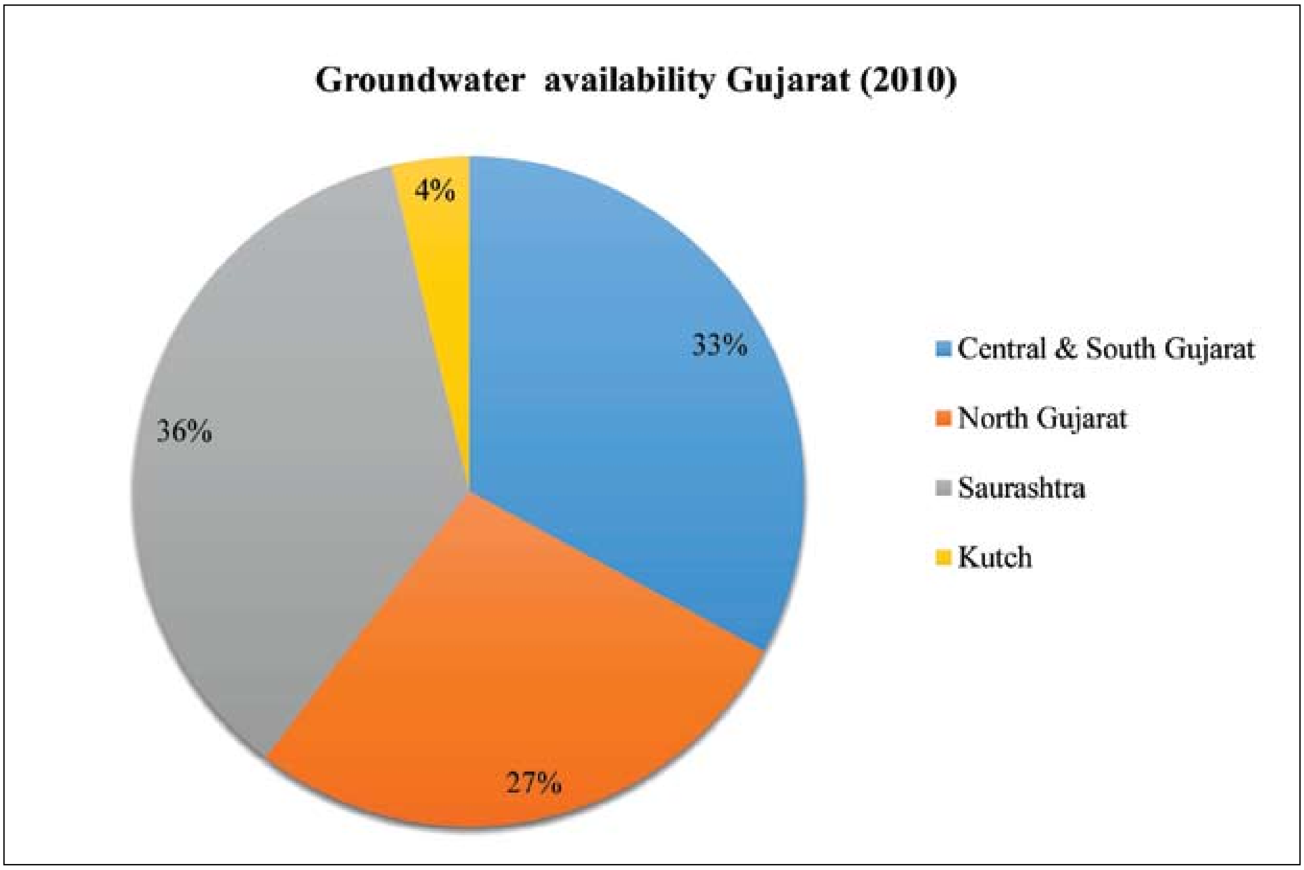

Figure 3.43: Ground Water Availability in Gujarat

Source: NWRWS

The development of irrigation in Saurashtra is mainly open well or deep well. These wells often dry in a couple of months at the end of the monsoon. If rainfall is insufficient, as is usually the case, these wells do not contain enough water to protect *Kharif* main crop of peanut and coarse grain-*bajra* and *jowar*. The following figure shows the percentage distribution of the different types of geo-hydrological conditions present in Gujarat. This could explain the uneven distribution of groundwater in different regions of Gujarat when studied in detail.

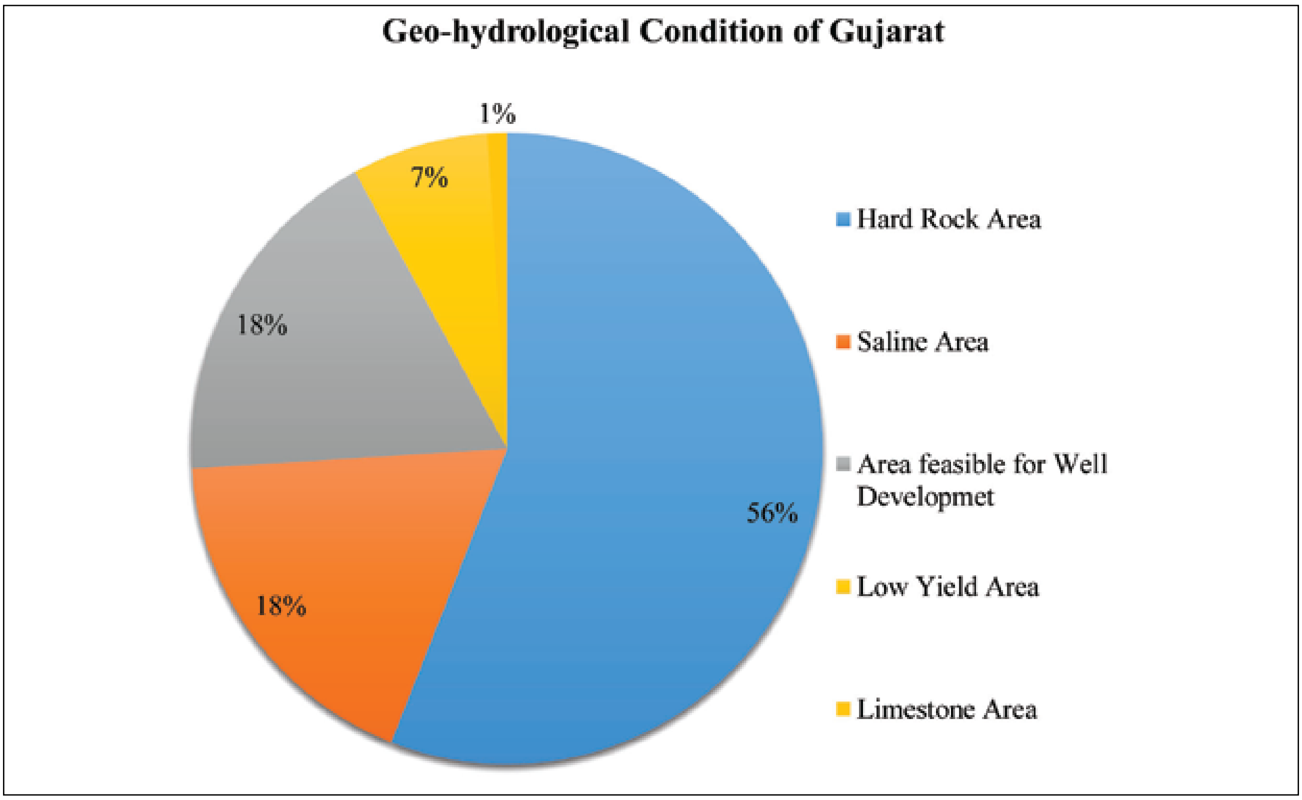

Figure 3.44: Geo-Hydrological Conditions in Gujarat

Courtesy: WASMO

Ground Water Fluctuation over the Last Two Decades

After looking closely at numbers 3.37 and 3.38, it is easy to see that the water table fell between May 1990 and May 2000 from 2 to 4 meters across the state except in parts of southern Gujarat and Rannof Kutch. Table 3.15 shows the regional fluctuation of groundwater during the last two decades, where, positive values indicate an increase, negative values indicate drop. It does not take into account a meter of rise/ fall. In northern Gujarat, about 34% of the area experiences more than 6 meters of groundwater fall during 1990-2010. The period under discussion witnessed a general downward trend of 0 to 2 meters of fall, as well as a rise of 0 to 2 meters in the groundwater table statewide. However, the extreme situation of the previous period still continues to plague the northern region of Gujarat. During the corresponding period, the Saurashtra region in general experienced an increase in its water table from 0 to 4 meters. This can be attributed to good rainfall in the last decade, as well as initiatives such as increasing surface water and groundwater recharge by building recharge structures such as large-scale control dams. Although, there is an increase in groundwater levels most of the state, northern Gujarat, and Kutch has seen a general decline, even during the decade 2000-2010.

Table 3.9: Groundwater Fluctuation over Last Two Decades

Regions	**1990–2000**	**2000–2010**
Kutch	215492	-725870
North Gujarat	-1323886	-83535
Central Gujarat	-554412	184861
South Gujarat	231169	142137
Saurashtra	-2601952	2742142
Gujarat	**-4033589**	**2259735**

Source: Based on spatially interpolated surface of data provided by Central Ground Water Board (CGWB) and Ground Water Resource Development Corporation (GWRDC)

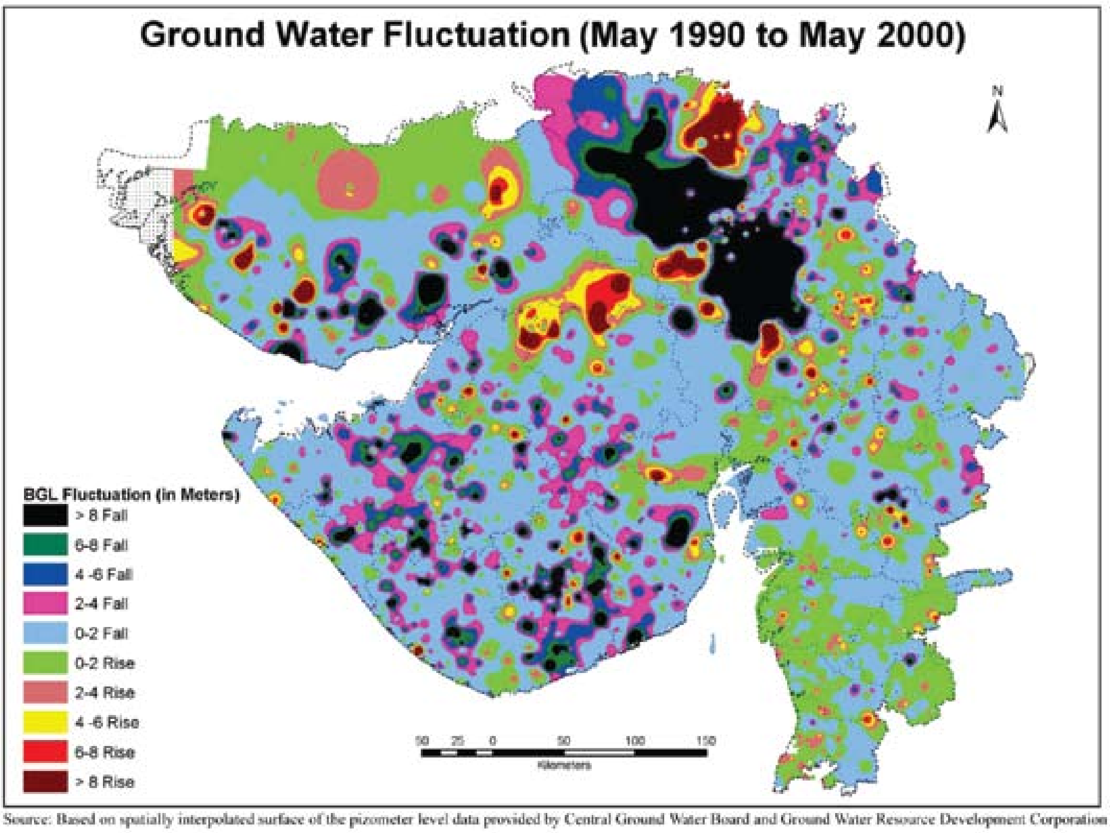

Figure 3.45: Dynamics of Ground Water (May 1990 to May 2000)

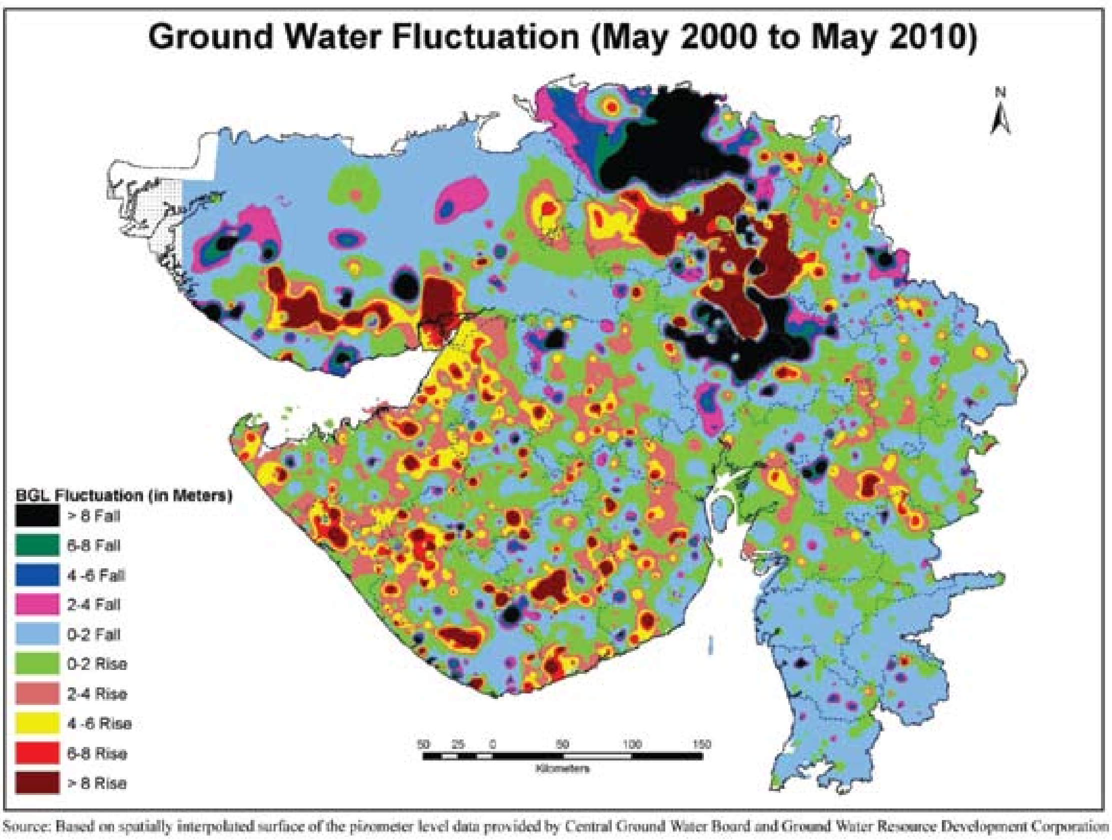

Figure 3.46: Ground Water Dynamics (May 2000 to May 2010)

III. Surface and Ground Water Use

The table below represent the uses of surface and groundwater in Gujarat. They also give an idea of the state's demand scenario.

Table 3.10: Surface and Ground Water use in Gujarat

Details	Surface water	Ground water	Total
Percentage of domestic water requirements met from	18	82	100
Percentage of industrial water requirements met from	35	65	100
Storage available for irrigation (80%) (Assumed) (MCM)	21,988	9,200	26,956

Courtesy: Parthasarathy and Dholakia 2011

B. Water Demand of Gujarat

The state of Gujarat is one of the first corridors in the country's economic development and agricultural growth. The state has also been awarded with the longest coast in comparison with the other states of India. Acclaimed as the microcosm of the Indian environment, it poses a greater challenge not only to water users, but also to state water managers. Along with other pressures, heavy industrialization puts pressure on both quantity and water quality, urging greater attention from the planners and managers responsible for water governance in Gujarat.

I. Demographic Pressures

Population growth contributes to environmental degradation in many ways. But it would be imprudent to accept such an argument without a proper perspective on how it contributes to the negative impact on the environment in general and on water in particular. Demographic influences are one of many factors that affect and create pressures on water resources. In this context, it would be interesting to analyze the demographic change in Gujarat and its implications for the state's water resources. According to the latest census (2011), the total population of Gujarat constitutes almost five (4.99%) of the total population of India. Gujarat achieved a total population growth of 19.17% in the recently concluded decade of 2001-2011.

Table 3.11: Decadal Demographic Change in Gujarat (2001–2011) (in Millions)

Year	Male	Female	Total
1991	21.36	19.95	41.31
2001	26.39	24.29	50.67
2011	31.48	28.9	60.38

Source: Census of India

II. Industrialisation

Gujarat being a major industrialized state of India has been at the forefront in terms of industrial coverage. The state has a large number of industrial estates already under the GIDC and with the establishment of Special Economic Zones (SEZs) and Special Investment Regions (SIRs), a much larger component of the state's economy and geographic area, found in industrial and allied activities. Almost 62% of the state's geographical area is under the influence of the Delhi Mumbai Industrial Corridor (DMIC) covering 18 of the 27 districts in its area of influence. SEZs have been allocated in different stages; have an area of 20761 hectares, while the SIR cover 373,100 hectares. These are huge areas allocated to streamline economic growth in the state and obviously need easy access to good quality water to achieve the expected growth targets, both economically and health.

III. Competing Demands and Resultant Conflict of Interest Among Stakeholders

Growing growth rates and increasing water demands from urban centers, industrial centers and business parks can lead to a cross-sectoral conflict of interests with respect to water. During the 1990s, there were several cases in which voices of protest arose when water intended for a specific sector was reassigned for different purposes. Irrigation regimes such as Dharoi in Sabarmati have had to change their irrigation priority to meet the drinking water needs of Ahmedabad. Thakkar (1999) had recorded incidences of farmers opposing the diversion of the waters of the Sabarmati River to the city of Ahmedabad. A similar situation arose in the arid Saurashtra region of Gujarat, where reservoir water was diverted to urban irrigation.

IV. Increasing Water Demands Due to Agriculture Growth

Agriculture is assumed to be the largest user of water accounting for almost 70% of total demand, although these patterns vary from state to state and from country to country depending on their level of development, their climate and population size. Given the spectacular agricultural growth (9-10%) observed by Gujarat during the last decade, it would be worth analyzing how the cultivated area in general has changed, thus creating an increased demand for irrigation water. High agricultural growth also leads to a greater need for water for irrigation. In addition, if the use of pesticides and fertilizers is not controlled, it can contaminate the water. Below the table shows details of the agricultural area included under irrigation in Gujarat.

Table 3.12: Details of Irrigated Area of Gujarat

Details	Area (*00000 hectare)
Total geographical area	196
Area under cultivation	125
Irrigation area covered by surface water	18
Irrigation area covered by ground water	20
Area under *Sardar Sarovar Yojna*	18
Area benefitted by *Sujalam Suflam* Project and check dams	9
Area dependent on rainfall	60

Source: Narmada, water resource, water supply, and *Kalpasar* department

C. Government Responses for Water Scarcity Mitigations

The main water scarcity mitigation tools that modified the Gujarat water availability scenario since 2000 relate to the progress made with respect to the completion of the *Sardar Sarovar* dam on the Narmada River, *Sujalam Sufalam Yojana*, the diffusion of the Narmada canals, the interconnection of rivers, the filling of ponds, reservoirs and rivers by the Narmada waters and the construction of control dams and other structures of water collection along the rivers.

I. Check-Dam Movement

A water recharge movement has been seen in Saurashtra as a response to growing water shortages until the late 1990s. A number of socio-technical actions have been carried out within the framework of the movement, led mainly by local farmers, community leaders, and NGOs with the financial support of a potable migratory population in the area, particularly settlers in cities such as Surat, Ahmedabad, etc. As a result, this region has experienced a sharp increase in agriculture-based incomes, mainly through increased availability of groundwater, along with improved quality of life (Mudrakartha 2008). Because of the enabling role played by the state government in recognizing the value of such initiatives and drawing lessons from their results, while the introduction of proactive policies and technical expertise along with the financial support provided by various government agencies, Gujarat has been a witness to a nearby mass in connection with the construction of control dams, especially since 2000. The figure below shows the increase in the number of Gujarat control dams as a result of the movement that could not have been possible without the participation of the people and the government after 2000. Before 2000 led to acute shortages of drinking water in the Saurashtra region, Kutch, and northern Gujarat. Of the total accumulated capacity of 2200 MCM of water in 113 dams in the Saurashtra region, only 140 million square meters of water had been accumulated in 2000. This accumulated water was reserved exclusively for the supply of drinking water. Thanks to the good rain witnessed during the recently concluded decade, this situation has not been repeated. Gujarat had been implementing water conservation works before including the construction of control dams. The work was done before by bidding or by department.

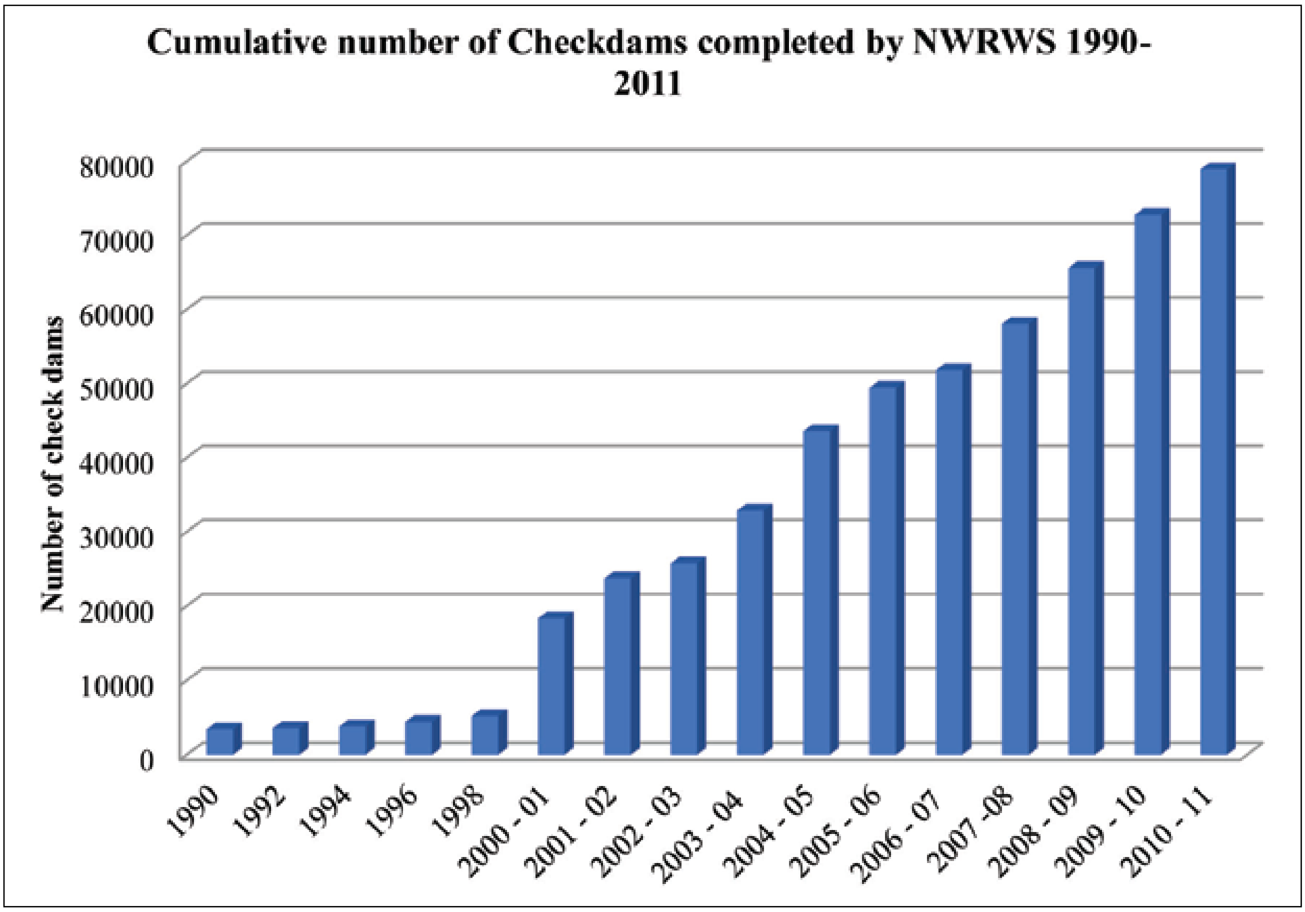

Figure 3.47: Check Dam Constructions in Gujarat (1990–2011)

Courtesy: SWDC

II. Sardar Patel Participatory Water Conservation Project (SPPWCP)

The state government became aware of the intense awakening fostering among residents of the state's sparse water regions. This mass consciousness, complemented by the efforts of social activists and NGOs, led to the construction of several water conservation projects in these regions. Voluntary contributions from people supported activities in the context of rainwater harvesting to recharge groundwater. This was done with a view to satisfying drinking water as well as agricultural needs. Taking the example of these experiences, the government launched the SPPWCP that has seen four stages of implementation so far.

The first phase of the project, which lasted from 17/01/2000 to 20/02/2001, elicited an enthusiastic response from the Saurashtra region. The first monsoon itself witnessed overflows in more than 7,000 control dams. This led farmers to benefit immensely from the increase in agricultural production. The second phase marked 21/06/2001 with suggestions for improvement ended on 31/03/2003. The third phase (from 01/04/2003 to 03/31/05) was observed for the 40% contribution it received from the beneficiary farmers. Farmers in tribal areas accounted for 20% of the total cost of the check dam. The fourth phase began on 01/04/2005 with a government contribution of 80% and the village contribution of 20% (80:20) statewide. The participation of the population allowed the construction of 67929 control dams in stages I to IV of the SPPWC. The above figure summarizes the comparison of dam verification constructions taken by six different government departments in Gujarat during two different years 2007 and 2011.

III. Sardar Sarovar Project

The Narmada is the fifth largest river in India and the largest river in Gujarat. It crosses Madhya Pradesh, Maharashtra, and Gujarat to meet the Gulf of Cambay. The idea of SSP was concreted as the construction of a dam on the Narmada in 1946-1947. Sardar Vallabhabhai Patel first conceived this idea as the underlying justification for the optimal utilization of river water for the well-being of the nation. The Sardar Sarovar Project, a multi-purpose project, was formulated by GoG in accordance with the mandates contained in the Narmada Water Disputes Tribunal Award (NWDT). The SSP has been a very controversial project in the history of Independent India. It has been at the center of Gujarat's water security planning and overall development.

Table 3.13: Salient Features of Sardar Sarovar Project

Location	
State	Gujarat
District	Narmada
Taluka	Rajpipla (Nandod)
River	Narmada
Hydrology	
Watershed area above dam site	88,000 km^2
Designed flood	87,000 cumecs
Full Reservoir Level (FRL)	138.68 m (455 ft)
Reservoir	
Full Reservoir Level (FWL)	138.68 m (455 ft)
Maximum Water Level (MWL	140.21 m (460 ft)
Gross Storage Capacity	0.95 Million ha m
Dead Storage Capacity	0.37 Million ha m
Live Storage Capacity	0.58 Million ha m
Annual evaporation	0.06 Million ha m
Submergence at FRL	37533 ha
Dam	
Type	Concrete gravity
Length	1210.02 m
Maximum height	163 m
Canal System	
Narmada main canal in Gujarat	458 km
Narmada main canal in Rajasthan	74 km

Full supply level	91.45 m (300 ft)
Design discharge capacity in head reach	1133 cumecs
Design discharge capacity at Gujarat-Rajasthan Border	71 cumecs
Gross Command Area in Gujarat	34.268 lakh ha
Annual Irrigation	17.92 lakh ha
Canal Distribution System	
No. of branch canals	38
Length of distribution system network	66,000 km
Cultivable command area in Gujarat	18.45 lakh ha
No. of districts covered in Gujarat	12
No. of talukas covered in Gujarat	62
No. of villages covered in Gujarat	3393
Hydropower	
No. of power houses	2 (one surface and one underground)
Power shared among states	MP, Maharashtra and Gujarat (57:37:16)
Total number of units	11
Total installed capacity	1450 MW

Source: nvda.nic.in

The *Sardar Sarovar* Project (SSP), because of its large size and potential to positively transform the state's water scenario, can be considered as the most crucial response to water-related concerns in the state. The *Sardar Sarovar* dam together with other complementary measures have the capacity to transform the water sector into Gujarat. The project aims to provide important irrigation, hydropower, and potable water supplies to the states of Gujarat, Maharashtra, Rajasthan, and Madhya Pradesh. The table above shows the silent feature of the SSP.

IV. *Sujalam Sufalam* Canal Network (SSCN)

The *Sujalam Sufalam* Canal Network, adopted in 2004, provides for a plan to divert excess water from the Narmada canal to nine dams in northern Gujarat through a network of 100 km of pipelines. It also envisages the construction of unlined canals along 21 rivers north of Gujarat while being built around two lakhs farms under the food-for-work regime. The project is likely to benefit about 2.35 hectares of scarce water areas in northern Gujarat by recharging groundwater through dams and ponds in the area surrounding the channel passage.

Table 3.14: Salient Features of Sujalm Sufalam Project

Name of pipeline	Off taking point	Terminating point	Length (km)	Capacity of head (Cusecs)
Modhera - Dharoi	311 km of Narmada Main Canal (NMC)	Dharoi Dam	89.00	200
Khorsam - Saraswati	326.40 km of NMC	Saraswati Barrage	21.00	200
Jalundra to Sujlam Suflam Spreading Canal (SSSC)	218 km of NMC	136 km of SSSC	35.00	300

Adundra to SSSC	278 km of NMC	201 km of SSSC	28.00	300
Modhera to SSSC	311 km of NMC	217 km of SSSC	29.00	300
Khorsam to SSSC	326.40 km of NMC	236 km of SSSC	26.00	300

Source: Narmada water resources and water supply, and *kalpsar* department (NWRWS)

A report examining the technical implementation of the *Sujalam Sufalam* Project submitted to the State Department of Water Resources (SWRD) in June 2008 indicates that the mainly retained area as a channel beneficiary has been struggling with recurrent drought almost every three years due to a level very high coefficient of variation. Nine dams in the region were filled up to 30% capacity in the last 10 years. What does it mean that while the reservoirs reserved for drinking water existed, there was no water available for irrigation? In that sense, *Sujalam Sufalam* canal network, once completed, will address the irrigation needs of drought-prone areas. The highlights of the *Sujalam Suflam* Project are summarized in the table above.

Knowledge Domain

The relatively poor and unevenly distributed natural resources of Gujarat pose enormous management challenges in containing environmental degradation, while ensuring the momentum for development. All stakeholders in the state must have a global understanding of the development and balance of the natural resources necessary for their sustained economic and social growth. The preparation of the report on the state of the environment can be considered a response to this effect. The Water State is one of the reports produced as part of this exercise.

The Department of Climate Change is also an initiative in the right direction as the water-climate dynamics needs to be properly understood to ensure healthy and sustainable water management in the state. This is all the more important as Gujarat has traditionally been a state affected by frequent droughts. Its long coastline (1600 km) only exacerbates the problem, as rising sea levels aided by severe depletion of groundwater only serve to worsen existing salinity problems in coastal Gujarat. The World Bank supported the Integrated Coastal Zone Management Project (ICZMP), which identifies multidisciplinary interventions to halt further coastal degradation, including salinity entry, is an important effort for a healthy and sustainable development of the state coast. It is important to have an idea of the relationship between climate and water, while relevant research studies should help us develop an understanding of phenomena that allow adequate responses to address issues related to climate change, industrial development, and water.

CHAPTER-4

Crop Suitability and Agro-Ecologically Attainable Yield

4.1 Agro-Climatic Analysis

4.1.1 Annual Actual Evapotranspiration

Presently annual actual evapotranspiration is highest in the region of south Gujarat, Saurashtra, and southern region of central Gujarat ranging between 500 and 700. In contrary to this, Kutch is observed to have lowest annual actual evapotranspiration between 282 and 410. The 30-year average for period 1971–1900, 1981–2000, and 1991–2010 shows a significant increase in annual actual evapotranspiration in different parts of Gujarat. In most of the Gujarat, 30 years average annual actual evapotranspiration for period 1981–2000 has increased by 0 to 50 mm from the base period of 1971–2000. However, southern Kutch and a small part of western Saurashtra observed a decline in average annual actual evapotranspiration by 0 to 50. The average annual actual evapotranspiration for period 1981–2010 was increased by 0 to 50 in Kutch, south Gujarat, and Saurashtra. Though, central Gujarat and north Gujarat observed a decline in annual actual evapotranspiration by 0 to 50.

Projection using Ensamble Mean of all Models across RCPs

Projection using different RCPs for period 2020s (2011–2040) mostly indicate a decline in annual actual evapotranspiration in most of the Gujarat. The maximum decline may be observed in southern part of south Gujarat ranging between 150 and 200. Though the small portion of western Kutch may observe an increase in annual actual evapotranspiration by 50 mm. Prediction for the 2050s (2041–2070) based on HadGEM2-ES RCP4.5 shows entire Gujarat can have less than 400 mm of actual evapotranspiration. Kutch region is showing significantly > 200 mm of actual evapotranspiration whereas NorESM1 model for RCP4.5 shows 650 mm of actual evapotranspiration decline in north regions. HadGEM2-ES RCP4.5 shows higher actual evapotranspiration in the 2080s than 2050s whereas NorESM1 model for RCP4.5 showing contradicting result as declining actual evapotranspiration for 2080s.The southern part of Gujarat shows a high decrease (150 to 250 mm) in actual evapotranspiration, whereas, northern regions show high increase (50 to 100 mm) in similar pattern during the 2050s and 2080s.

The table below shows annual mean actual evapotranspiration of reference soil and reference crop (mm) for reference climate (CRUTS32: 1981–2010); and E-Mean: ENSEMBLE mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN- ESM2M) is taken into consideration to avoid extreme variation in the result.

Table 4.1: Annual Mean Actual Evapotranspiration of Reference Soil and Reference Crop (mm) for Reference Climate (1981–2010) and ETa Change for Future Climate Scenarios 2050s (2041–2070) and 2080S (2071–2100)

Regions	Reference Climate 1981-2010	ETa change in 2050s (%)				ETa change in 2080s (%)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	429	-1	1	-4	7	2	6	5	7
North	530	2	3	4	7	5	6	7	5
Central	611	-4	-1	2	-1	-2	0	2	2
Saurashtra	557	-4	-2	-5	1	-4	-1	-1	1
South	669	-3	-2	1	-2	0	-1	1	2
Gujarat	586	-3	-1	0	1	-1	0	2	2

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ENSEMBLE mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M,) is taken into consideration to avoid extreme variation in the result.

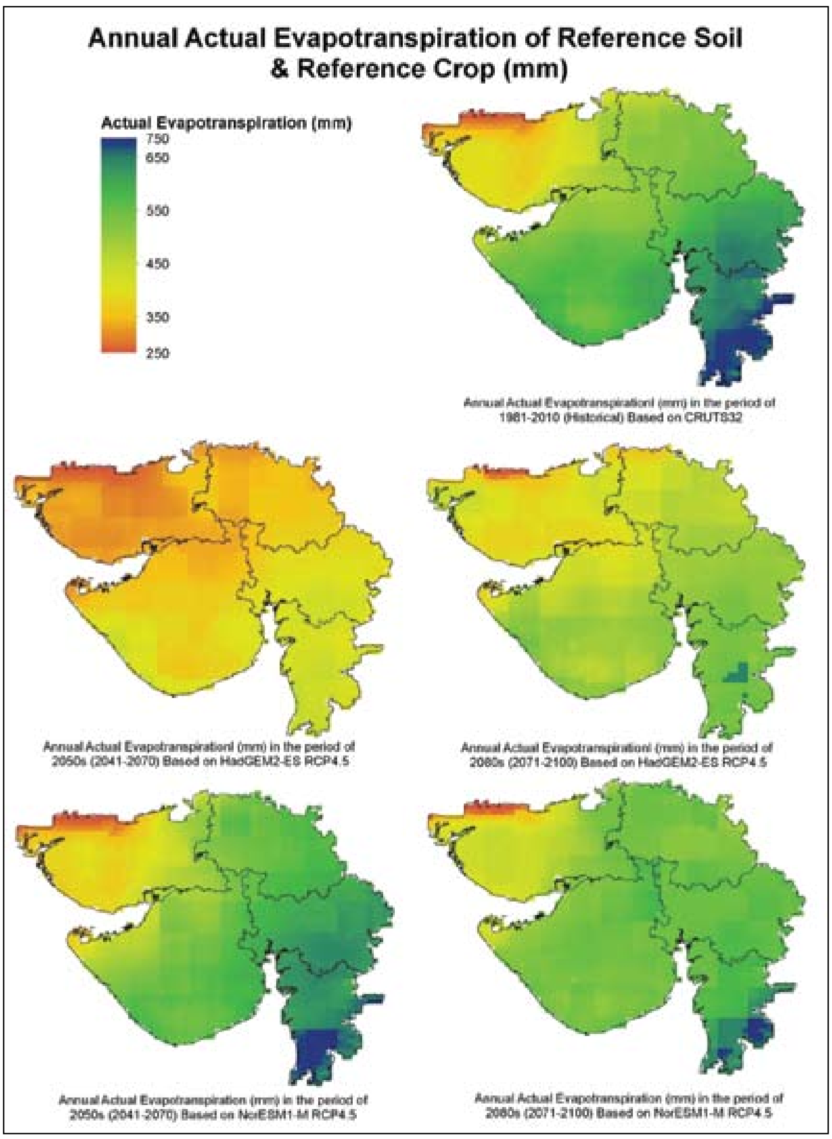

Figure 4.1: Actual Evapotranspiration of Reference Soil and Reference Crop for Gujarat

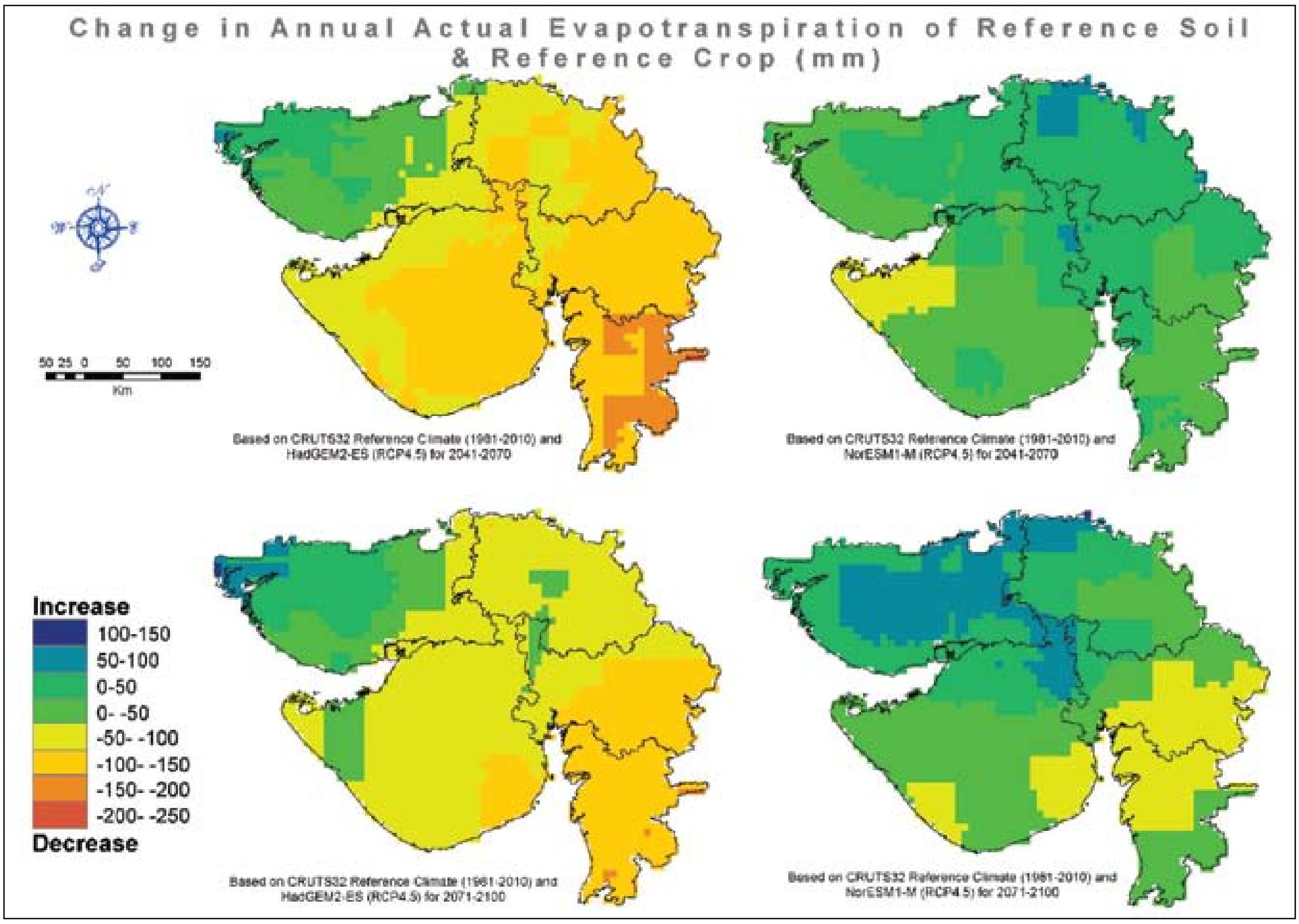

Figure 4.2: Change in Actual Evapotranspiration of Reference Soil and Reference Crop for Gujarat

4.1.2 Reference Evapotranspiration Deficit (mm)

In the current climatic condition in Gujarat, reference evapotranspiration deficit varies between 1065 to 2002 mm with a maximum and minimum deficit in the region of Kutch and southern part of the south Gujarat respectively. Saurashtra, central Gujarat, south Gujarat, and eastern part of north Gujarat lies in lower deficit region ranging between 1065 to 1500 mm. Reference climate averages are increasing by 1 to 100 mm in most of the Gujarat.

Projection using Ensamble Mean of all Models across RCPs

Projection across different RCPs suggests that Kutch experience highest reference evapotranspiration deficit during 2020s, 2050s, and 2080s. Evapotranspiration deficit in Kutch may reach to more than 1800 mm in the 2050s and 2080s; however, southern Saurashtra and south Gujarat regions may remain with the lowest reference evapotranspiration deficit (less than 1200 mm) in Gujarat. Comparing to current climatic conditions, HadGEM2-ES projection results also infer that most of the region may observe increase in reference evapotranspiration deficit by 100 to 200 mm and small parts of northern Kutch and north Gujarat may observe deficit by 1 to 50 mm, whereas, NorESM1-M RCP 5 Show 2050s and 2080s scenarios follow pattern of increase in reference evapotranspiration deficit by 1 to 100 mm and Kutch region shows decrease in reference evapotranspiration deficit 50 mm and more.

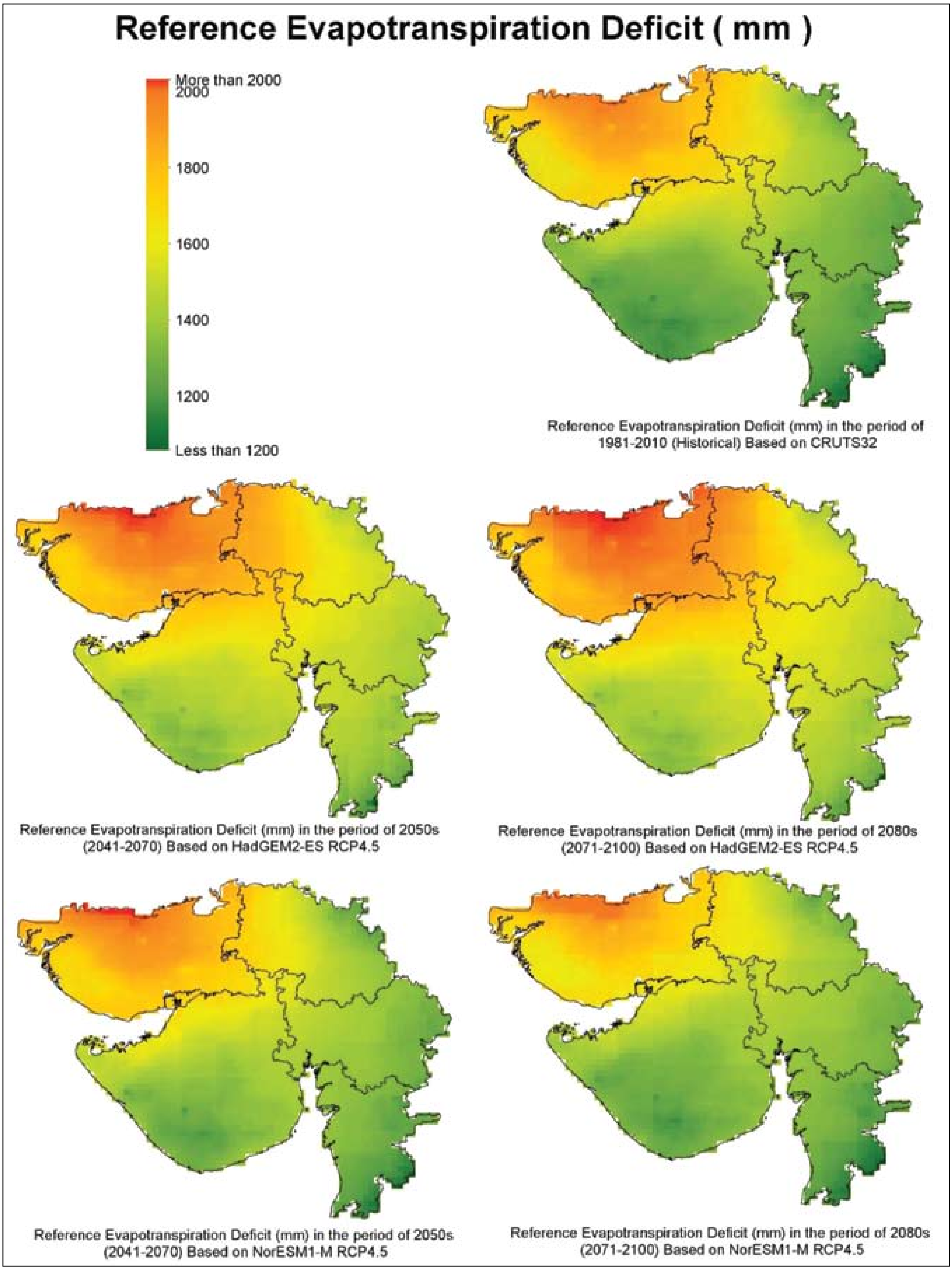

Figure 4.3: Reference Evapotranspiration Deficit for Gujarat

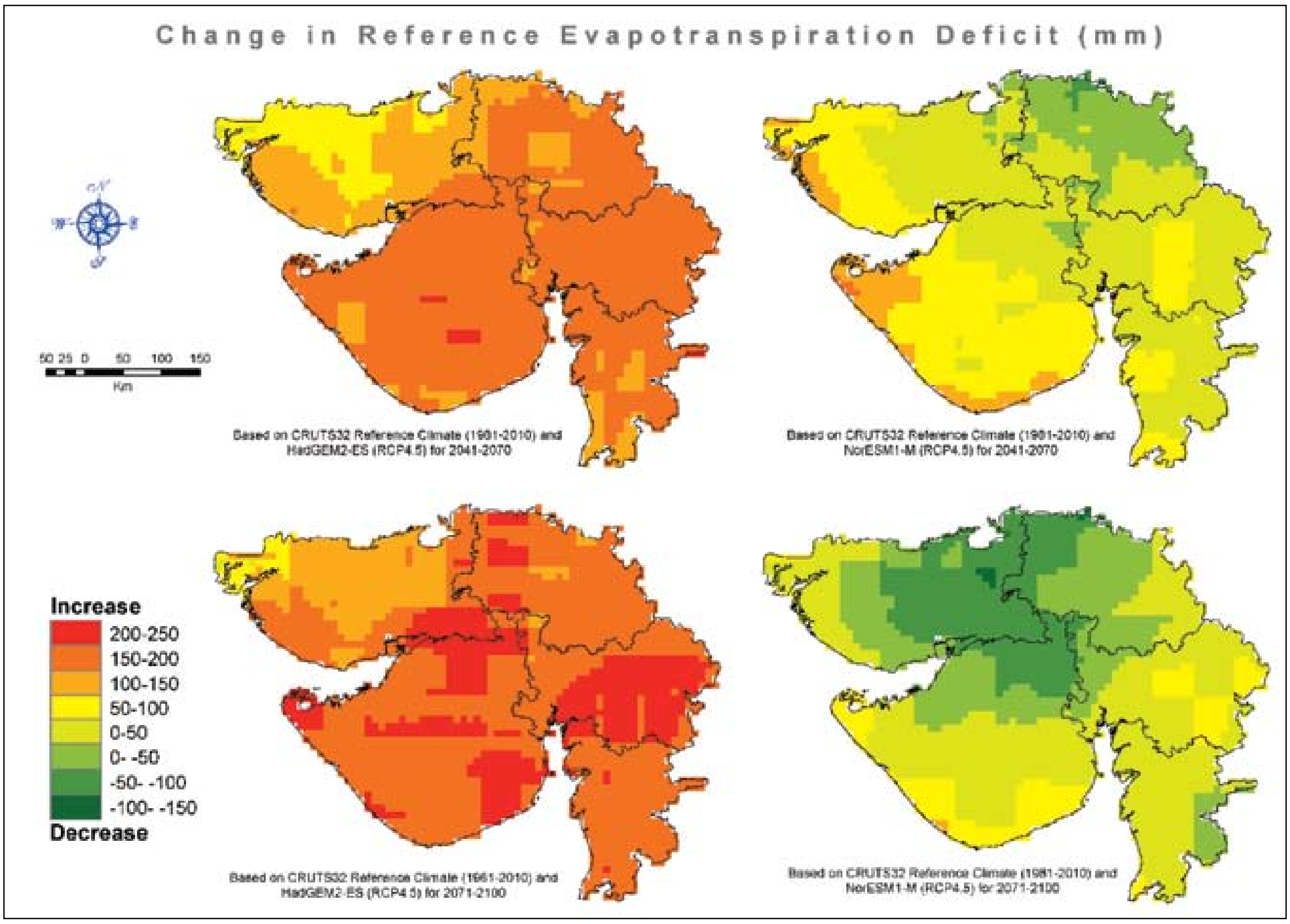

Figure 4.4: Change in Reference Evapotranspiration Deficit for Gujarat

The table below shows annual mean reference evapotranspiration deficit (mm) for reference climate (CRUTS32: 1981–2010); and E-Mean: ENSEMBLE mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M) is taken into consideration to avoid extreme variation in the result.

Table 4.2: Annual Mean Reference Evapotranspiration Deficit (mm) for Reference Climate (1981–2010) and Respective Change in Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	WDE change in 2050s (%)				WDE change in 2080s (%)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	1677	3	3	4	3	2	3	5	8
North	1498	-1	0	1	0	-2	0	8	7
Central	1347	2	2	2	3	2	2	11	8
Saurashtra	1356	4	4	6	4	5	5	7	8
South	1244	1	2	1	3	1	2	6	6
Gujarat	1364	2	2	3	2	2	3	7	7

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ENSEMBLE mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M,) is taken into consideration to avoid extreme variation in the result.

4.1.3 Potential Evapotranspiration of Reference Soil (mm)

In the current climatic condition in Gujarat, potential evapotranspiration of reference soil varies between 1600 to 2600 mm with maximum and minimum potential evapotranspiration of reference soil in the region of southern part of the south Gujarat and Kutch respectively. Saurashtra, central Gujarat, south Gujarat, and eastern part of north Gujarat region lies in Potential evapotranspiration ranging between 1600 to 2100 mm.

Projection using Ensamble Mean of all Models across RCPs

Projection using different RCPs suggests that Kutch has highest potential evapotranspiration of reference soil during entire projection periods of 2020s, 2050s, and 2080s. Potential evapotranspiration of reference

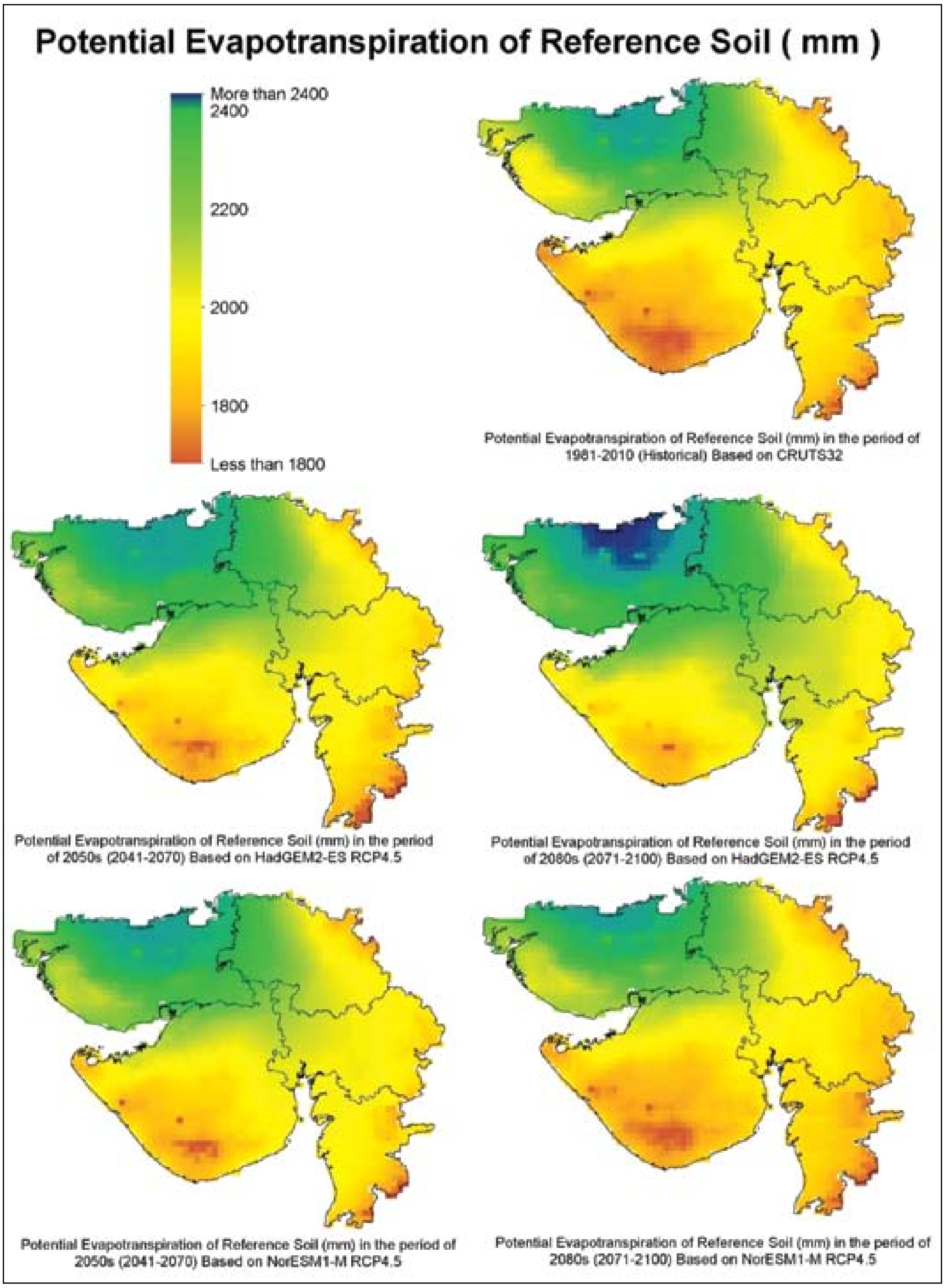

Figure 4.5: Potential Evapotranspiration of Reference Soil (mm)

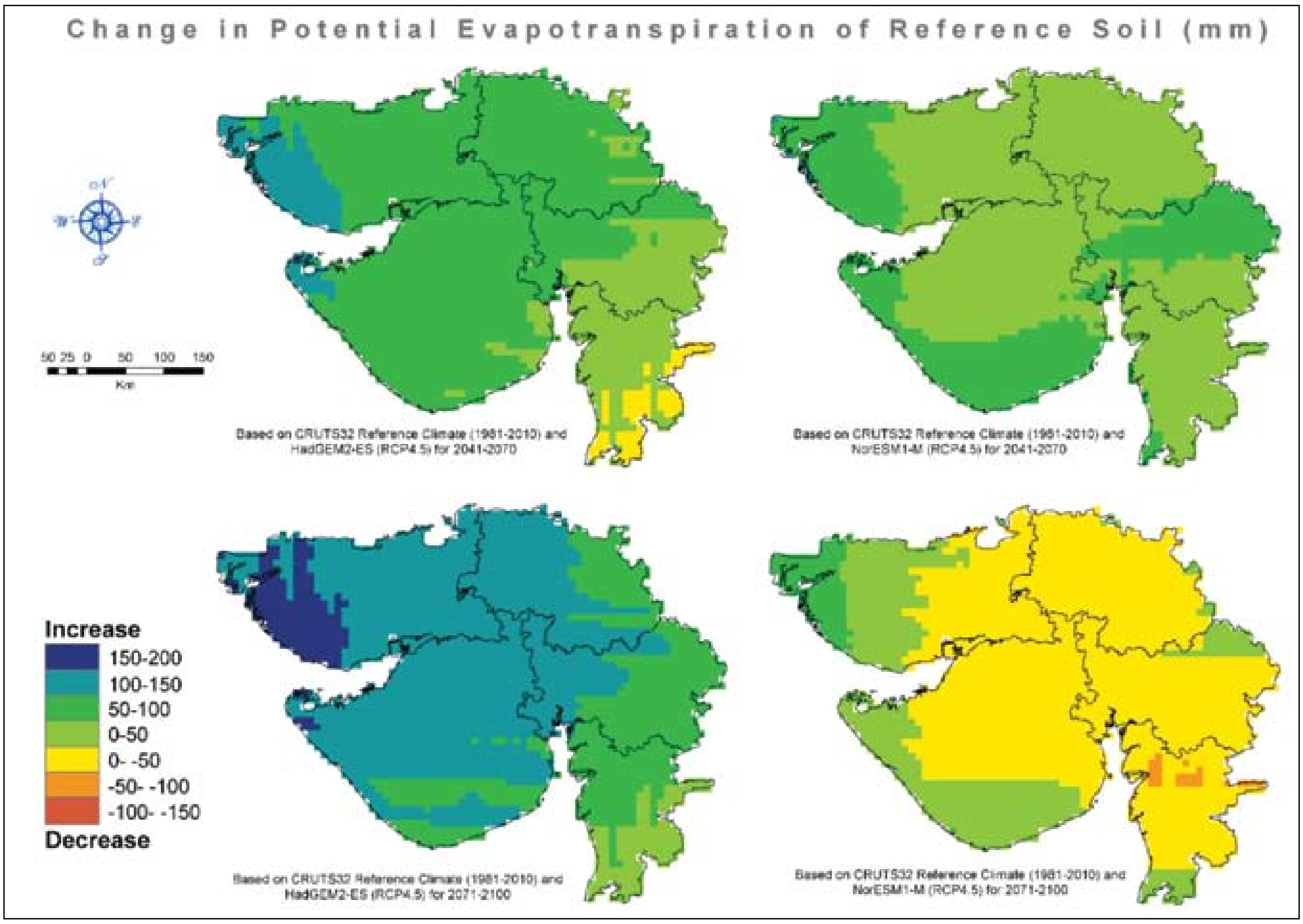

Figure 4.6: Potential Evapotranspiration of Reference Soil (mm)

soil in Kutch may reach to more than 2400 mm in the 2050s and 2080s. However, southern Saurashtra, and south Gujarat may remain with lowest potential evapotranspiration of reference soil (less than 1800 mm) in Gujarat. Comparing to current climatic conditions, HadGEM2-ES projection results projects that most of the region may observe an increase in potential evapotranspiration by 100 to 200 mm and a small portion of south Gujarat may observe decrease by 0 to 50 mm in 2050s scenarios and by 2080s it show an overall increase. Kutch, Saurashtra, and eastern part of north and central Gujarat regions experience potential evapotranspiration increase by 100 to 200 mm, however, south Gujarat may show less increase up to 50 mm. NorESM1-M RCP 5 Show 50 to 100 mm increase during the 2050s and 0 to 50 mm decrease during 2080s scenarios. The Ensemble mean of all model shows increasing trend of potential evapotranspiration of reference soil.

The table below shows annual mean potential evapotranspiration of reference soil (mm) for reference climate (CRUTS32: 1981–2010); and E-Mean: ENSEMBLE mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN- ESM2M) is taken into consideration to avoid extreme variation in the result.

Table 4.3: Annual Mean Potential Evapotranspiration of Reference Soil (mm) for Reference Climate (1981–2010) and ET0 Change for Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	ET0 change in 2050s (%)				ET0 change in 2080s (%)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	2106	2	2	3	3	2	4	5	8

North	2028	0	0	2	1	0	1	8	6
Central	1958	0	1	2	2	1	1	8	6
Saurashtra	1913	2	2	3	3	2	3	5	6
South	1912	0	0	1	1	1	1	4	5
Gujarat	1949	1	1	2	2	1	2	6	6

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ENSEMBLE mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M,) is taken into consideration to avoid extreme variation in the result.

4.1.4 Length of Growing Period (LGP, Days)

The length of growing period (LGP, days) was calculated using annual aridity index (100*PCP/ET0), where, PCP: Mean annual precipitation, and ET0: Potential evapotranspiration of reference soil (mm).

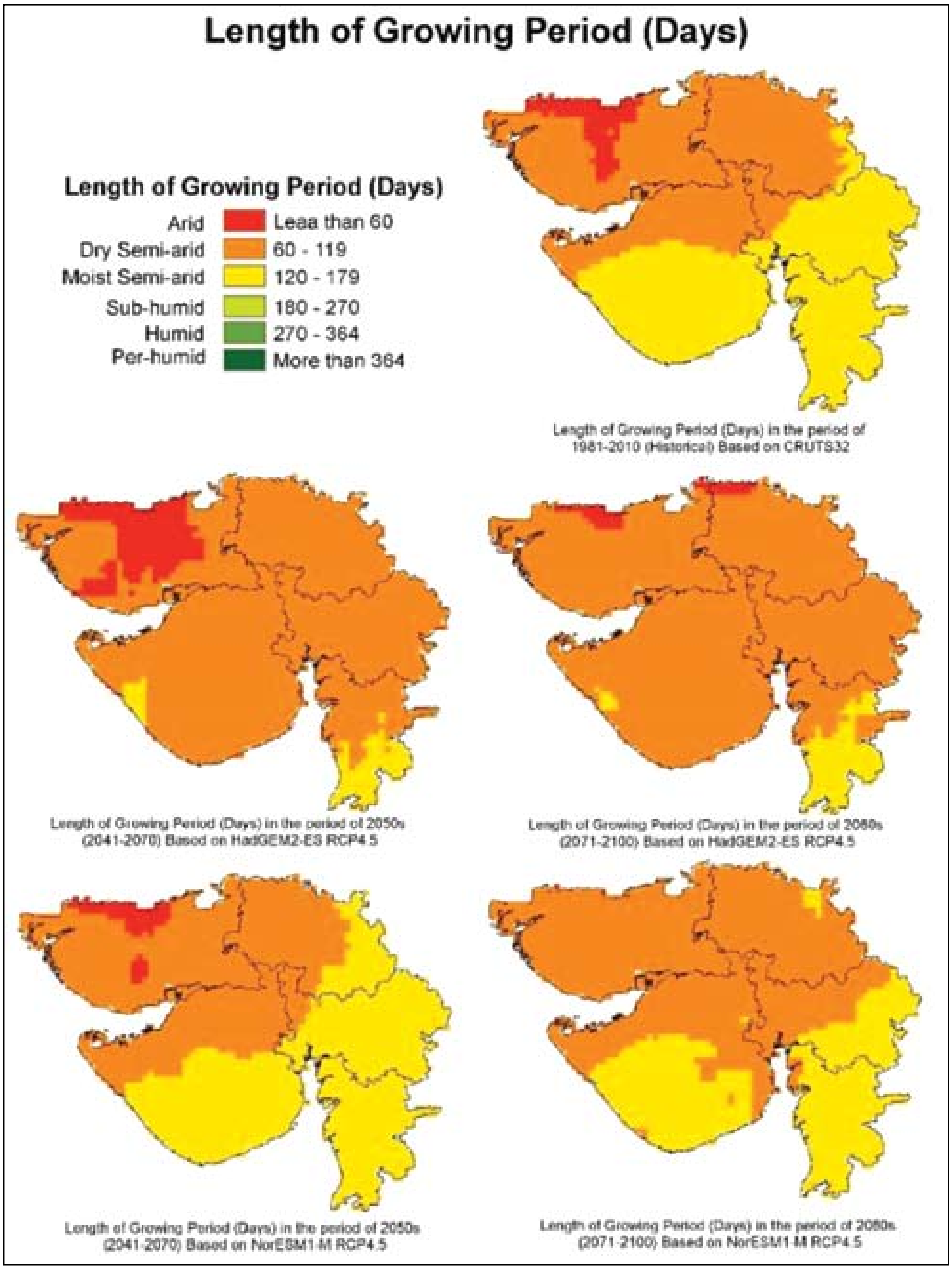

Figure 4.7: Length of Growing Period (LGP, Days) for Gujarat

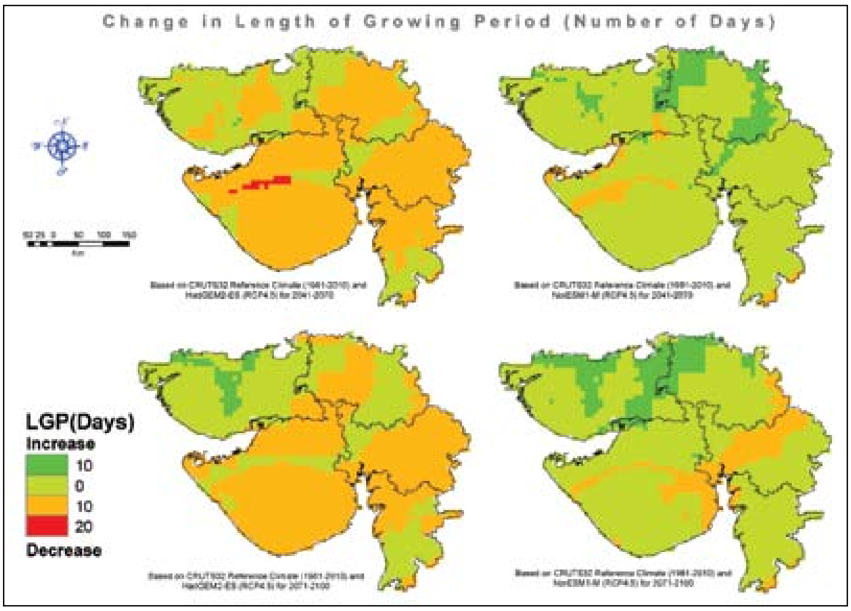

Figure 4.8: Change in Length of Growing Period (LGP, Days) for Gujarat

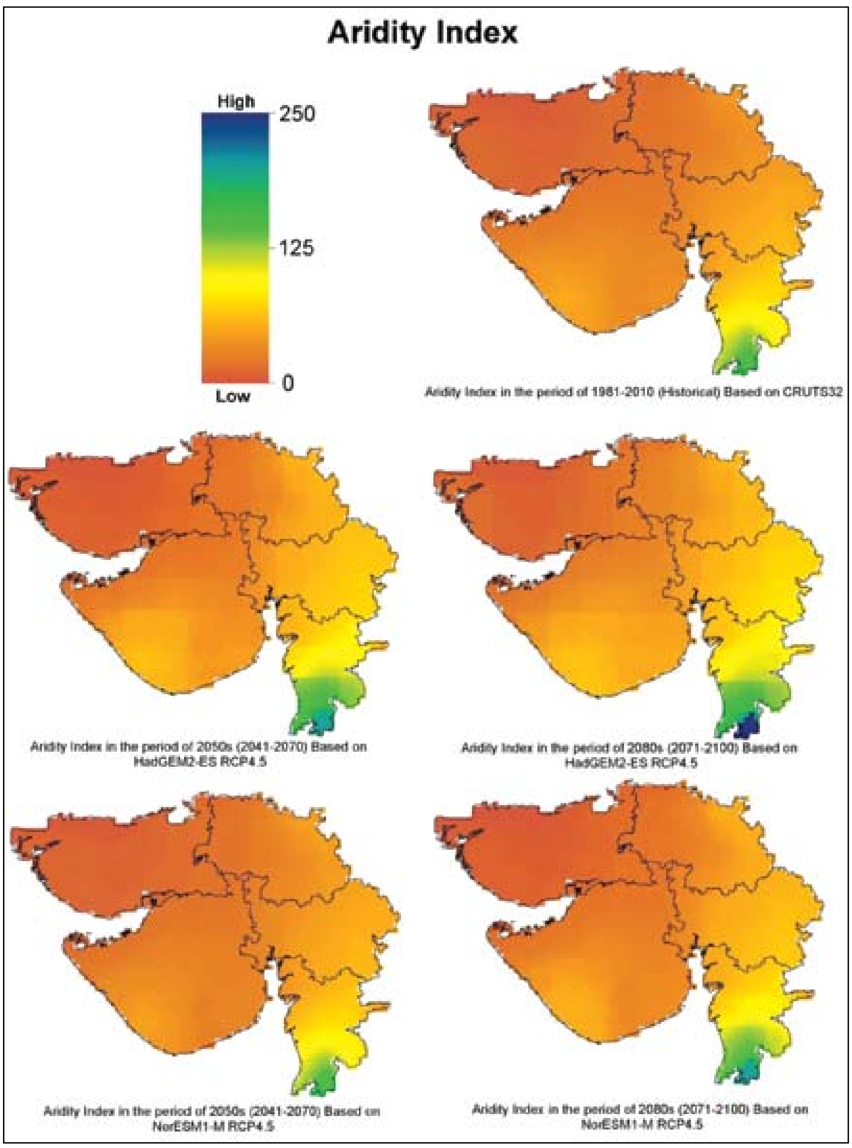

Figure 4.9: Aridity Index for Gujarat

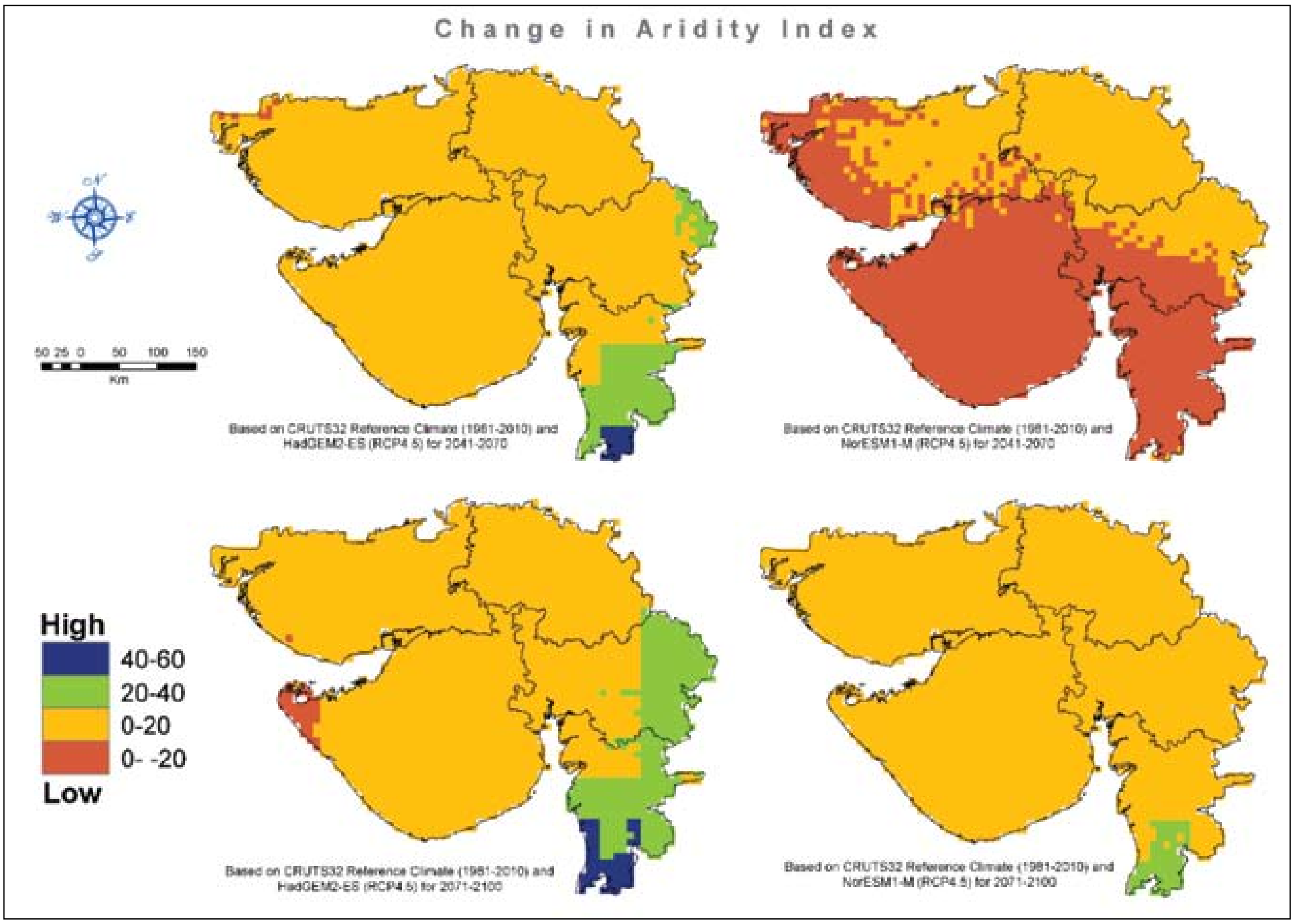

Figure 4.10: Change in Aridity Index for Gujarat

Current climatic data shows western part of Gujarat as a least arid region which tends to increase toward the southeast of Gujarat. Therefore, Kutch and western part of north Gujarat are observed to be least arid (13 to 28). However, aridity index reaches to its maximum toward the southern part of south Gujarat (95 to 146). Rest of the regions such as Saurashtra, the eastern part of north Gujarat, and central Gujarat ranges between 28 and 62. Reference climate average aridity index of 1961–1990 declined during 1971–2000 in most of the Gujarat, except western part of north Gujarat where it was increased by 0 to 5. However, average aridity index again increased by 0 to 10 in Saurashtra, south Gujarat, and central Gujarat during 1981–2010. Meanwhile, north Gujarat, Kutch, and some part of central Gujarat observed decline by 0 to 5.

Projection using Ensamble Mean of all Models across RCPs

Projected results using RCPs scenario indicates an increase in aridity index in entire Gujarat. During 2011–2040, Results predict a minor increase (0 to 10) in aridity index in the western half of Gujarat comprising Kutch, Saurashtra, and west of north and central Gujarat. Eastern half of the Gujarat may experience a relatively higher increase in aridity index, by 10 to 40, with a maximum increase in the southern part of south Gujarat.

Projected length of growing period days for during reference climate has 120-180 day covering south Gujarat, most part of central Gujarat, and Saurashtra. The northern region has 60 to 120 days of growing period and some part of Kutch has less than 60 days growing period. During the 2050s (2041–2070) length of growing period may also remain more or less unchanged but during 2080s (2071–2100) there may be slight decrease (less than 10 days) in length of growing period.

4.1.5 P/PET Ratio

Annual P/PET ratio relates two events, rainfall and water loss through evapotranspiration, in one value. Climatic parameters vary with season, which is also reflected in P/PET ratio. In the current climatic situation, P/PET ratio remains at its minimum level, between 0 and 2, during January-March in entire Gujarat. However, April-June show ratio between 3 and 70 with lowest in Kutch and increasing toward south Gujarat. The ratio reaches at maximum in July-September during monsoon, ranging between 44 and 581. The ratio remains lowest in Kutch (44 to 84) and increases toward south Gujarat (300 to 581). The P/PET ratio again starts to fall down to 3 to 30 in October-December. Lowest ratio, 3 to 5, is again observed in Kutch, part of north Gujarat, and Saurashtra. However, the highest ratio, 27 to 30, is observed in southern most part of south Gujarat.

Projection using Ensamble Mean of all Models across RCPs

HadGEM2-ES model does not show much variation in the result for RCP4.5. Result mostly indicates no change of P/PET ratio in Gujarat between 2011–2100 during January-March. However, some place may experience decrease or increase in the ratio by 1. During April-June results for RCP4.5 scenario suggest decreasing in the ratio by 0 to 8 in the region of Kutch, Saurashtra, south Gujarat, and part of central Gujarat between 2011–2070. However, north Gujarat and the northern part of central Gujarat may receive an increase in the ratio by 0 to 20. In 2070–2100, most of the Gujarat may show the increase in ratio, by 0 to 20, from current condition. However, some small part of Kutch and south Gujarat may experience a decline in the ratio by 0 to 8. The Model delivers almost similar results during July-September, suggesting an increase in the ratio in most of the Gujarat. The major part of the Gujarat, comprising Kutch, Saurashtra, north Gujarat, and part of central Gujarat exhibit the ratio between 0 and 100 in 2011–2100. The western half of Gujarat, comprising south Gujarat and part of central Gujarat, however, may witness a higher increase in the ratio from 100 to 664. Results during October-December suggest an increase in the ratio by 0 to 10 in Kutch and part of central Gujarat. Remaining Gujarat may show a decrease in the ratio from current ratio by 0 to 11. Projection using different RCPs Ensemble mean for scenario suggests increasing trend of annual P/PET Ratio (*100) except the small part of Saurashtra.

The table below shows P/PET ratio (%) for reference climate (CRUTS32: 1981–2010); and E-Mean: ENSEMBLE mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN- ESM2M) is taken into consideration to avoid extreme variation in the result.

Table 4.4: 100*P/PET Ratio (%) for Reference Climate (1981–2010) and Respective Change in Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	100*P/PET ratio change in 2050s (%)				100*P/PET ratio change in 2080s (%)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	26	5	3	-3	9	3	10	9	9
North	33	18	12	10	19	18	19	18	14
Central	45	16	10	9	15	16	20	18	18
Saurashtra	35	-1	-1	-5	4	-2	5	7	10
South	79	7	4	2	9	5	13	12	15
Gujarat	48	9	5	3	11	8	14	13	14

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ENSEMBLE mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M,) is taken into consideration to avoid extreme variation in the result.

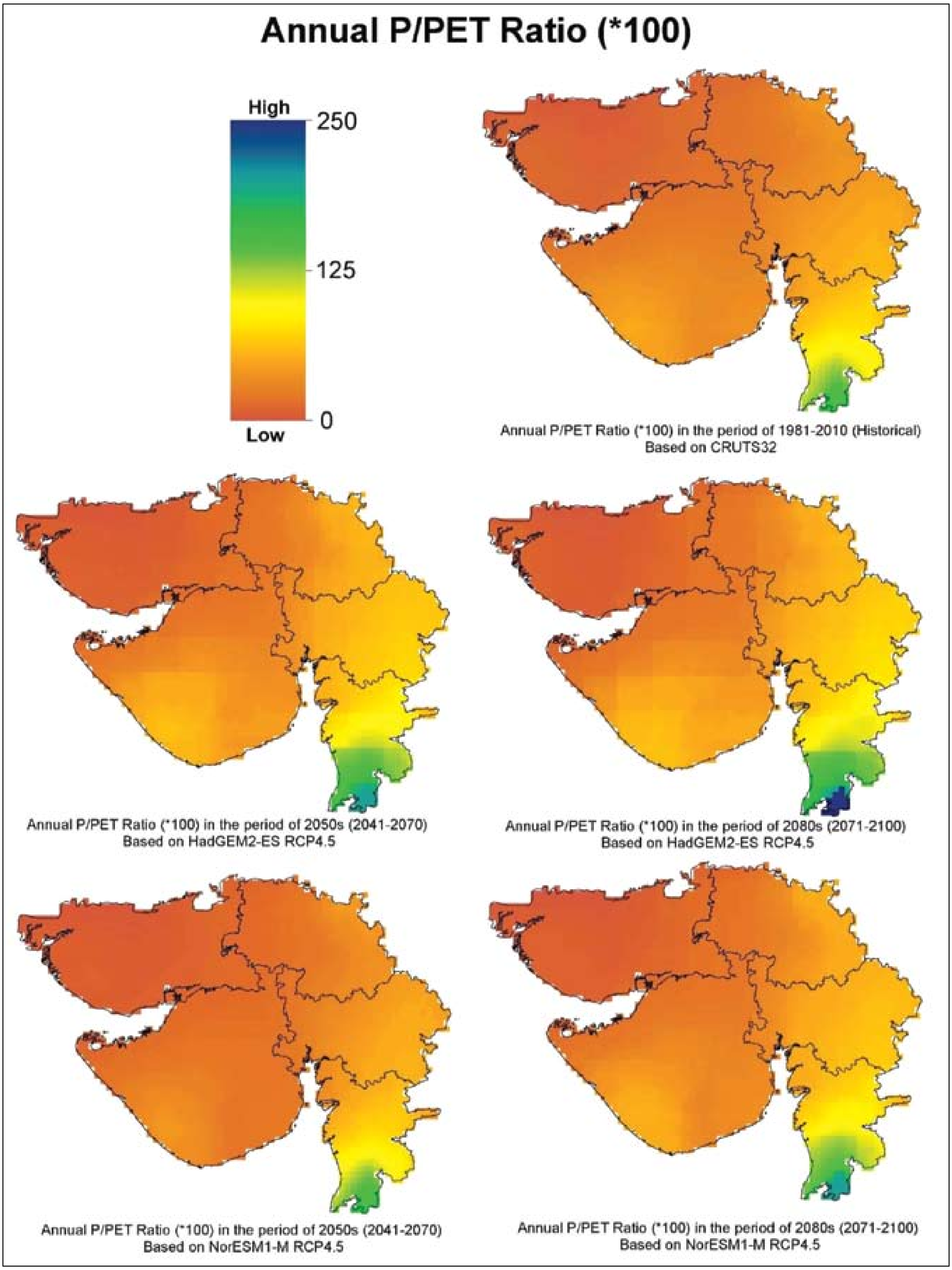

Figure 4.11: Annual P/Pet Ratio for Gujarat

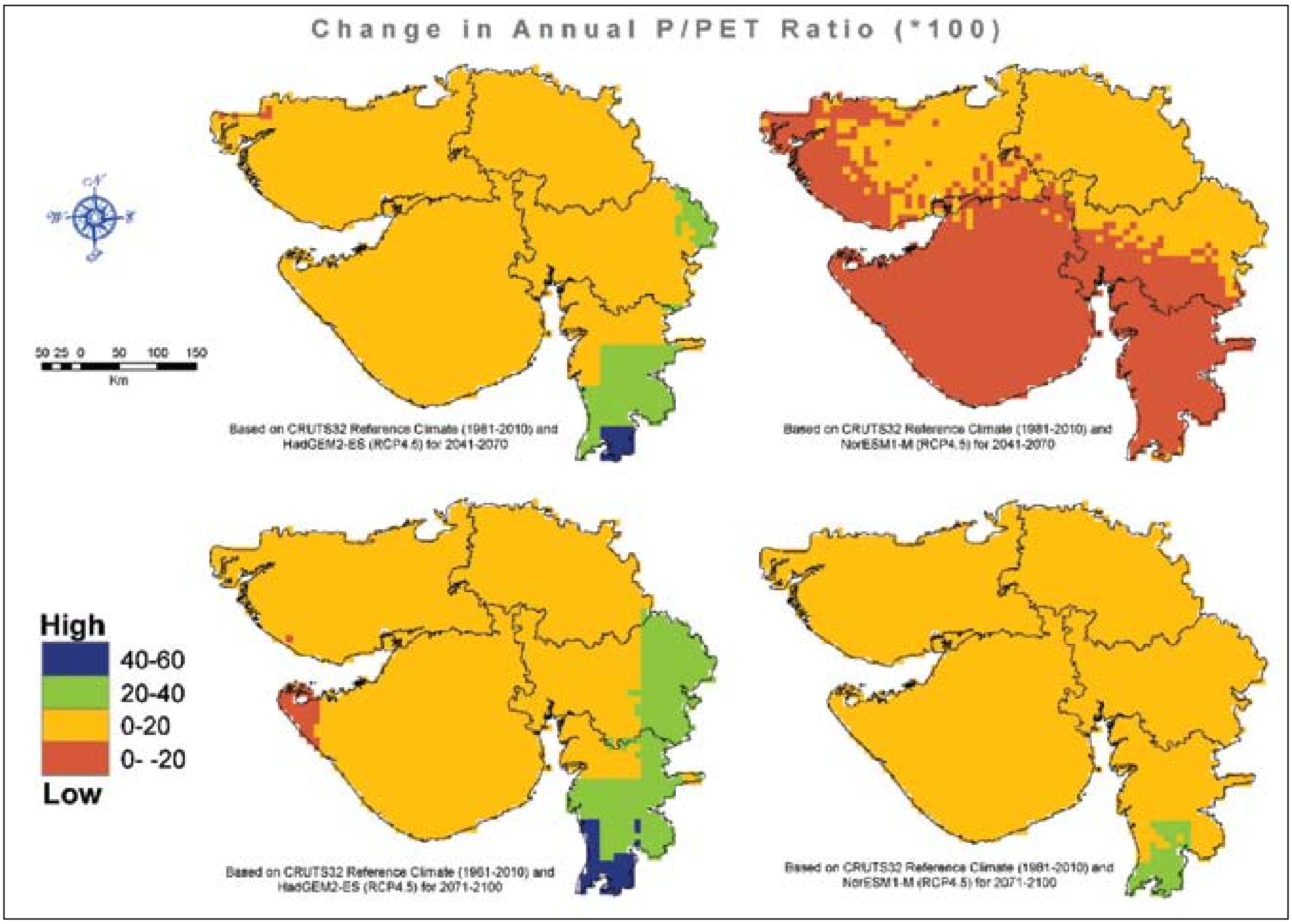

Figure 4.12: Change in Annual P/Pet Ratio for Gujarat

4.2 Biomass and Yield Calculation

The main purpose of the AEZ module II is the calculation of the biomass and the obtainable yield agro-climatically for specific land use types (LUTs) under different input/handling levels for rainfall and irrigation conditions.

Module II consists of two steps:

i. Calculation of crop biomass and yield potentials considering only the predominant conditions of radiation and temperature; and

ii. Calculation of yield losses due to water stress during the crop growth cycle. The estimation is based on the water balances of the rain crops for different levels of water retention capacity in the soil

Estimating yield for irrigation conditions assumes that there will be no water deficit during the crop growth cycle.

Land Utilization Types

Differences in crop types and production systems are empirically characterized by the concept of LUTs. An LUT consists of a set of technical specifications for crop production in a given socio-economic environment. The specific attributes of a particular LUT include agronomic information, the nature of the main product, and the type of water supply, cultivation practices, use of the product and residues and by-products of associated crops. The calculated yield of each crop/LUT depends on the climate, the water sources and the assumed intensity of the inputs and the management. Three generic levels of input/management conditions are defined: low, intermediate, and high input level.

Under a low level of inputs (traditional crop management), the farming system is mainly based on subsistence. The production is based on the use of the traditional crop, labor-intensive techniques and no application of nutrients, use of chemical products for control of pests and diseases; minimum conservation measures. Under a high level of inputs (advanced crop management), the farming system is mainly market oriented. Commercial production is the goal of management. The production is based on improved or high-yielding varieties, fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pests, diseases, and weed control measures. This variety in management and input levels translates into performance differences by assigning different parameters to LUTs depending on the input/management level, e.g. such as the crop index and the maximum leaf area index. The LUTs are parameterized to reflect the environmental and eco-physiological requirements for the growth and development of different types of crops. The numerical values of the crop parameters vary depending on the level of input/handling assumed by the LUTs.

Biomass and Yield Calculation

As an initial criterion for assessing the suitability of grid cells for the possible presence of individual LUTs, the AEZ Gujarat tests the pairing of the predominant conditions with the parametric requirements of the LUT. A total of 15 matching is tested for the full range of possible start dates and resulting in an optimal combination, a suboptimal fit and not suitable conditions. The "optimal and sub-optimal concordance categories" are considered for other biomass and performance calculations. Calculation of free biomass and yield (i.e., carbon accumulation driven primarily by prevailing regimes of radiation and temperature in a grid cell) are based on a robust eco-physiological model (Kassam 1977).

Unrestricted crop yields calculated in the AEZ Gujarat reflect yield potentials with respect to the temperature and radiation regimes prevailing in the respective grid cells. The model requires the following crop characteristics: (i) duration of the growth cycle (days from emergency to full expiration); (ii) minimum temperature requirements for the emergency; (iii) maximum rate of photosynthesis, (iv) respiration rates for leguminous and non-leguminous crops as temperature functions; (v) duration of the performance training period; (vi) leaf area index (LAI) at the maximum rate of growth; (vii) harvest index (Hi); (viii) crop adaptation group; and (ix) sensitivity of the duration of the crop growth cycle to the provision of heat. Biomass calculation also includes simple procedures to take into account different levels of atmospheric CO2 concentrations.For each type of crop and grid cell, the start and end dates of the crop growth cycle are optimally determined to obtain the best crop yields, separately for rainfall and irrigation conditions. This procedure also involves the adaptation of crop calendars (smart farmer) in simulations with climatic conditions of reference year by year or under climatic distortions applied according to various scenarios of climate change.

Water Limited Biomass Production and Yields

The water stress can occur during different stages of crop development, under the rain-fed conditions, reducing biomass production and yields. In the AEZ Gujarat, the water requirements for each LUT are calculated and taken into account in the calculation of the LUT-specific water balance and the actual evapotranspiration in a grid cell. It is assumed that the total water consumption of a crop without any water stress is potential crop specific evapotranspiration (ETm). ETm is calculated in proportion to potential reference evapotranspiration (ET0), as in module I, multiplied by the specific parameters of the crop and the 'kc' cultivation stage. The kc values for different stages of crop development are given as input parameters (FAO 1992a, 1992b, 1992c, 1998).

The yield reduction in response to the water deficit is calculated as a function of the relationship between actual crop evapotranspiration and maximum crop evapotranspiration accumulated within and between the four stages of cultivation. The sensitivity of each crop to water stress is expressed by the value of the water stress coefficient, a specific parameter of LUT that changes with the stage of development of the crop. The limited yield in water is then calculated as the potential yield multiplied by the water stress reduction factor specific to the network cell (FAO 1992b, 1998).

4.3 Agro-Climatic Constraints

At the stage of calculating biomass and potential yields, the climatic effects related to pests and diseases and workability are not taken into account. The agro-climatic restrictions cause direct or indirect losses in the yield and the quality of the products. Performance losses in rain-fed crops due to agro-climatic constraints have been formulated on the basis of the principles and procedures originally proposed in FAO (1978-1981a, b) and on experiences in individual countries (e.g., China, Bangladesh, Mozambique, Ghana, and Kenya).The relationships between these constraints and general agro-climatic conditions, such as moisture stress and excess air humidity, vary by location, between agricultural activities and the use of control measures. The impact of these performance constraints on the basis of prevailing climatic conditions has been approximated. The effectiveness of controlling these constraints are explained by the assumed levels of inputs. Due to the relatively high level of uncertainty, the evaluation of agro-climatic constraints has been applied separately in module III, so that the effects are transparent and well separated.

Five different yield constrains (i.e. yield-reducing factors) are taken into account; (i) long-term limitation to crop performance due to year-to-year rainfall variability; (ii) pests, diseases and weeds damage on plant growth; (iii) pests, diseases and weeds damage on quality of produce; (iv) climatic factors affecting the efficiency of farming operations; and (v) frost hazards (not applicable in case of Gujarat).

4.4 Agro-Edaphic Constraints

The module IV estimates factors for the yield reduction caused by constraints due to prevailing soil and slope conditions. The suitability of the soil is evaluated by specific crop/LUT assessments of the main soil qualities. The adequacy of the terrain is estimated from the characteristics of the slope of the terrain and the concentration of rainfall. The soil and soil characteristics are read from 3 arc-second cells in which the predominant soil and soil combinations have been quantified. Soil units are characterized by the following soil parameters: organic carbon, pH, water storage capacity, soil depth, and cation exchange capacity of the soil and clay fraction, total interchangeable nutrients, lime and gypsum content, percentage of sodium exchange, salinity, textural class, and granulometry. For the AEZ Gujarat study, the calculations are crop specific/LUT and are performed for a high input level and four separate water supply systems, including rainfall, sprinkler irrigation, gravity irrigation, and drip irrigation.

Soil Suitability Assessment Procedures

In the AEZ Gujarat, edaphic suitability is assessed in terms of various soil qualities specifically related to soil properties and conditions, as reflected in the Gujarat soil database and the AEZ Gujarat terrain-slope database. Soil profile attributes, soil drainage conditions, and the prevalence of soil phases that have been linked to crop requirements and tolerances were ultimately combined into the specific soil suitability classifications from the earth. In the first place, the individual qualities of the soil are defined and quantified. The following table provides an overview of the seven soil qualities used in the AEZ Gujarat in relation to the relevant attributes of the soil profile, including soil drainage conditions, and soil phase prevalence.

Table 4.5: Soil Qualities and Soil Attributes

Rating	Soil Qualities	Soil quality related soil profile attributes, soil drainage conditions and soil phase characteristics
SQ1	Nutrient availability	Soil texture, soil organic carbon, soil pH, total exchangeable bases

SQ2	Nutrient retention capacity	Soil texture, base saturation, cation exchange capacity of soil and of clay fraction
SQ3	Rooting conditions	Soil textures, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume
SQ4	Oxygen availability to roots	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts (salinity and sodicity)	Soil salinity, soil sodicity and soil phases influencing soil salinity and sodicity conditions
SQ6	Toxicity	Calcium carbonate and gypsum
SQ7	Workability (constraining field management)	Soil texture, effective soil depth/volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans)

The seven soil qualities (SQ1-7) are estimated from soil characteristics (e.g., organic carbon content, soil pH, texture, etc.) read from the soil database. Soil qualities that influence the yield of crops considered in the evaluation include: nutrient availability (SQ1); nutrient retention capacity (SQ2); rooting conditions (SQ3); availability of oxygen to the roots (SQ4); salinity and sodicity (SQ5); toxicities (SQ6); and workability (SQ7). Each of the seven SQ ratings is derived from the specific characteristics of the soil. The attributes of the soil profile considered for both the upper soil (0 to 30 cm) and the subsoil (30 to 100 cm) include separately: soil texture; organic carbon content; pH, cation exchange capacity of soil, and clay fraction; base saturation; interchangeable total bases; calcium carbonate content; gypsum content; sodicity and salinity. Also considered are the prevalence of soil phases, soil drainage characteristics, and vertical soil properties.

Soil Suitability

Soil suitability classification procedures, follow a two-step approach:

i. Crop responses to individual soil attributes conditions and relevant soil drainage and phase conditions are combined in soil quality (SQ) ratings, and

ii. Soil qualities are combined into specific crop specifications, specific input and management levels, and specific soil fitness ratings

The functional relationships of the soil qualities have been formulated to quantify the adequacy of the soil units to the crop/ LUT. The results of the soil unit suitability assessment are stored by each soil unit/ slope class/crop/input level/water supply system combination for integration with the results of the agro-climatic suitability assessment (in module V). The following guiding principles formed the basis for the combination of soil qualities for different levels of inputs and management:

- The availability of nutrients and nutrient retention capacity are the main qualities of the soil;
- The availability of nutrients is of paramount importance for the cultivation of low-level inputs; the nutrient retention capacity is more important for high level inputs;
- The availability of nutrients and nutrient retention capacity are considered to be of equal importance for intermediate level input agriculture;
- The availability of nutrients and nutrient retention capacity are strongly related to root depth and available soil volume; and
- Oxygen available for roots, excess salts, toxicity, and workability are considered equally important soil qualities and the combination of these four soil qualities is best achieved by multiplying the most limiting classification with the average of the qualities of the three soils

Terrain Suitability

The influence of topography on the use of agricultural land is manifold. The agricultural practices are adapted to the slope of the terrain, appearance of the slope, configuration of the slope, and micro-relief. For example, steep irregular slopes are not practical for mechanized cultivation, whereas, these slopes could very well be cultivated with adapted machinery and hand tools. Sustainable agricultural production on sloping land is mainly concerned with the prevention of erosion of the topsoil and the reduction of fertility. This is usually achieved by combining special crop management and soil conservation measures. Cultivated sloping land may provide inadequate soil protection and without sufficient soil conservation measures, they pose a considerable risk of accelerated soil erosion. In the short term, slope cultivation could lead to yield reductions due to the loss of applied fertilizers and the fertile surface layer. In the long term, this will result in loss of productivity of the soil due to the truncation of the soil profile and consequently to the reduction of the natural fertility of the soil and the available soil moisture.

The adequacy rating of the terrain slope used in the AEZ Gujarat study captures the factors described above that influence production and sustainability. This is achieved through; (i) to define for the different crops the permissible slope ranges for the crop, establishing maximum slope limits; (ii) for slopes within permissible limits, which explains the likely reduction in yield due to the loss of fertilizers and the topsoil; and (iii) the distinction between agricultural practices ranging from manual cultivation to full cultivation machining. Slope ratings are defined by crop group, entry level and for the eight slope range classes used in the land resource database.

4.5 Integration of Climatic and Edaphic Evaluation

The module V carried out the final step in assessing the productivity of the land and the suitability of the AEZ Gujarat crops. The LUT-specific results of the agro-climatic evaluation for biomass and yield calculated in module II/ III for different soil classes and their uses are the edaphic indices produced for each soil/ slope combination in module IV. Soil resource inventories and slope-land conditions are integrated by ordering all soil types in each soil map unit with respect to occurrence in different slope classes. Considering simultaneously for all mesh cells belonging to a particular soil map unit, the respective slope class distribution results in a consistent and consistent distribution of soil-ground slope combinations by individual soil map association units and 3 arc-second grid cells. The soil assessment and slope rules are applied separately for each water supply system. The algorithm in module V passes through the cells of the grid of the spatial layer of the soil association of the Gujarat soil database and determines for each grid cell the respective composition of the soil units in terms of soil types and classes of slopes. Each of these component ground units is assigned separately with the appropriate suitability and performance values and the results are accumulated for all elements. The processing of the information on the distribution of the soil and the slope takes place to 3 arc-second grid cells.

The main purpose of module V is to compile a grid-cell database for each crop or crop group storing evaluation results that summarize the processed sub-grid information. Computations include the following steps:

i. Reading agro-climatic yields calculated for separate crop water balances of six broad soil AWC classes (from module II/III);

ii. Applying AEZ rules for water-collecting sites (defined as Fluvisols and Gleysols in flat terrain);

iii. Applying reduction factors due to edaphic evaluation for the specific combinations of soil types/ slope classes making up a grid-cell; and

iv. Aggregating results over component land units (i.e. soil type/slope combinations)

The results of the culture evaluations in module V are stored as separate databases, each organized by grid cells. Separate files are generated by crop, input level, and water supply system and stage/ time period. Each database contains information in terms of adequate extent and potential output by suitability classes. Several utility programs have been developed for grouping and tabulating the results by administrative units or for mapping the content of the V database cultures in terms of suitability index and grid cell production potential. The assessment of crop suitability is an important component of evaluation studies, including changes in the geographical distribution of crops under climate change in the coming decades. On the one hand, it is well known that the crops will respond to specific changes in temperature and precipitation in the places where they are currently grown; on the other hand, it is hoped that not all crops and cultivars will remain adequate within their current geographic range, with trends to migrate towards higher latitudes and a push for production in areas already in the production margin. However, most of the crop modeling platforms currently available present fixed simulations of the crop network, i.e. they do not allow dynamic movements of ideal crop ranks and, therefore, tend to underestimate adaptation responses of farmers. These will certainly try to change, as far as possible, cultivars and crops better adapted to changing conditions. Likewise, those model platforms that have excelled in the suitability of computing have much less crop modeling detail than those available under the proposed platform.

Adequate agricultural exploitation of climatic potentials and maintenance of land productivity depend to a large extent on soil fertility and soil management on an ecologically sustainable basis. Soil fertility refers to the soil's ability to retain and supply nutrients and water to enable crops to maximize the climatic resources of a particular location. The fertility of a soil is determined by its physical and chemical properties. Understanding these factors and understanding their interrelations is essential for the effective use of climate, land and crop resources for optimum use and production. Based on the basic requirements of the soil of the crops, a series of soil characteristics related to the yield of the crops have been established. For most crops, optimum, suboptimal, marginal and inadequate levels of these soil characteristics are known and quantified. Beyond critical ranges, crops cannot be expected to produce satisfactorily unless special precautionary measures are taken. Soil fitness classifications are based on knowledge of crop needs of soil conditions and applied soil management. In other words, soil adequacy procedures quantify the extent to which soil conditions conform to crop requirements under defined management and input conditions.

4.6 Net Primary Production

4.6.1 Net Primary Production for Rain-Fed Region

Current net primary production in rain-fed (NPP-R) condition ranges between 27000 and 44000 in Gujarat. Highest NPP-R is observed in south and central Gujarat varying between 38000 to 44000. Lowest NPP-R is observed in Kutch ranging between 27000 and 34000. Average NPP-R in 1961–1990 increase by 1 to 1000 in 1971–2000 in most of the Gujarat except in the small western region of Kutch and Saurashtra, where it decreased by 1 to 1000. The average NPP-R in 1971–2000 further increased by 1 to 1000 in 1981–2010 in most of the Gujarat comprising Kutch, south Gujarat, part of Saurashtra, and central Gujarat. The remaining Kutch observed the highest increase by 1000 to 2000. In another hand, north Gujarat and part of central Gujarat observed a decline in average NPP-R by 0 to 1000.

Projection using HadGEM2-ES RCP4.5

Projection using this model suggests south and central Gujarat having highest and Kutch having lowest NPP-R. Projection using RCP4.5 scenario suggests a reduction in NPP-R in Gujarat, except Kutch in 2020s (2011–2040). Most of the Kutch may experience an additional increase of NPP-R by 1 to 100; however, certain regions in Kutch may witness an increase, as high as, 1000 to 2000. Highest decline in NPP-R will possibly be observed in south and central Gujarat, where NPP-R may decline by 2000 to 5000. Rest of the Gujarat comprising Saurashtra, part of north, and central Gujarat may observe a decline in NPP-R by 1000 to 3000. The projection for the 2050s (2041–2070) and 2080s (2071–2100) presents almost similar results showing an increase in NPP-R in Kutch.

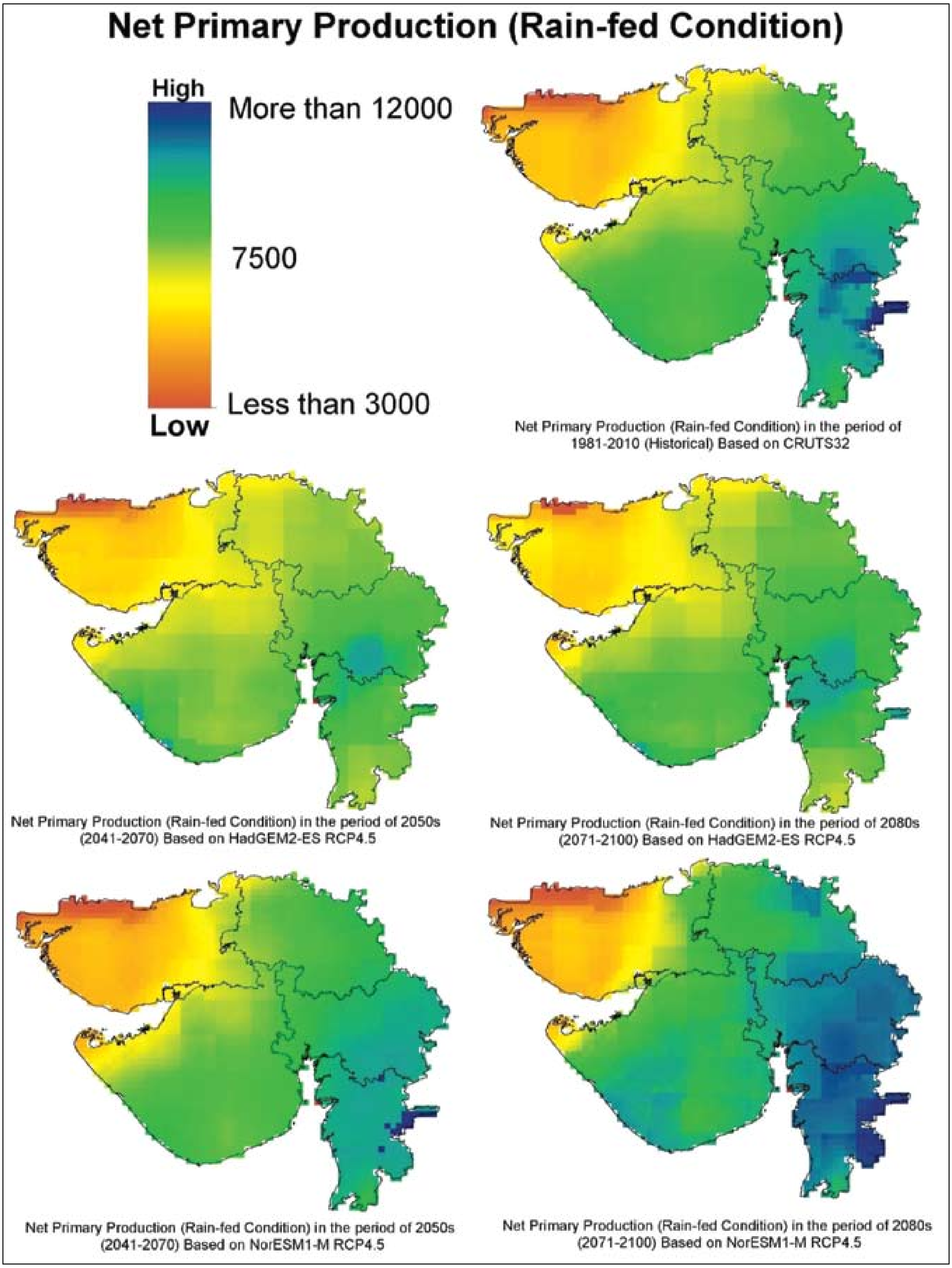

Figure 4.13: Net Primary Production for Rain-Fed Region in Gujarat

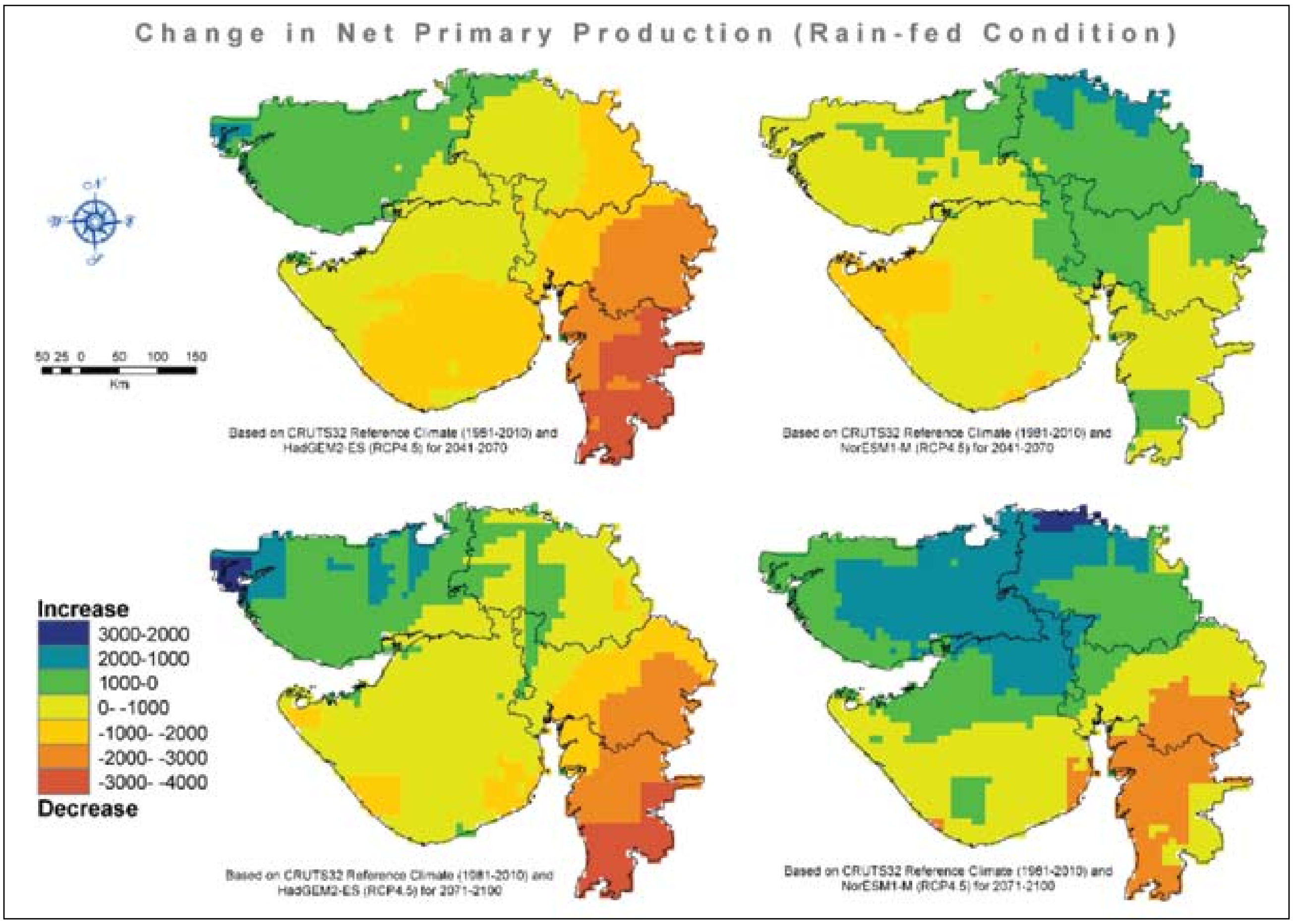

Figure 4.14: Change in Net Primary Production for Rain-Fed Region in Gujarat

The table below shows Net Primary Production (Kg /ha) for reference climate (CRUTS32: 1981–2010); and E-Mean: ENSEMBLE mean of all models, where values of following models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN- ESM2M) is taken into consideration to avoid extreme variation in the result.

Table 4.6: Rain-Fed Net Primary Production (Kg/Ha) for Reference Climate (1981–2010) and Respective Change in Future Climate Scenarios 2050s (2041–2070) and 2080s (2071–2100)

Regions	Reference Climate 1981-2010	Net Primary production (Rain-fed) change in 2050s (%)				Net Primary production (Rain-fed) change in 2080s (%)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Kutch	5163	3	4	-5	15	6	13	12	15
North	8534	6	6	5	13	10	13	13	10
Central	10867	-4	0	0	1	-1	2	2	2
Saurashtra	8729	-7	-4	-9	3	-7	1	-1	3
South	12052	-4	-3	0	-4	-1	-3	-1	-1
Gujarat	9799	-4	-1	-2	2	-1	2	2	3

*Reference climate (CRUTS32: 1981–2010); **E-Mean: ENSEMBLE mean 2050s (2041–2070) and 2080s (2071–2100) of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M, and ENSAMBLE MEAN-ESM2M,) is taken into consideration to avoid extreme variation in the result.

4.6.2 Net Primary Production for Irrigated Region

Current net primary production for irrigated region (NPP-I) is highest in the region of Kutch and western region of north Gujarat ranging between 40000 to 43000. It reduces to the minimum in the southern part of south Gujarat ranging between 27000 and 36000. Rest of the Gujarat, comprising Saurashtra, central Gujarat, and some part of north and south Gujarat, show NPP-I ranging between 36000 and 40000. Reference climate 30 years average of NPP-I in1961–1990 decreased by 1 to 1000 in the coastal region of Kutch and Saurashtra in 1971–2000. However, it increased by 1 to 2000 in remaining Gujarat. The maximum increase is observed in western part of north Gujarat and eastern part of Kutch.

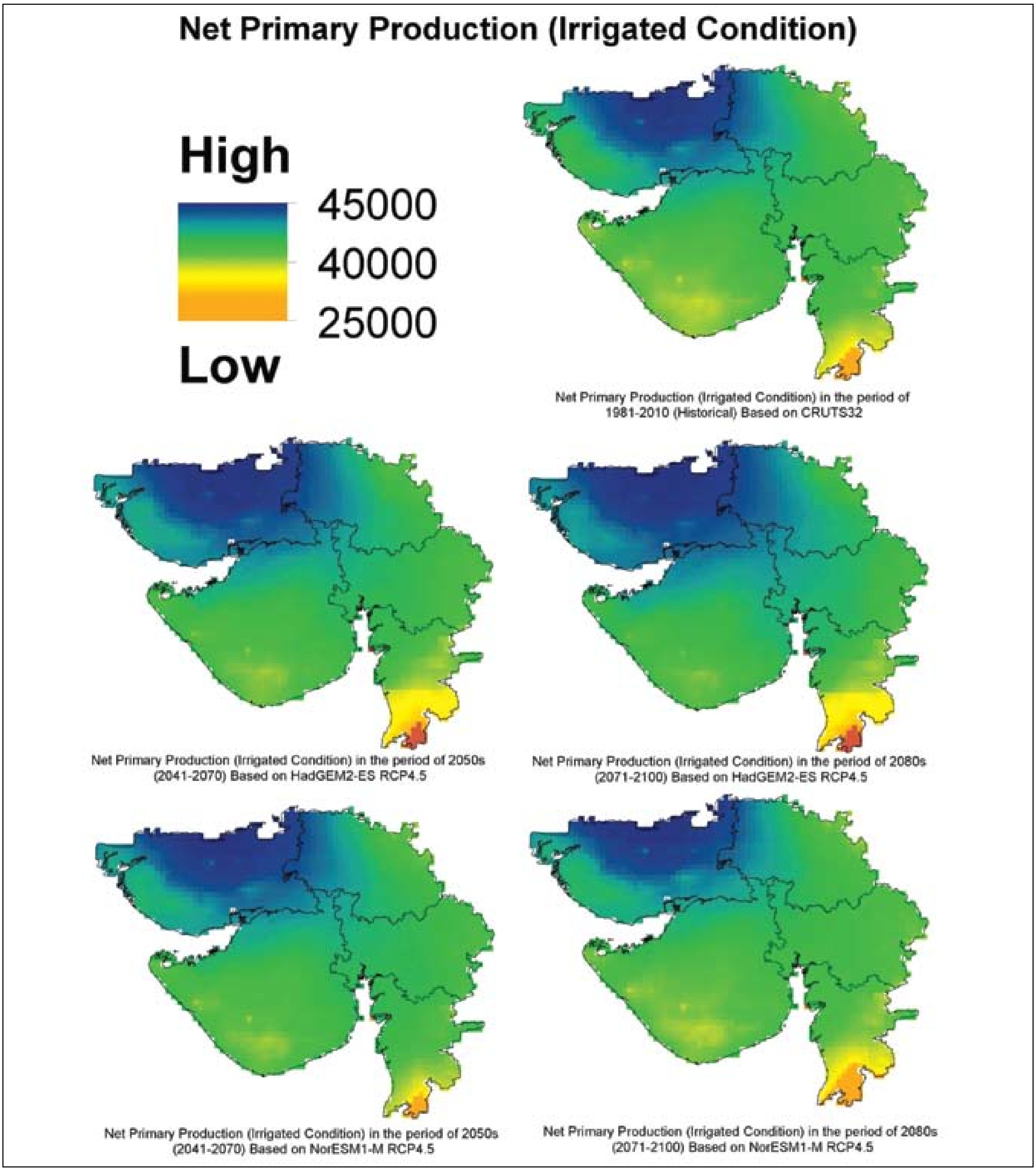

Figure 4.15: Net Primary Production for Irrigated Region in Gujarat

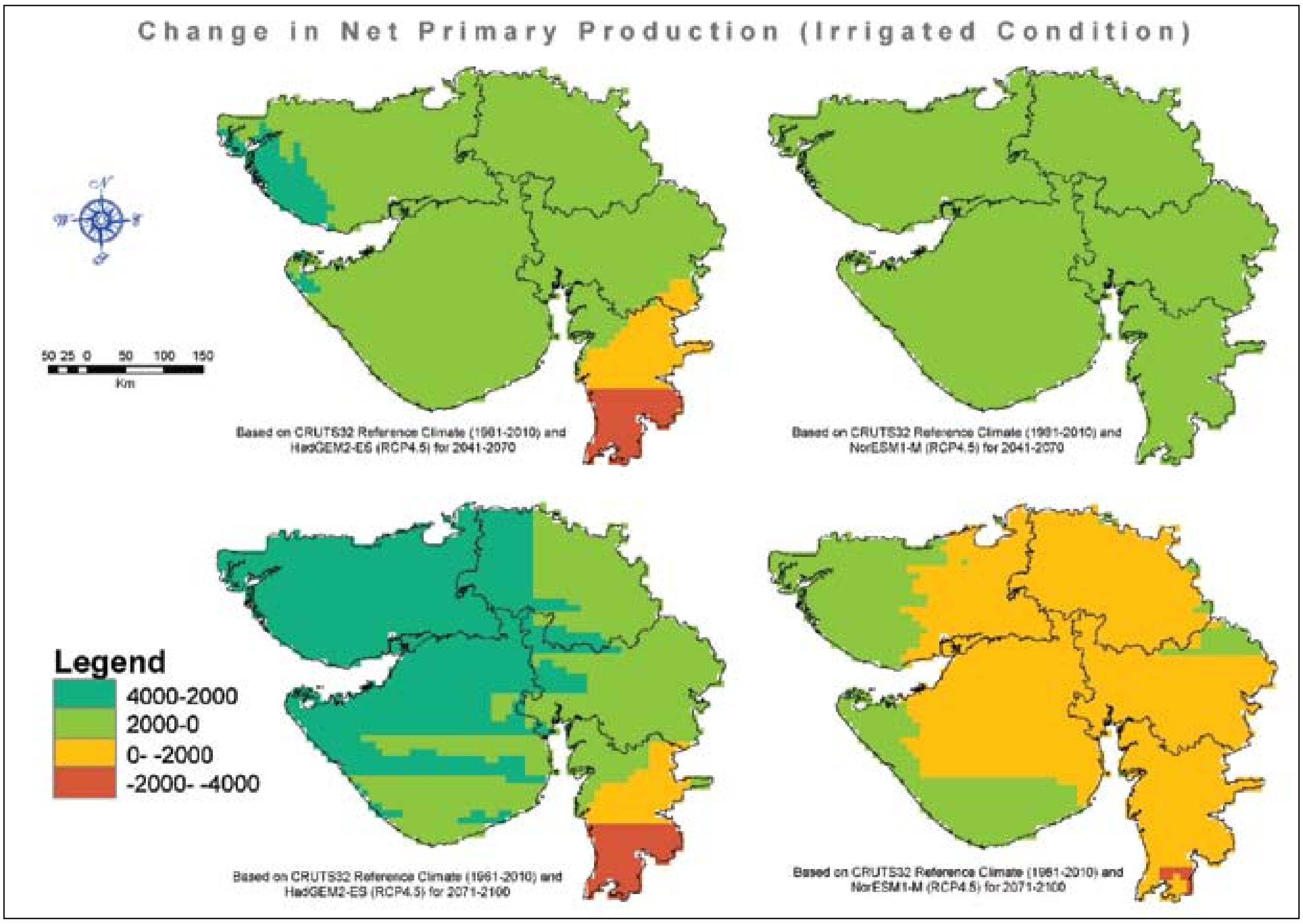

Figure 4.16: Change in Net Primary Production for Irrigated Region in Gujarat

Projection using HadGEM2-ES RCP4.5

Results from HadGEM2-ES Model show Kutch and south Gujarat having highest and lowest NPP-I respectively. Projection using RCP4.5 scenario indicates that NPP-I may decrease in most of the Gujarat except the western coastal region of Kutch and Saurashtra in the 2020s (2011–2040). The western coastal region of Kutch and Saurashtra may rather experience an increase of 1 to 1000. South Gujarat may observe a maximum decline in NPP-I ranging between 1000 and 4000. During 2041–2070 most of the Gujarat, except south Gujarat, may experience an increase in NPP-I from the current situation. Western coastal part of Kutch and Saurashtra may observe an increase in NPP-I by 1000 to 2000 from the current situation. A major portion of Saurashtra, central Gujarat, north Gujarat, and part of Kutch may observe an increase of 1 to 1000. South Gujarat may face a decline in NPP-I by 1000 to 5000 during the same period. In 2071–2100, the western part of Kutch and the small portion in western Saurashtra may experience an increase in NPP-I by 2000 to 4000 rest part may follow the same pattern of increase or decrease.

4.7 Climate Change Impacts on Crop Suitability and Attainable Yield

The analysis as carried out for reference climate conditions (1981–2010) was also undertaken for the ENSAMBLE MEAN RCP4.5climate scenarios (2041–2070) derived from outputs of available GCMs. As time horizon the 2050s were chosen. Results of the analysis for the crops BT cotton, cotton, groundnut, wheat, bajra, maize, castor seed, sesamum, jowar/sorghum, pigeon pea/tur/arhar, rapeseed, mustard, potato, mango, cumin, tobacco, and banana are summarized by regions and districts of Gujarat showing: (i) suitability index, area (*000 hectares) & percentage, occurrence of very suitable and suitable agricultural land; (ii) average output per unit area (kg/ha); and (iii) agro-ecologically attainable yield

(*00000 tons) for current and future climates, i.e. reference climatic conditions (1981–2010) and for the ENSAMBLE MEAN of five models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M) under RCP4.5climate scenarios for the period 2041–2070. AEZ results show that projected climate change affects crop production differently across crops regions in Gujarat.

In comparison to the reference climate data for harvested area to the predicted future model, the areas have drastically reduced everywhere except Saurashtra which shows an increase in harvested area by only a couple thousand square kilometers. The harvested are of mustard, groundnut, bajra, castor, pigeon pea, mango, wheat and white potato is visibly decreasing varying from 63 to 100%. Figures 4.14 to 4.18 present the potentially harvested areas for main crops in Gujarat since 1981. Besides, tables 4.7 and 4.8 presents potentially harvested areas and yield for main crops in Gujarat.

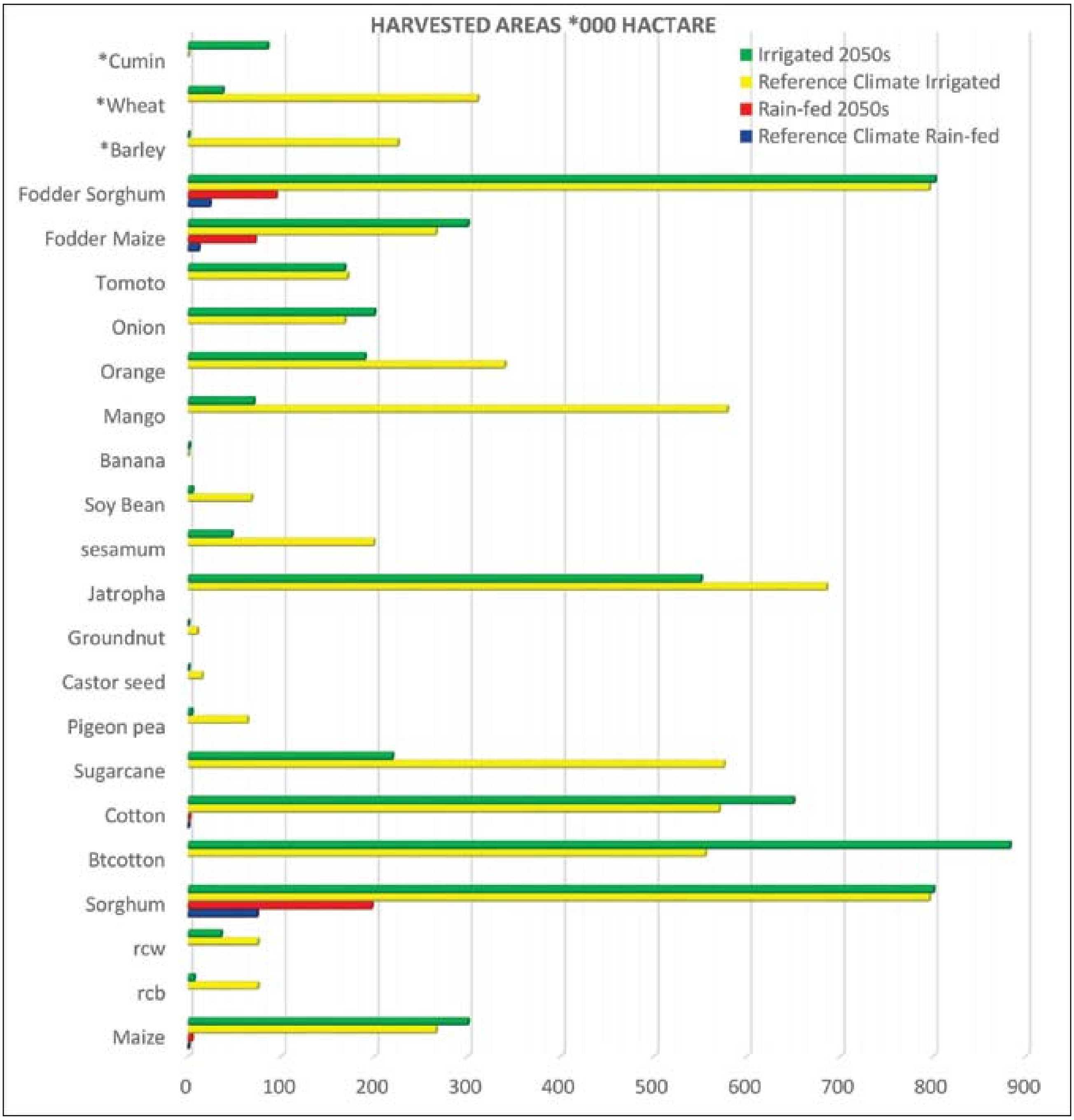

Figure 4.17: Harvested Areas by Crops for Reference Climate (1981–2010) and for RCP4.5 Scenario 2050s (2041–2070) in Kutch

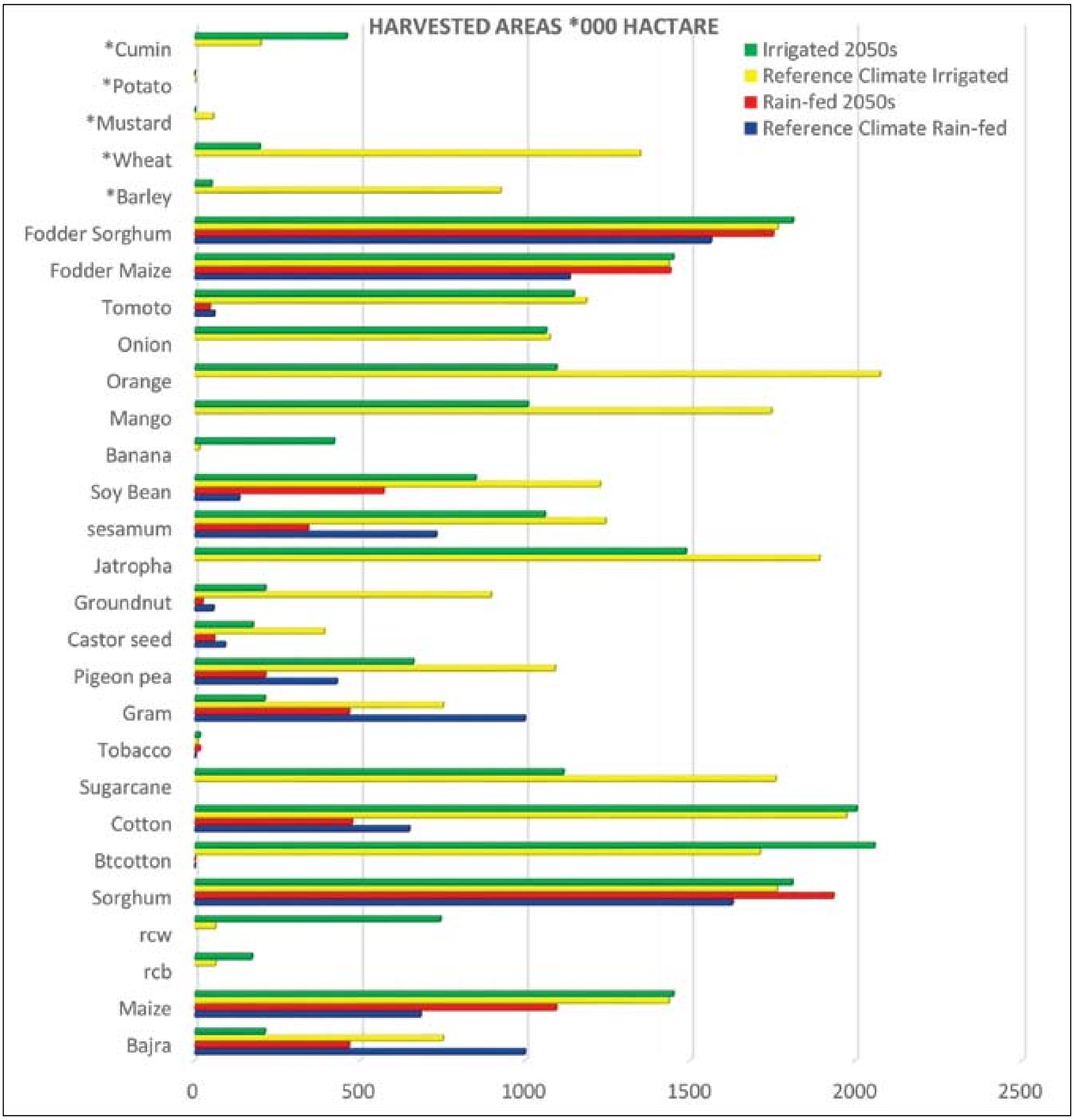

Figure 4.18: Harvested Areas by Crops for Reference Climate (1981–2010) and for RCP4.5 Scenario 2050s (2041–2070) in North Gujarat

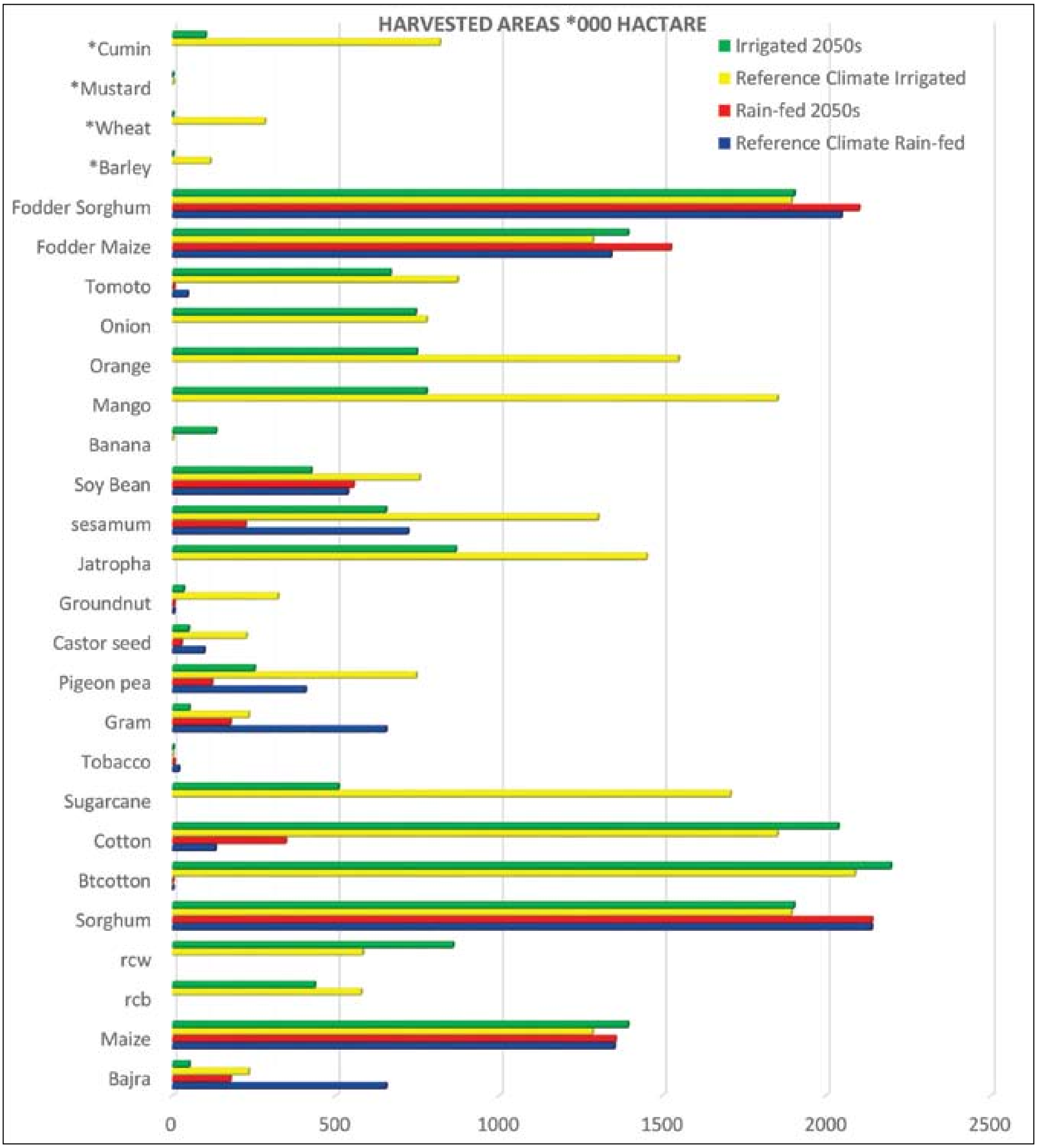

Figure 4.19: Harvested Areas by Crops for Reference Climate (1981–2010) and for RCP4.5 Scenario 2050s (2041–2070) in Central Gujarat

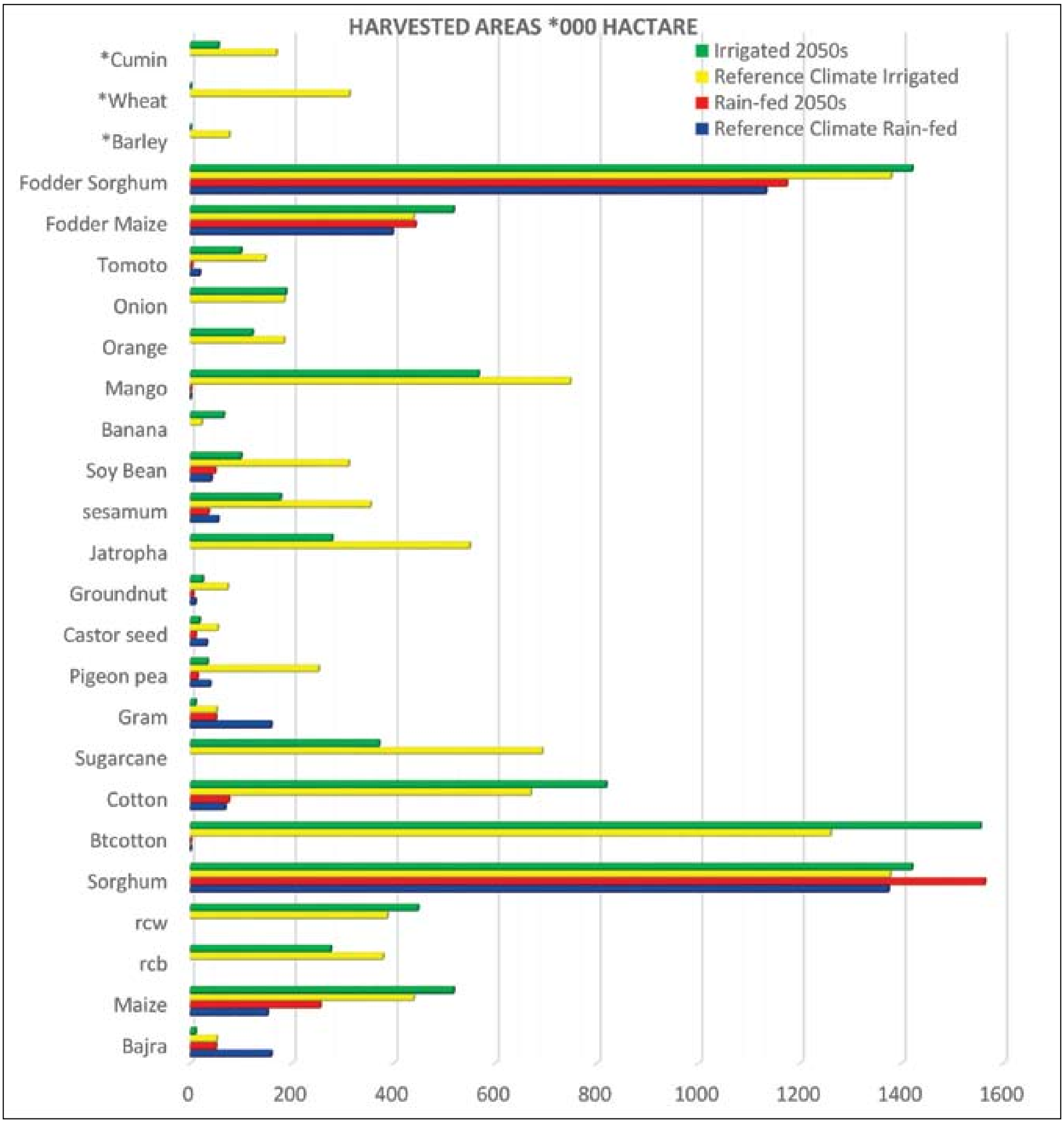

Figure 4.20: Harvested Areas by Crops for Reference Climate (1981–2010) and for RCP4.5 Scenario 2050s (2041–2070) in Saurashtra

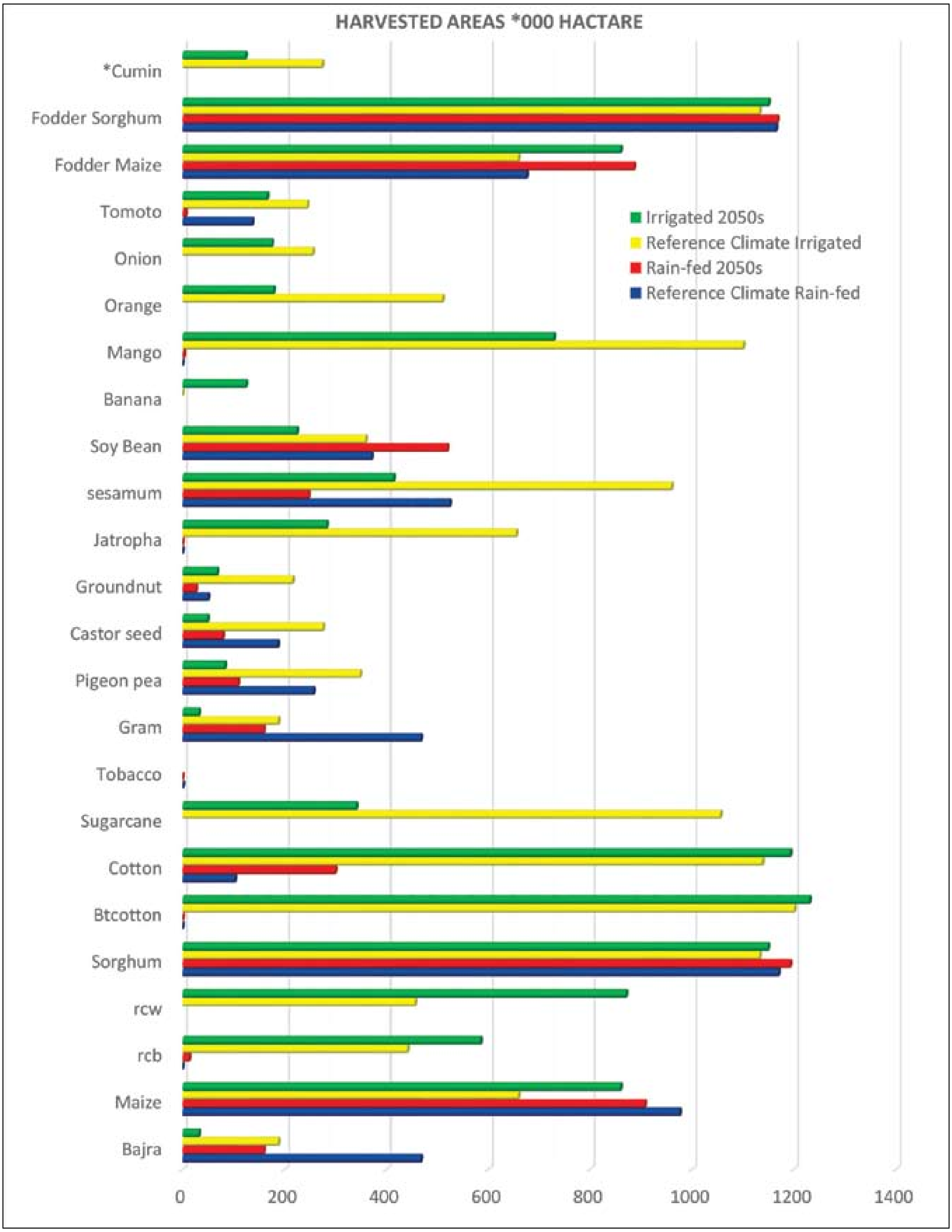

Figure 4.21: Harvested Areas by Crops for Reference Climate (1981–2010) and for RCP4.5 Scenario 2050s (2041–2070) in South Gujarat

The below tables provide a reference climate overview of harvested areas, average output, and production for the top agricultural commodities of Gujarat under rain-fed and irrigated conditions. For rain-fed conditions only sorghum has sustenance in future completely under rain fed conditions in Kutch specifically but also has growth in the rest of Gujarat as well. Mustard, BT Cotton, mango, wheat, and white potato have never been grown under rain and there's only the same in future also. Cotton, maize, and sorghum show an increase in production by 5 to 10%. For irrigated conditions as for production, the substantial decline of harvested areas has been mirrored by yield decreases, with only sorghum, cotton, BT cotton, and maize showing promise of increase in yield between 8 and 32%.

Table 4.7: Area Harvested (000 Hectare), Production (00000 Tons) and Yield (Kg/Hectare) of Gujarat for Rain-Fed Crops:

Crop Type	Rain-fed Crops	------------------------------ VS+S ---------------------------					
		Area *000 Hectare			Yield kg / Hectare		
		1981-2010	2050s	% Difference	1981-2010	2050s	% Difference
Food Grains	Bajra	2277.8	852.1	-62.6	1695.0	1703.3	0.5
	Maize	3162.9	3616.2	14.3	6702.4	6692.2	-0.2
	Rice (rcb)	0.0	12.8		0.0	3216.0	
	Rice (rcw)	0.0	0.0		0.0	0.0	
	Sorghum	6386.0	7026.9	10.0	5844.8	6089.0	4.2
Cash Crops	Btcotton	0.0	0.4		0.0	789.0	
	Cotton	950.3	1198.6	26.1	577.0	615.4	6.7
	Sugarcane	0.0	0.0		0.0	0.0	
	Tobacco	22.0	18.8	-14.5	478.3	884.5	84.9
Pulses	Gram	2277.8	852.1	-62.6	1695.0	1703.3	0.5
	Pigeon pea	1130.8	455.4	-59.7	1982.5	1983.3	0.0
Oil Crops	Castor seed	406.3	172.5	-57.5	1995.8	2011.3	0.8
	Groundnut	117.4	56.7	-51.7	2171.8	2203.5	1.5
	Jatropha	0.0	0.0		0.0	0.0	
	sesamum	2030.0	847.9	-58.2	2666.2	2617.4	-1.8
	Soy Bean	1080.3	1692.7	56.7	3130.4	2946.0	-5.9
Horticulture crops	Mango	0.0	3.1		0.0	8371.0	
	Onion	0.0	0.0		0.0	0.0	
	Orange	0.0	0.2		0.0	5809.0	
	Tomoto	258.6	55.9	-78.4	2979.4	3122.0	4.8
Fodder Crops	Fodder Maize	3561.7	4366.6	22.6	10557.4	10995.2	4.1
	Fodder Sorghum	5931.0	6288.6	6.0	10540.8	11026.8	4.6

Table 4.8: Area Harvested (000 Hectare), Production (00000 Tons) and Yield (Kg/Hectare) of Gujarat for Irrigated Crops:

Crop Type	Irrigated Crops	------------------------------ VS+S ---------------------------					
	* Rabi Crops	Area *000 Hectare			Yield kg / Hectare		
		1981-2010	2050s	% Difference	1981-2010	2050s	% Difference
Food Grains	Bajra	1223.5	303.6	-75.2	1810.0	1487.6	-17.8
	Barley*	1343.0	51.0	-96.2	3822.8	3875.5	1.4
	Maize	4086.0	4521.0	10.6	7764.0	7863.6	1.3
	Rice (rcb)	1535.5	1474.6	-4.0	4382.2	4253.0	-2.9
	Rice (rcw)	1563.4	2954.6	89.0	7560.8	4837.6	-36.0
	Sorghum	6964.5	7081.7	1.7	6538.4	6686.4	2.3
	Wheat*	2255.3	234.3	-89.6	3969.3	3864.0	-2.7
Cash Crops	Btcotton	6815.9	7923.4	16.2	1032.4	1135.6	10.0
	Cotton	6202.5	6702.3	8.1	906.8	953.8	5.2
	Sugarcane	5789.7	2554.3	-55.9	10074.8	9402.4	-6.7
	Tobacco	9.8	15.7	60.2	853.0	1000.0	17.2
Pulses	Gram	1223.5	303.6	-75.2	1810.0	1859.5	2.7
	Pigeon pea	2499.9	1031.3	-58.7	2219.2	2175.6	-2.0
Oil Crops	Castor seed	961.0	290.0	-69.8	2209.6	2187.4	-1.0
	Groundnut	1518.5	337.5	-77.8	2473.6	2472.5	0.0
	Jatropha	5234.0	3464.8	-33.8	3155.6	3031.0	-3.9
	Mustard*	56.9	0.8	-98.6	1398.5	1558.0	11.4
	sesamum	4060.4	2349.3	-42.1	3087.2	2997.4	-2.9
	Soy Bean	2722.6	1601.5	-41.2	3429.0	3444.0	0.4
Horticulture crops	Banana	36.0	745.4	1970.6	6818.5	6836.4	0.3
	Mango	6024.8	3152.1	-47.7	10710.4	10235.0	-4.4
	Potato*	2.5	0.0	-100.0	8109.0	0.0	-100.0
	Onion	53.9	7.5	-86.1	6331.0	6599.0	4.2
	Onion*	2407.5	2362.0	-1.9	7188.8	7281.4	1.3
	Orange	2329.3	8.2	-99.6	7621.0	6956.0	-8.7
	Orange*	2329.3	2324.5	-0.2	7621.0	7644.8	0.3
	Tomoto	34.7	19.6	-43.5	5075.5	3831.0	-24.5
	Tomato*	2585.4	2227.8	-13.8	5696.2	5636.0	-1.1
Fodder Crops	Fodder Maize	4086.8	4521.4	10.6	11815.0	11965.8	1.3
	Fodder Sorghum	6968.3	7087.7	1.7	11966.6	12237.4	2.3
Spices	Cumin*	1460.6	825.1	-43.5	958.0	885.0	-7.6

*Reference climate (CRUTS32: 1981–2010); **E-Mean 2041–2070, 2071-210: ENSEMBLE mean of all models (CRUTS32, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M,and ENSAMBLE MEAN-ESM2M)

1A BT Cotton: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 14676.2 hectare area of Gujarat is suitable (VS+S+MS+mS+vmS) for BT cotton, of which no area falls under very suitable and suitable class.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 14049.7 hectare areas suitable (VS+S+MS+mS+vmS) for BT cotton, a small patch of land 400 hectares (0.003%) in Valsad district of south Gujarat fall under very suitable and suitable (VS+S) category.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high input, suitable areas of Gujarat could give the output of 204 kg/hectare BT cotton.

Projected Climate (2041–2070): Projected average output of BT cotton for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat will give 243 kg/hectare of BT cotton, whereas, very small area falls under very suitable and suitable (VS+S) class which can give a yield of 789 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 25.26 tons of BT cotton from areas suitable (VS+S+MS+mS+vmS) for BT cotton. No area falls under very suitable and suitable (VS+S) class. Hence, there is no production in this category.

Projected Climate (2041–2070): Considering the reference climatic conditions of Gujarat, the state can produce a total of 28.41 tons of BT cotton from areas suitable (VS+S+MS+mS+vmS) for BT cotton. Given the Rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 0.003 tons of BT cotton.

1B BT Cotton: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectare area of Gujarat is suitable (VS+S+MS+mS+vmS) for BT cotton, of which 6815.9 hectare areas (44.05%) are very suitable and suitable (VS+S). Kutch has 554.8 hectares (8.13%) areas very suitable and suitable for BT cotton. 1712.2 hectare (25.12%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 2087.9 hectares (30.63%) in central Gujarat, 1201.2 hectares (17.62%) in south Gujarat, and 1259.8 hectares (18.48%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15467.7 hectare areas suitable (VS+S+MS+mS+vmS) for BT cotton, of which 7923.4 hectare (51.94%) falls under very suitable and suitable (VS+S) class. For the projected period, Kutch Region has 882.8 hectares (11.14%) area under very suitable and suitable (VS+S) classes for the cultivation of BT cotton. North Gujarat region has 2058.3 hectares (25.98%) very suitable and suitable (VS+S) area. Central Gujarat region has 2196.7 hectares (27.72%) very suitable and suitable area, whereas, south Gujarat region has 1230.6 hectares (15.53%) very suitable and suitable (VS+S) area. Saurashtra region has 1555 hectare (19.63%) very suitable and suitable (VS+S) area for cultivation of BT cotton.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 712.2 kg/hectare, very suitable and suitable (VS+S) areas of Gujarat can give an output of 1032.4 kg/hectare average output of BT cotton.Very suitable and suitable (VS+S) areas of Kutch region can give output of 1009 kg/hectare average output of BT cotton followed by north Gujarat region 1020 kg/hectare, central Gujarat region 1057 kg/hectare, south Gujarat region 1100 kg/hectare, and Saurashtra region 976 kg/hectare.

Projected Climate (2041–2070): Projected average output of BT cotton for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat will give 4094 kg/hectare average output of BT cotton, where very suitable and suitable (VS+S) areas will give 5740 kg/hectare average output of BT cotton. Kutch Region can give 1120 kg/hectare average output from very suitable and suitable for BT cotton cropping. North Gujarat region can give 1200 kg/hectare average output. Central Gujarat region can give 1154 kg/hectare average output from very suitable and suitable class, whereas, south Gujarat region can give 1201 kg/hectare average output from very suitable and suitable areas. Saurashtra region having will give 1065 kg/hectare average output from very suitable and suitable areas.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 93.798 tons of BT cotton from areas suitable (VS+S+MS+mS+vmS) for BT cotton. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 63.564 (67.77% of total production) tons of BT cotton. Kutch region can produce 5.037 tons (7.92%) of BT cotton followed by north Gujarat region 15.714 tons (24.72%), Central Gujarat region 19.862 tons (31.24%), south Gujarat region 11.888 tons (18.70%), and Saurashtra region 11.063 tons (17.40%).

Projected Climate (2041–2070): Considering the projected agro-ecological conditions of Gujarat, the state can produce a total of 105.928 tons of BT cotton from areas suitable (VS+S+MS+mS+vmS) for BT cotton. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 81.262 (76.71% of total production) tons of BT cotton. Kutch Region can give of 8.826 tons (10.86%) of production from very suitable and suitable (VS+S) for BT cotton. North Gujarat region can give 21.997 tons (27.04%) of yield. Central Gujarat region can give 22.607 tons (27.82%) from very suitable and suitable (VS+S) areas, whereas, south Gujarat region can give 13.112 tons (16.14%) from very suitable and suitable areas. Saurashtra region will give 14.740 tons (18.14%) from very suitable and suitable (VS+S) areas. Kutch district has highest production of 8.826 tons (10.86%) of BT cotton, followed by Banaskantha 7.039 tons (8.66%), Ahmedabad 5.20 tons (6.40%), Bharuch 4.564 tons (5.62%), Mehsana 4.421 tons (5.44%), Vadodara 3.951 tons (4.86%), Surendranagar 3.686 tons (4.54%), Kheda 3.58 tons (4.41%), Surat 3.288 tons (4.05%), and Patan 3.209 tons (3.95%).

2A Cotton Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15462 hectare area of Gujarat is suitable (VS+S+MS+mS+vmS) for cotton, of which 950.3 hectare areas (6.15%) fall under very suitable and suitable (VS+S) classes. Kutch has no areas very suitable and suitable (VS+S) for cotton. 649.1 hectare (68.30%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 130.8 hectares (13.76%) in central Gujarat, 102.6 hectares (10.80%) in south Gujarat, and 67.8 hectares (7.13%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15448.6 hectares areas suitable

(VS+S+MS+mS+vmS) for cotton, of which 1198.6 hectare (7.76%) falls under very suitable and suitable (VS+S) class. Kutch Region has 1.1 hectares areas very suitable and suitable (VS+S) for cotton, north Gujarat region has 476 hectares (39.71%) of very suitable and suitable (VS+S) areas. Central Gujarat region has 345.9 hectares (28.86%) of very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 300.1 hectares (25.04%) of very suitable and suitable (VS+S) areas. Saurashtra region has 75.5 hectares (6.30%) of very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 308 kg/hectare cotton, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 577 kg/hectare. Kutch region doesn't have very suitable and suitable (VS+S) areas for cotton. North Gujarat region can give average output of 532 kg/hectare, central Gujarat region 534 kg/hectare, south Gujarat region 681 kg/hectare, and Saurashtra region 561 kg/hectare.

Projected Climate (2041–2070): Projected average output of cotton for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 323.2 kg/hectare cotton, whereas very suitable and suitable (VS+S) areas can give average output 615.4 kg/hectare of cotton. Kutch region can give average output 523 kg/hectare of cotton. North Gujarat region can give average output 590 kg/hectare of cotton. Central Gujarat region can give 630 kg/hectare from very suitable and suitable (VS+S) class, whereas, south Gujarat region can give 708 kg/hectare from very suitable and suitable (VS+S) areas. Saurashtra region will give 626 kg/hectare of cotton from very suitable and suitable (VS+S) areas.

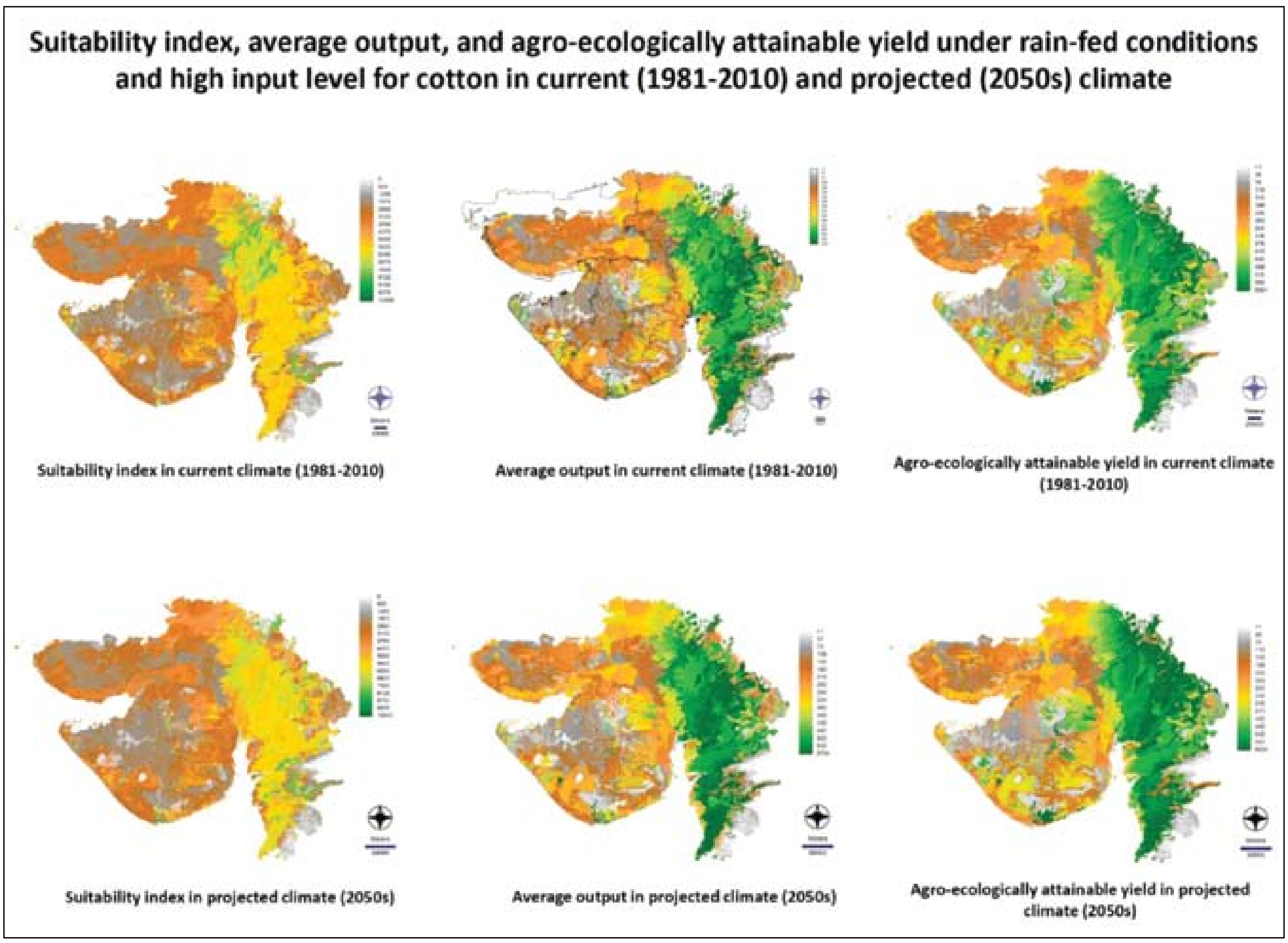

Figure 4.22: Climate Change Impacts on Crop Suitability and Attainable Yield of Cotton under Rain-Fed Conditions Across Gujarat

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 39.783 tons from its areas suitable (VS+S+MS+mS+vmS) for cotton. Given the rain-fed conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can give 4.704 tons (11.8% of total production) yield of cotton. Kutch region doesn't have very suitable and suitable (VS+S) areas for cotton. North Gujarat region can produce 3.105 tons (66%), central Gujarat region 0.629 tons (13.37%), south Gujarat region 0.628 tons (13.35%), and Saurashtra region 0.342 tons (7.27%) of cotton.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 41.379 tons of cotton from areas suitable (VS+S+MS+mS+vmS) for cotton. Given the rain-fed conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can give 6.831 tons (16.51% of total production) yield of cotton. Kutch region can produce 0.005 tons (0.07%) from very suitable and suitable (VS+S) areas for cotton, north Gujarat region can produce 2.528 tons (37.01%) of cotton. Central Gujarat region can produce 1.96 tons (28.69%) from very suitable and suitable (VS+S) class, whereas, south Gujarat region can produce 1.913 tons (28%) from very suitable and suitable (VS+S) areas. Saurashtra region will produce 0.425 tons (6.22%) from very suitable and suitable (VS+S) lands for cultivation of cotton.

2B Cotton: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for cotton, of which 6202.5 hectares areas (40.09%) fall under very suitable and suitable (VS+S) class. Kutch has 569.7 hectares (9.19%) areas very suitable and suitable (VS+S) for cotton. 1973.7 hectare (31.82%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 1850.4 hectares (29.83%) in central Gujarat, 1138.7 hectares (18.35%) in south Gujarat, and 670 hectares (10.80%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15477.4 hectares areas suitable (VS+S+MS+mS+vmS) for cotton, of which 6702.3 hectare (43.30%) falls under very suitable and suitable class. Kutch Region has 649.4 hectares (9.69%) areas very suitable and suitable (VS+S) for cotton. North Gujarat region has 2004.9 hectares (29.91%) very suitable and suitable (VS+S) areas. Central Gujarat region has 2037.1 hectares (30.39%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 1193 hectare (17.80%) very suitable and suitable (VS+S) areas. Saurashtra region has 817.9 hectares (12.20%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable areas (VS+S+MS+mS+vmS) of Gujarat can give average output 613.4 kg/hectare of cotton, whereas, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 906.8 kg/hectare. Kutch region can give average output 925 kg/hectare of cotton followed by north Gujarat region 913 kg/hectare, central Gujarat region 886 kg/hectare, south Gujarat region 901 kg/hectare, and Saurashtra region 909 kg/hectare in Very suitable and suitable (VS+S) areas.

Projected Climate (2041–2070): Projected average output of cotton for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 653.2 kg/hectare of cotton, whereas, very suitable and suitable (VS+S) areas can give 953.8 kg/hectare of cotton. Kutch region can give an average output of 962 kg/hectare cotton from very suitable and suitable (VS+S) areas. North Gujarat region can give average output 974 kg/hectare of cotton. Central Gujarat region can give average output 935 kg/hectare of cotton from very suitable and suitable (VS+S) class, whereas, south Gujarat region can give average output 961 kg/hectare of cotton from very suitable and suitable (VS+S) areas. Saurashtra region can give an average output of 937 kg/hectare cotton from very suitable and suitable (VS+S) areas.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 80.515 tons of cotton from areas suitable (VS+S+MS+mS+vmS) for cotton. Given the irrigated conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can produce 50.434 (62.64% of total production) tons of cotton. Kutch region can produce 4.744 tons (9.41%) of cotton. North Gujarat region can produce 16.221 tons (32.16%), central Gujarat region can produce 14.755 tons (29.26%), south Gujarat region can produce 9.231 tons (18.30%), and Saurashtra region can produce 5.483 tons (10.87%) of cotton.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 85.691 tons of cotton from areas suitable (VS+S+MS+mS+vmS) for cotton, whereas, very suitable and suitable (VS+S) areas can give 57.543 tons of production. Kutch region can produce 5.620 tons (9.77%) of cotton from very suitable and suitable (VS+S) areas. North Gujarat region can produce 17.567 tons (30.53%) of cotton. Central Gujarat region can produce 17.140 tons (29.79%) from very suitable and suitable (VS+S) areas, whereas, south Gujarat region can produce 10.315 tons (17.93%) from very suitable and suitable (VS+S) areas. Saurashtra region can produce 8.179 tons (11.99%) from very suitable and suitable (VS+S) lands for cultivation of cotton.

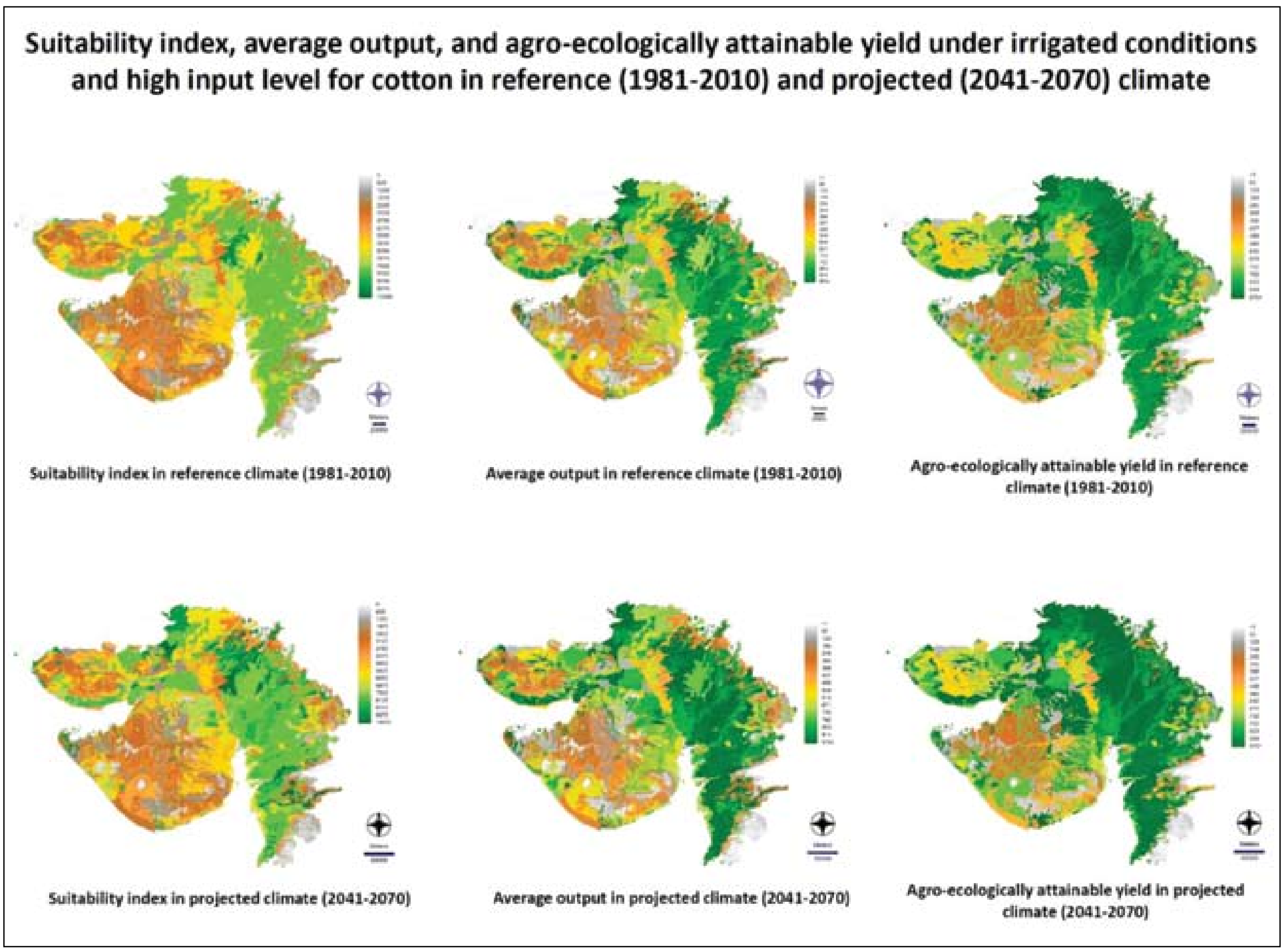

Figure 4.23: Climate Change Impacts on Crop Suitability and Attainable Yield of Cotton under Irrigated Conditions Across Gujarat

3A Groundnut: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15437 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for groundnut cultivation, of which 117.4 hectares areas (0.76%) are very suitable and suitable (VS+S). Kutch has no areas very suitable and suitable (VS+S) for groundnut. 55.4 hectare (47.19%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 3.6 hectares (3.06%) in central Gujarat, 49.6 hectares (42.25%) in south Gujarat, and 8.8 hectares (7.50%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 13643.8 hectares areas suitable (VS+S+MS+mS+vmS) for groundnut, of which 56.7 hectares (0.42%) areas fall under very suitable and suitable (VS+S) class. Kutch region has no areas very suitable and suitable for groundnut. North Gujarat region has 23.3 hectares (41.09%) very suitable and suitable (VS+S) areas. Central Gujarat region has 3 hectares (5.29%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 26.1 hectares (46.03%) very suitable and suitable (VS+S) areas. Saurashtra region has 4.3 hectares (7.58%) very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 748 kg/hectare, whereas, very suitable and suitable (VS+S) areas of Gujarat can give average output 2172 kg/hectare of groundnut. Kutch region has no areas very suitable and suitable (VS+S) for groundnut. North Gujarat region can give an average output of 2178 kg/hectare, central Gujarat region can give an average output of 2190 kg/hectare, south Gujarat region can give an average output of 2111 kg/hectare, and Saurashtra region can give an average output of 2208 kg/hectare.

Projected Climate (2041–2070): Projected average output of groundnut for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 629 kg/hectare groundnut, whereas, very suitable and suitable (VS+S) areas can give an average output of 2203.5 kg/hectare. Kutch region has no areas very suitable and suitable (VS+S) for groundnut. north Gujarat region can give average output 2215 kg/hectare of groundnut. Central Gujarat region can give average output 2226 kg/hectare from very suitable and suitable (VS+S) class, whereas, south Gujarat region can give average output 2219 kg/hectare from very suitable and suitable (VS+S) areas.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 97.615 tons of groundnut from areas (VS+S+MS+mS+vmS) suitable for groundnut. Given the rain-fed conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can produce 2.272 (2.33% of total production) tons of groundnut. Kutch region has no areas very suitable and suitable for groundnut. North Gujarat region can produce 1.086 tons (47.80%), central Gujarat region can produce 0.070 tons (3.08%), south Gujarat region can produce 0.942 tons (41.46%), and Saurashtra region can produce 0.174 tons (7.66%) of groundnut.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 74.453 tons of groundnut from areas suitable (VS+S+MS+mS+vmS) for groundnut. Given the rain-fed conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can produce 1.131 (1.52% of total production) tons of groundnut. Kutch region has no areas very suitable and suitable (VS+S) for groundnut. North Gujarat region can produce 0.464 tons (41.03%)

of groundnut. Central Gujarat region can produce 0.061 tons (5.39%) from very suitable and suitable (VS+S) class, whereas, south Gujarat region can produce 0.522 tons (46.15%) from very suitable and suitable (VS+S) areas.

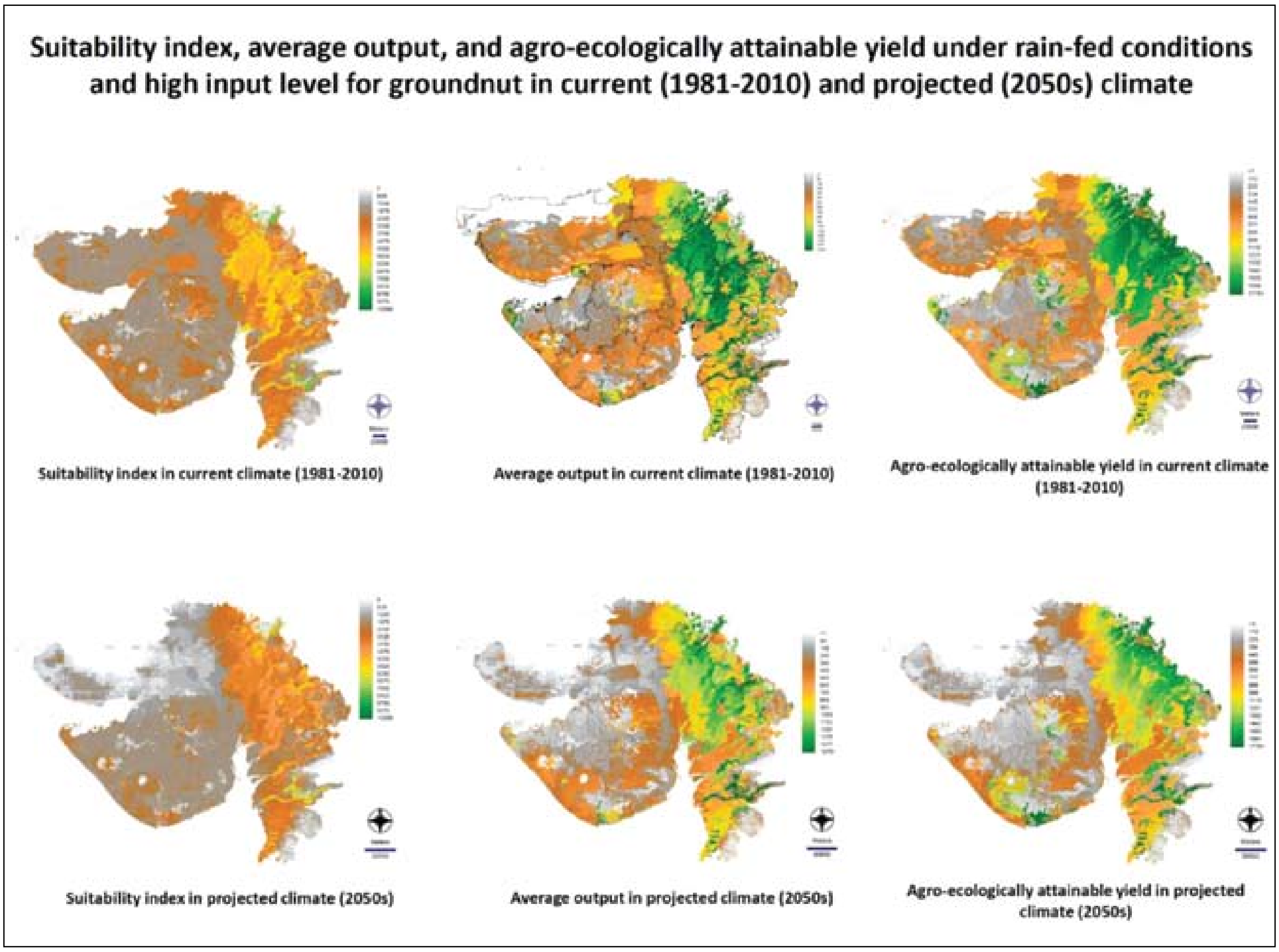

Figure 4.24: Climate Change Impacts on Crop Suitability and Attainable Yield of Groundnut under Rain-Fed Conditions Across Gujarat

3B Groundnut: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for groundnut, of which 1518.5 hectares areas (9.82%) are very suitable and suitable (VS+S). Kutch has 9.6 hectares (0.63%) areas very suitable and suitable (VS+S) for groundnut. 897.3 hectare (59.09%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 322.3 hectares (21.22%) in central Gujarat, 216 hectares (14.22%) in south Gujarat, and 73.3 hectares (4.83%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15289.6 hectares areas suitable (VS+S+MS+mS+vmS) for groundnut, of which 337.5 hectares (2.21%) areas are very suitable and suitable (VS+S). Kutch region has no area very suitable and suitable for groundnut. North Gujarat region has 213.5 hectares (63.26%) very suitable and suitable (VS+S) areas. Central Gujarat region has 32.5 hectares (9.63%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 67.7 hectares (20.06%) very suitable and suitable (VS+S) areas. Saurashtra region has 23.8 hectares (7.05%) very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 1276 kg/hectare whereas very suitable and suitable (VS+S) areas of Gujarat can give average output 2474 kg/hectare of groundnut. Kutch region can give average output 2426 kg/hectare of groundnut. North Gujarat region can give average output 2499 kg/hectare, central Gujarat region can give average output 2418 kg/hectare, south Gujarat region can give average output 2518 kg/hectare, and Saurashtra region can give average output 2507 kg/hectare.

Projected Climate (2041–2070): Projected average output of groundnut for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 1024 kg/hectare of groundnut, whereas, very suitable and suitable (VS+S) areas can give average output 2473 kg/hectare. Kutch region has no area very suitable and suitable for groundnut. North Gujarat region can give average output 2545 kg/hectare of groundnut. Central Gujarat region can give average output 2425 kg/hectare from very suitable and suitable (VS+S) areas, whereas, south Gujarat region can give average output 2442 kg/hectare from very suitable and suitable (VS+S) areas. Saurashtra region can give average output 2478 kg/hectare from very suitable and suitable (VS+S) areas.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 165.163 tons of groundnut from areas suitable (VS+S+MS+mS+vmS) for groundnut. Given the irrigated conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can produce 33.958 (20.54% of total Production) tons of groundnut. Kutch region can produce 0.210 tons (0.62%) of groundnut. North Gujarat region can produce 20.184 tons (59.44%), central Gujarat region can produce 7.015 tons (20.66%), south Gujarat region can produce 4.896 tons (14.42%), and Saurashtra region can produce 1.653 tons (4.87%).

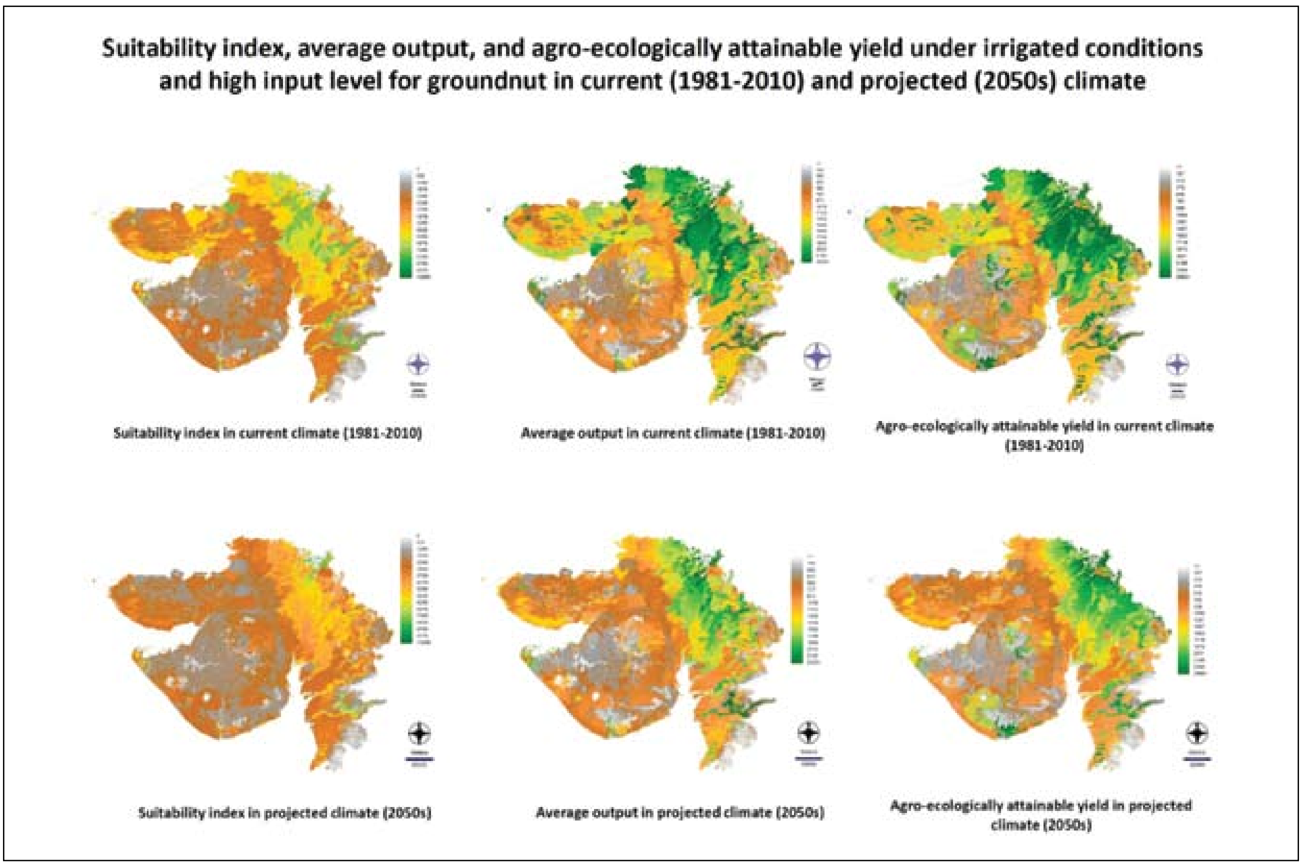

Figure 4.25: Climate Change Impacts on Crop Suitability and Attainable Yield of Groundnut under Irrigated Conditions Across Gujarat

Projected climate (2041–2070): Considering the projected climatic conditions of Gujarat, the suitable (VS+S+MS+mS+vmS) areas of the state has a potential of producing a total of 131.798 tons of groundnut, whereas, very suitable and suitable (VS+S) areas can produce 7.618 (5.78% of total production) tons of groundnut. Kutch region doesn't have very suitable and suitable (VS+S) areas for groundnut. North Gujarat region can produce 4.89 tons (64.19%) of groundnut from very suitable and suitable (VS+S) areas. Central Gujarat region can produce 0.709 tons (9.31%) from very suitable and suitable (VS+S) areas, whereas, south Gujarat region can produce 1.488 tons (19.53%) from very suitable and suitable (VS+S) areas. Saurashtra region can produce 0.531 tons (6.97%) from very suitable and suitable (VS+S) areas.

4A Wheat: Rain-Fed

Suitability Index (Hectare)

Reference climate (1981–2010): Reference climate shows, 2000 hectare area of Gujarat is suitable (VS+S+MS+mS+vmS) for wheat, of which no area falls under very suitable and suitable class.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 44800 hectares areas suitable (VS+S+MS+mS+vmS) for wheat, of which no area falls under very suitable and suitable class.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 368 kg/hectare of wheat, where very suitable and suitable (VS+S) areas yield 0 kg/hectare of wheat.

Projected Climate (2041–2070): Projected average output of wheat for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give 562 kg/hectare of wheat, where very suitable and suitable (VS+S) areas yield 0 kg/hectare of wheat.

Agro-Ecologically Attainable Yield (tons)

Reference Climate (1981–2010): Considering the historic agro-ecological conditions of Gujarat, the state can produce a total of 600 tons of wheat from areas suitable (VS+S+MS+mS+vmS) for wheat. However, no area falls under very suitable and suitable class.

Projected Climate (2041–2070): Considering the projected agro-ecological conditions of Gujarat, the state has a potential of producing a total of 211 tons of wheat from areas suitable (VS+S+MS+mS+vmS) for wheat. However, no area falls under very suitable and suitable class.

4B Wheat: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15469.5 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for wheat, of which 2255.3 hectares (14.58%) areas are very suitable and suitable (VS+S). Kutch has 310.6 hectares (13.77%) areas very suitable and suitable (VS+S) for wheat. 1349.4 hectare (59.83%) of very suitable and suitable (VS+S) areas happen to be in north Gujarat, 282.3 hectares (12.52%) in central Gujarat, and 313 hectares (13.87%) in Saurashtra. South Gujarat has no areas very suitable and suitable (VS+S) for wheat.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 13504.1 hectares area suitable (VS+S+MS+mS+vmS) for wheat, of which 234.3 hectares (1.74%) areas are very suitable and suitable (VS+S).

Kutch region has 37 hectares (15.79%) areas very suitable and suitable (VS+S) for wheat. North Gujarat region has 197 hectares (84.08%) very suitable and suitable (VS+S) areas. Central Gujarat and south Gujarat regions have no areas very suitable and suitable. Saurashtra region has only 0.3 hectares (0.13%) very suitable and suitable (VS+S) areas for wheat cultivation.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs very suitable and suitable (VS+S) areas of Gujarat can give an average output of 12892 kg/hectare wheat. Kutch region can give an average output of 4008 kg/hectare wheat. North Gujarat region can give an average output of 4186 kg/hectare, central Gujarat region can give an average output of 3892 kg/hectare, and Saurashtra region can give an average output of 3791 kg/hectare. South Gujarat region has no area very suitable or suitable for wheat. Banaskantha can give highest average output of 4379 kg/hectare wheat, followed by Sabarkantha 4273 kg/hectare, Mehsana 4158 kg/hectare, Patan 4095 kg/hectare, Junagadh 4079 kg/hectare, Aravalli 4033 kg/hectare, Kutch 4008 kg/hectare, Dahod 3985 kg/hectare, and Gandhinagar 3948 kg/hectare.

Projected Climate (2041–2070): Projected average output of wheat for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 2172 kg/hectare wheat, whereas, very suitable and suitable (VS+S) areas can give an average output of 3864 kg/hectare wheat. Kutch region can give an average output of 3836 kg/hectare from areas very suitable and suitable (VS+S) for wheat. North Gujarat region can give an average output of 4120 kg/hectare. Saurashtra region can give an average output of 3636 kg/hectare. Central Gujarat and south Gujarat regions have no areas very suitable and suitable for wheat.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 351.020 tons of wheat from areas suitable (VS+S+MS+mS+vmS) for wheat, whereas,

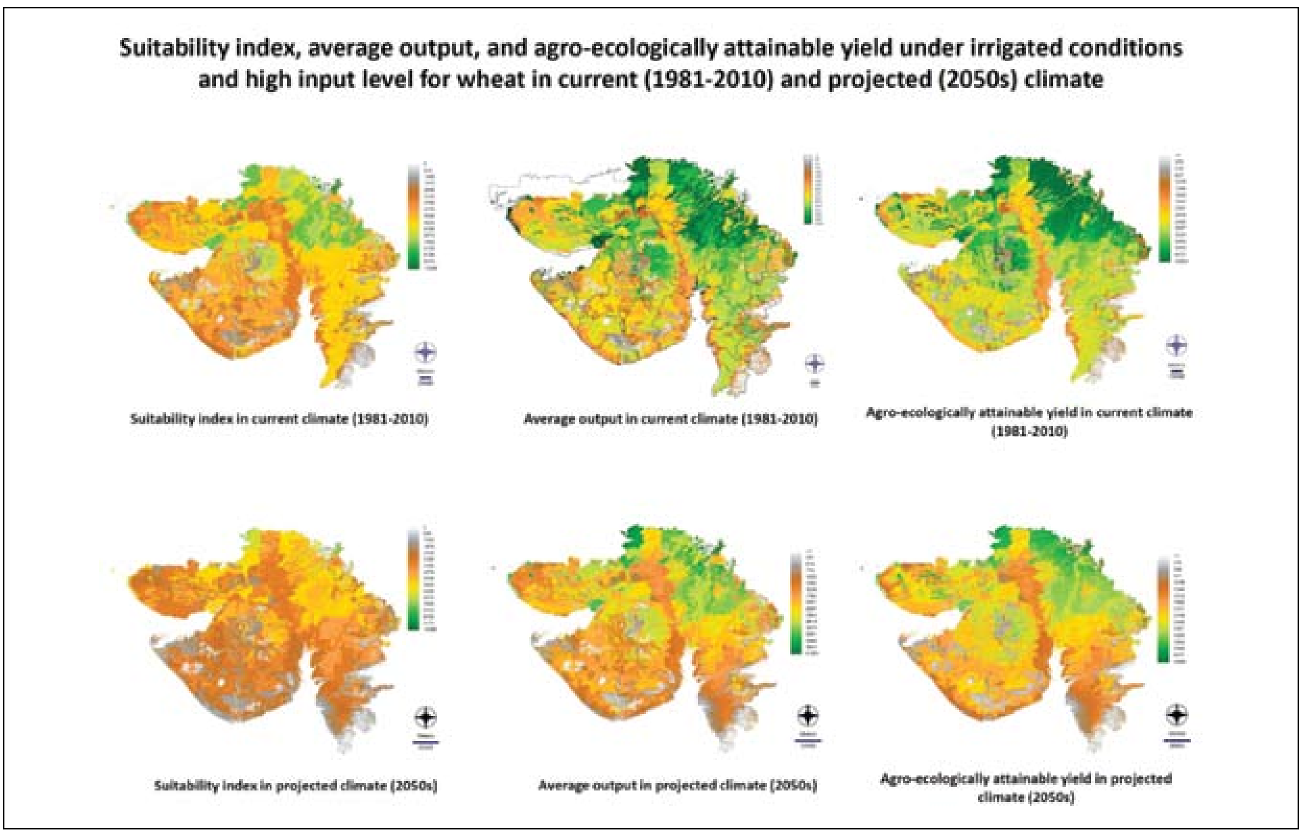

Figure 4.26: Climate Change Impacts on Crop Suitability and Attainable Yield of Wheat under Irrigated Conditions Across Gujarat

very suitable and suitable (VS+S) areas of Gujarat can produce 82.613 tons of wheat. Kutch region can produce 11.204 tons (13.56%) of wheat. North Gujarat region can produce 50.840 tons (61.54%), central Gujarat region can produce 9.889 tons (11.97%), and Saurashtra region can produce 10.68 tons (12.93%). South Gujarat region has no areas very suitable or suitable (VS+S) for wheat.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 263.28 tons of wheat from areas suitable (VS+S+MS+mS+vmS) for wheat whereas very suitable and suitable (VS+S) areas can produce 8.588 tons (3.26). Kutch region can produce 1.276 tons (14.86%) of wheat from very suitable and suitable (VS+S) areas. North Gujarat region can produce 7.304 tons (85.05%). Saurashtra region can produce 0.8 tons (0.09%) from the very suitable and suitable (VS+S) areas. Central Gujarat and south Gujarat regions have no areas very suitable and suitable for wheat.

5A Bajra: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15387.5 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for bajra, of which 2277.8 hectares areas (14.80%) are very suitable and suitable. Kutch region has no areas very suitable and suitable for bajra. 999.9 hectare (43.9%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 651.9 hectares (28.62%) in central Gujarat, 467.8 hectares (20.54%) in south Gujarat, and 158.2 hectares (6.95%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 14181.5 hectares areas suitable (VS+S+MS+mS+vmS) for bajra, of which 852.1 hectares (6.01%) areas are very suitable and suitable (VS+S). Kutch region has no areas very suitable and suitable for bajra. North Gujarat region has 467.2 hectares (54.83%) very suitable and suitable (VS+S) areas. Central Gujarat region has 1.758 hectares (20.63%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 1.594 hectares (18.71%) very suitable and suitable (VS+S) areas. Saurashtra region has 0.497 hectares (5.83%) very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 904 kg/hectare bajra, whereas, very suitable and suitable (VS+S) areas can give an average output of 1720 kg/hectare. Kutch region can give an average output of 1594 kg/hectare bajra. North Gujarat region can give an average output of 1801 kg/hectare, central Gujarat region can give an average output of 1705 kg/hectare, south Gujarat region can give an average output of 1698 kg/hectare, and Saurashtra region can give an average output of 1677 kg/hectare.

Projected Climate (2041–2070): Projected average output of bajra for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 745 kg/hectare bajra, whereas, very suitable and suitable (VS+S) areas can give an average output of 1703 kg/hectare. Kutch region has no areas very suitable and suitable for bajra. North Gujarat region can give an average output of 1761 kg/hectare bajra. Central Gujarat region can give an average output of 1695 kg/hectare from very suitable and suitable (VS+S) class, whereas, south Gujarat region can give an average output of 1681 kg/hectare from very suitable and suitable areas. Saurashtra region can give an average output of 1676 kg/hectare from very suitable and suitable areas.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 121.044 tons of bajra from areas suitable (VS+S+MS+mS+vmS) for bajra. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 35.746 tons (29.53% of total production) of bajra. Kutch region has no region very suitable and suitable for bajra. North Gujarat region can produce 16.204 tons (45.33%), central Gujarat region can produce 10.005 tons (27.99%), south Gujarat region can produce 7.149 tons (20%), and Saurashtra region can produce 2.388 tons (6.68%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 94.547 tons of bajra from areas suitable (VS+S+MS+mS+vmS) for bajra whereas very suitable and suitable (VS+S) areas can produce 13.248 tons (14.01% of total production). Kutch region has no areas very suitable and suitable for bajra. North Gujarat region can produce 7.404 tons (55.89%) of bajra. Central Gujarat region can produce 2.682 tons (20.24%) from very suitable and suitable (VS+S) class, whereas, south Gujarat region can produce 2.412 tons (18.21%) from very suitable and suitable (VS+S) areas. Saurashtra region can produce 0.750 tons (5.66%) from very suitable and suitable (VS+S) class.

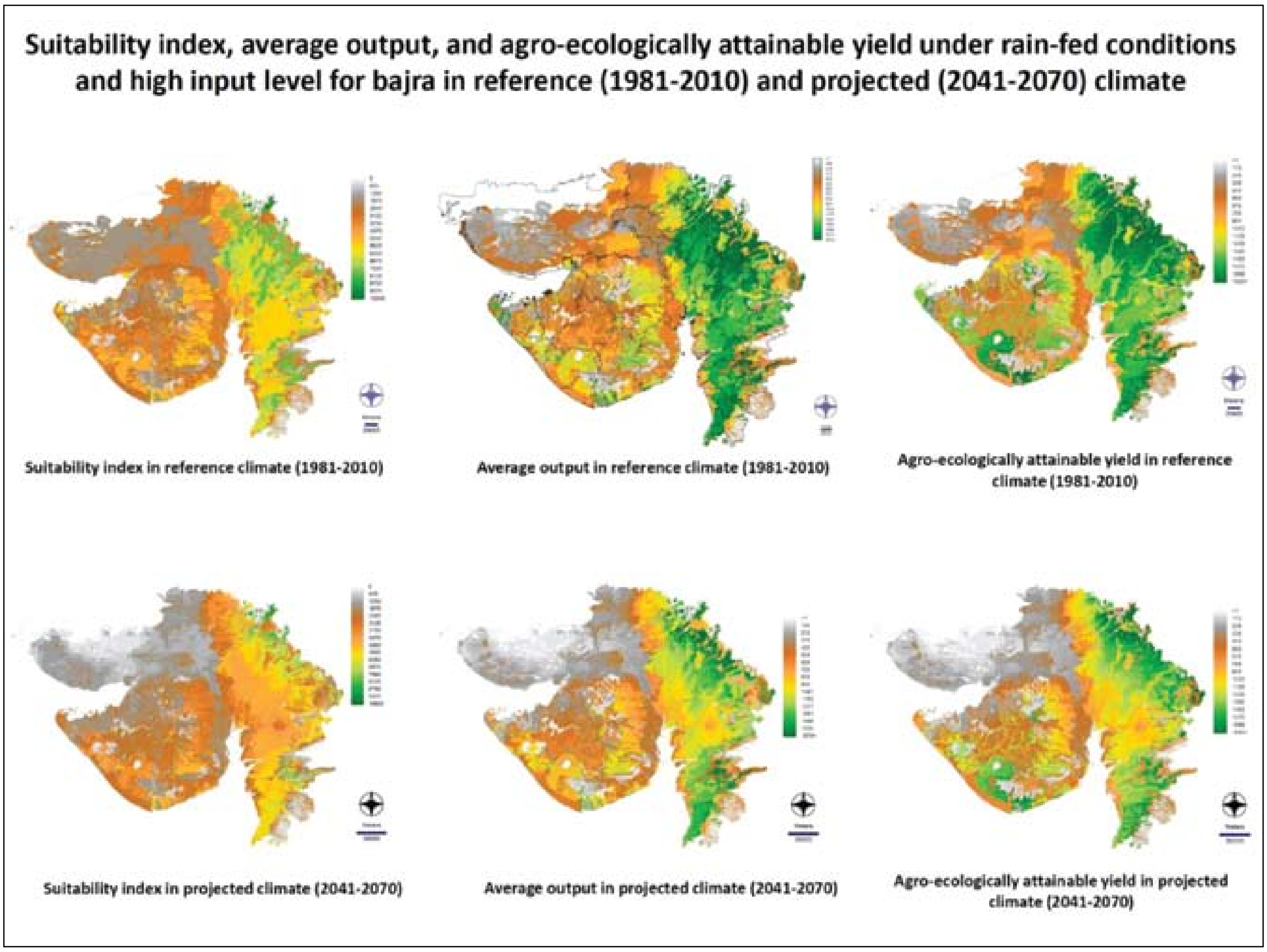

Figure 4.27: Climate Change Impacts on Crop Suitability and Attainable Yield of Bajra under Rain-Fed Conditions Across Gujarat

5B Bajra: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for bajra, of which 1223.5 hectares areas (7.91%) are very suitable and suitable (VS+S). Kutch has no areas very suitable and suitable (VS+S) for bajra. 752.1 hectare (61.47%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 232.1 hectares (18.97%) in central Gujarat, 187.8 hectares (15.35%) in south Gujarat, and 51.5 hectares (4.21%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15079.6 hectares areas suitable (VS+S+MS+mS+vmS) for bajra, of which 303.6 hectares (2.01%) areas are very suitable and suitable. Kutch region has no areas very suitable and suitable for bajra. North Gujarat region has 212 hectares (69.83%) very suitable and suitable (VS+S) areas. Central Gujarat region has 50.5 hectares (16.23%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 31.9 hectares (10.51%) very suitable and suitable (VS+S) areas. Saurashtra region has 9.2 hectares (3.03%) very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 1090 kg/hectare, whereas, very suitable and suitable (VS+S) areas can give an average output of 1828 kg/hectare bajra. Kutch region can give an average output of 1740 kg/hectare bajra. North Gujarat region can give average output 1876 kg/hectare, central Gujarat region can give average output 1827 kg/hectare, south Gujarat region can give average output 1816 kg/hectare, and Saurashtra region can give average output 1791 kg/hectare.

Projected Climate (2041–2070): Projected average output of bajra for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give average output 844 kg/hectare of bajra, whereas, very suitable and suitable (VS+S) areas can give average output 1860 kg/hectare. Kutch region has no areas very suitable and suitable (VS+S) for bajra. North Gujarat region can give average output 1929 kg/hectare of bajra. Central Gujarat region can give average output 1857 kg/hectare from very suitable and suitable (VS+S) class, whereas, south Gujarat region can give average output 1828 kg/hectare from very suitable and suitable (VS+S) areas. Saurashtra region can give average output 1824 kg/hectare from very suitable and suitable (VS+S) class.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 145.301 tons of bajra from areas suitable (VS+S+MS+mS+vmS) for bajra. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 20.417 tons (14.05% of total production) of bajra. Kutch region has no areas suitable for bajra. North Gujarat region can produce 12.701 tons (62.21%), central Gujarat region can produce 3.816 tons (18.69%), south Gujarat region can produce 3.070 tons (15.04%), and Saurashtra region can produce 0.830 tons (4.07%) of bajra.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 111.062 tons of bajra from areas suitable (VS+S+MS+mS+vmS) for bajra, whereas, very suitable and suitable regions can give a yield of 5.201 tons (4.68% of total production). Kutch region has no areas very suitable and suitable for bajra. North Gujarat region can produce 3.681 tons (70.77%) of bajra. Central Gujarat region can produce 0.844 tons (16.23%) from very suitable and suitable (VS+S) class, whereas, south Gujarat region can produce 0.525 tons (10.09%) from very suitable and suitable (VS+S) areas. Saurashtra region can produce 0.151 tons (2.90%) from very suitable and suitable (VS+S) class.

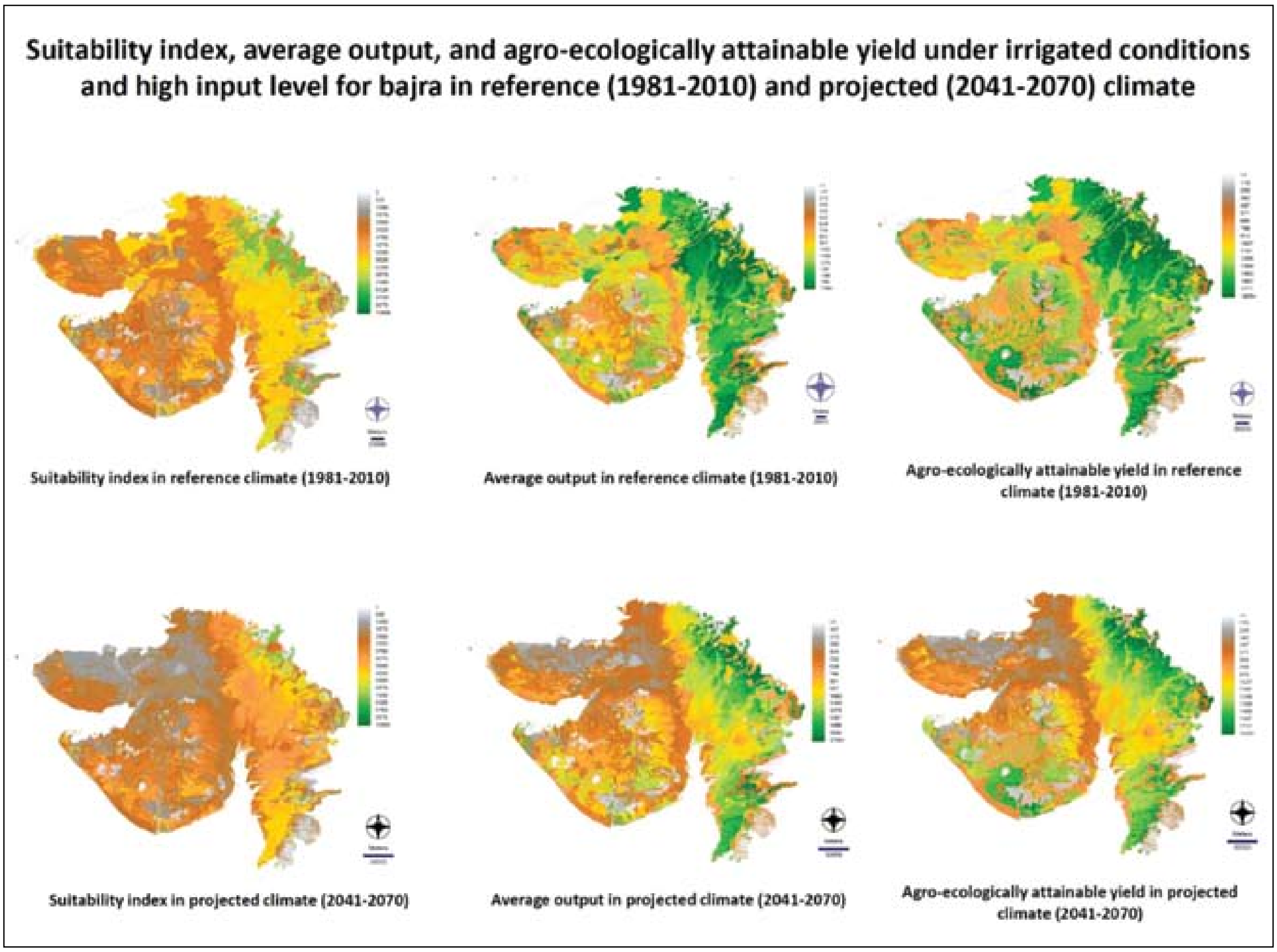

Figure 4.28: Climate Change Impacts on Crop Suitability and Attainable Yield of Bajra under Irrigated Conditions Across Gujarat

6A Maize: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15314.5 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for maize, of which 3162.9 hectares areas (20.65%) are very suitable and suitable (VS+S). Kutch has no areas very suitable and suitable (VS+S) for maize. 683.2 hectare (21.60%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 1351.7 hectares (42.74%) in central Gujarat, 976.5 hectares (30.87%) in south Gujarat, and 151.5 hectares (4.79%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15203.1 hectares areas suitable (VS+S+MS+mS+vmS) for maize, of which very suitable and suitable (VS+S) areas 3616.2 hectares (23.79%). Kutch region has 3.6 hectares (0.10%) areas very suitable and suitable (VS+S) for maize. North Gujarat region has 1094.5 hectares (30.27%) very suitable and suitable (VS+S) area. Central Gujarat region has 1355.3 hectares (37.48%) very suitable and suitable (VS+S) areas, whereas, south Gujarat region has 908 hectares (25.11%) very suitable and suitable (VS+S) areas. Saurashtra region will have 254.8 hectares (5.35%) very suitable and suitable (VS+S) areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 3570 kg/hectare maize, whereas, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 6702 kg/hectare. Kutch region can give an average output of 6934 kg/hectare maize. North Gujarat region can give average output 6655 kg/hectare, central Gujarat region can give average output 6780 kg/hectare, south Gujarat region can give average output 6662 kg/hectare, and Saurashtra region can give average output 6481 kg/hectare.

Projected Climate (2041–2070): Projected average output of maize for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 3787 kg/hectare maize, whereas, very suitable and suitable (VS+S) areas can give an average output of 6692 kg/hectare. Kutch region can give an average output of 5952 kg/hectare from very suitable and suitable for maize. North Gujarat region can give an average output of 7068 kg/hectare. Central Gujarat region can give an average output of 6930 kg/hectare from very suitable and suitable class, whereas, south Gujarat region can give an average output of 6986 kg/hectare yield from very suitable and suitable areas. Saurashtra region can give an average output of 6525 kg/hectare of yield by the very suitable and suitable class.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 469.760 tons of maize from areas suitable (VS+S+MS+mS+vmS) for maize. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can give 190.784 tons (40.61% of total production) of maize. Kutch region can produce 0.003 tons (0.00%) of maize. North Gujarat region can produce 40.915 tons (21.45%), Central Gujarat region can produce 82.485 tons (43.23%), South Gujarat region can produce 58.546 tons (30.69%), and Saurashtra region can produce 8.835 tons (4.63%).

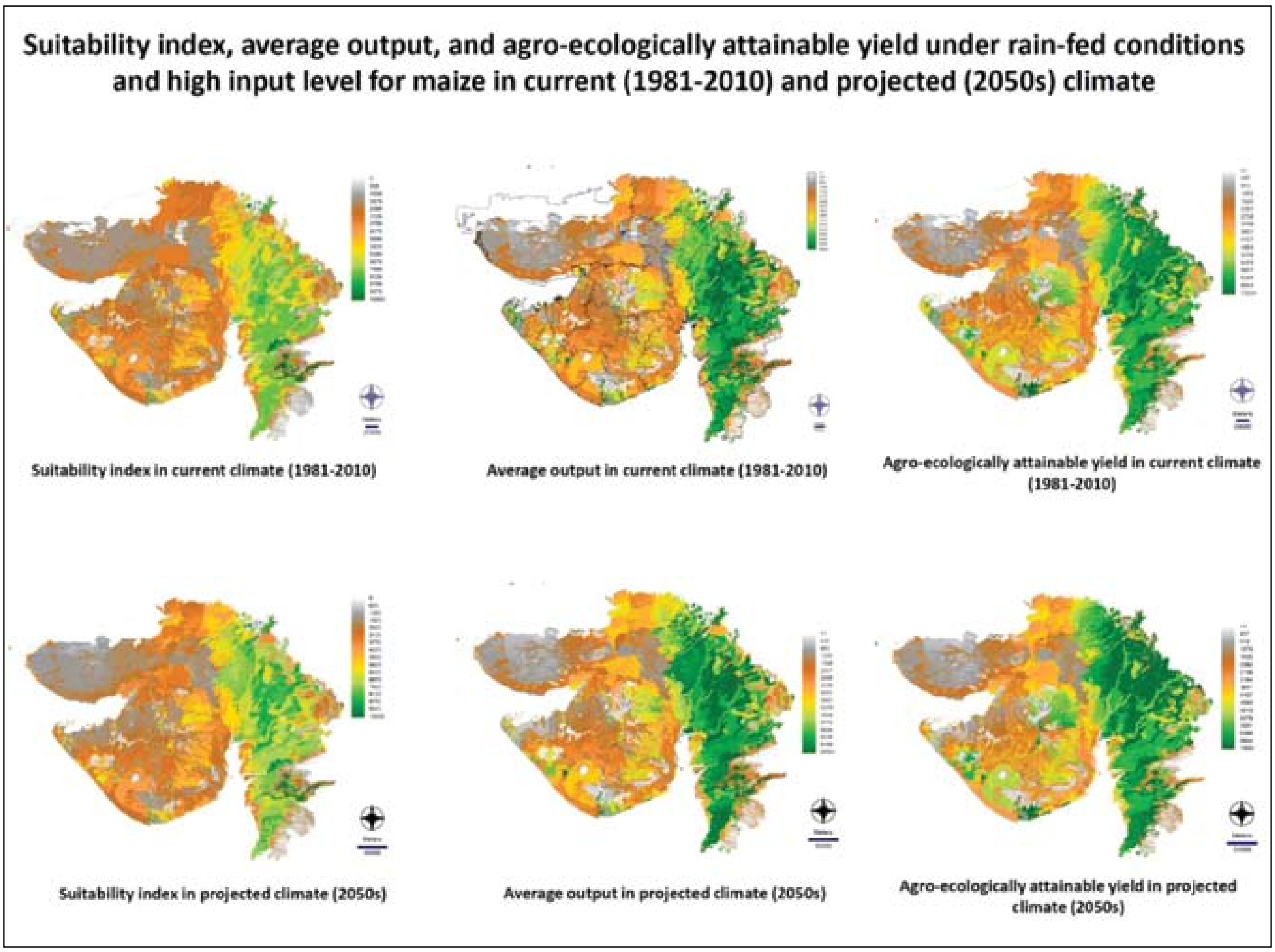

Figure 4.29: Climate Change Impacts on Crop Suitability and Attainable Yield of Maize under Rain-Fed Conditions Across Gujarat

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 495.332 tons of maize from areas suitable (VS+S+MS+mS+vmS) for maize. Very suitable and suitable (VS+S) areas share of production can be 226.409 tons (45.71% of total production). Kutch region can produce 0.191 tons (0.08%) of production from areas very suitable and suitable for maize. North Gujarat region can produce 69.628 tons (30.75%) of yield. Central Gujarat region can produce 84.537 tons (37.34%) from very suitable and suitable class, whereas, south Gujarat can produce 57.090 tons (25.22%) through very suitable and suitable areas. Saurashtra region can produce 14.963 tons (6.61%) from the very suitable and suitable class.

6B Maize: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for maize, of which 4086 hectares areas (26.41%) are very suitable and suitable. Kutch has 266 hectares (6.51%) areas very suitable and suitable for maize. 1436.5 hectare (35.16%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 1285.3 hectares (31.46%) in central Gujarat, 659.3 hectares (16.14%) in south Gujarat, and 438.9 hectares (10.74%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15467.7 hectares areas suitable (VS+S+MS+mS+vmS) for maize, of which 4521 hectares (29.23%) areas are very suitable and suitable. Kutch region has 300 hectares (6.64%) areas very suitable and suitable for maize. North Gujarat region has 1449.7 hectares (32.07%) very suitable and suitable areas. Central Gujarat region have 1393.5 hectares (30.82%) very suitable and suitable areas, whereas, south Gujarat region has 860.1 hectares (19.02%) very suitable and suitable areas. Saurashtra region will have 517.7 hectares (11.45%) area of the very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 5274 kg/hectare maize, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 7764 kg/hectare maize. Kutch region can give an average output of 7858 kg/hectare maize. North Gujarat region can give an average output of 8122 kg/hectare, central Gujarat region can give an average output of 7674 kg/hectare, south Gujarat region can give average output 7499 kg/hectare, and Saurashtra region can give average output 7667 kg/hectare.

Projected Climate (2041–2070): Projected average output of maize for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 5386 kg/hectare maize, whereas, very suitable and suitable (VS+S) areas can give an average output of 7864 kg/hectare. Kutch region can give an average output of 7934 kg/hectare from areas very suitable and suitable for maize. North Gujarat region can give an average output of 8300 kg/hectare. Central Gujarat region can give an average output of 7799 kg/hectare from very suitable and suitable class, whereas, south Gujarat region can give an average output of 7553 kg/hectare yield from very suitable and suitable areas. Saurashtra region can give an average output of 7732 kg/hectare from very suitable and suitable class.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 698.262 tons of maize from areas suitable (VS+S+MS+mS+vmS) for maize. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce

287.379 tons (41.16% of total production) of maize. Kutch region can produce 18.812 tons (6.55%) of maize. North Gujarat region can produce 105.001 tons (36.54%), central Gujarat region can produce 88.779 tons (30.89%), south Gujarat region can produce 44.501 tons (15.49%), and Saurashtra region can produce 30.286 tons (10.54%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 698.262 tons from suitable (VS+S+MS+mS+vmS) areas of maize, whereas, very suitable and suitable (VS+S) areas can produce the share of the total production can be 287.379 tons (45.19% of the total production). Kutch region can produce 21.420 tons (6.65%) from areas very suitable and suitable for maize. North Gujarat region can produce 108.286 tons (33.63%) of yield. Central Gujarat region can produce 97.805 tons (30.37%) from very suitable and suitable class, whereas, south Gujarat can produce 58.466 tons (18.16%) from very suitable and suitable areas. Saurashtra region can produce 36.025 tons (11.19%) from the very suitable and suitable class.

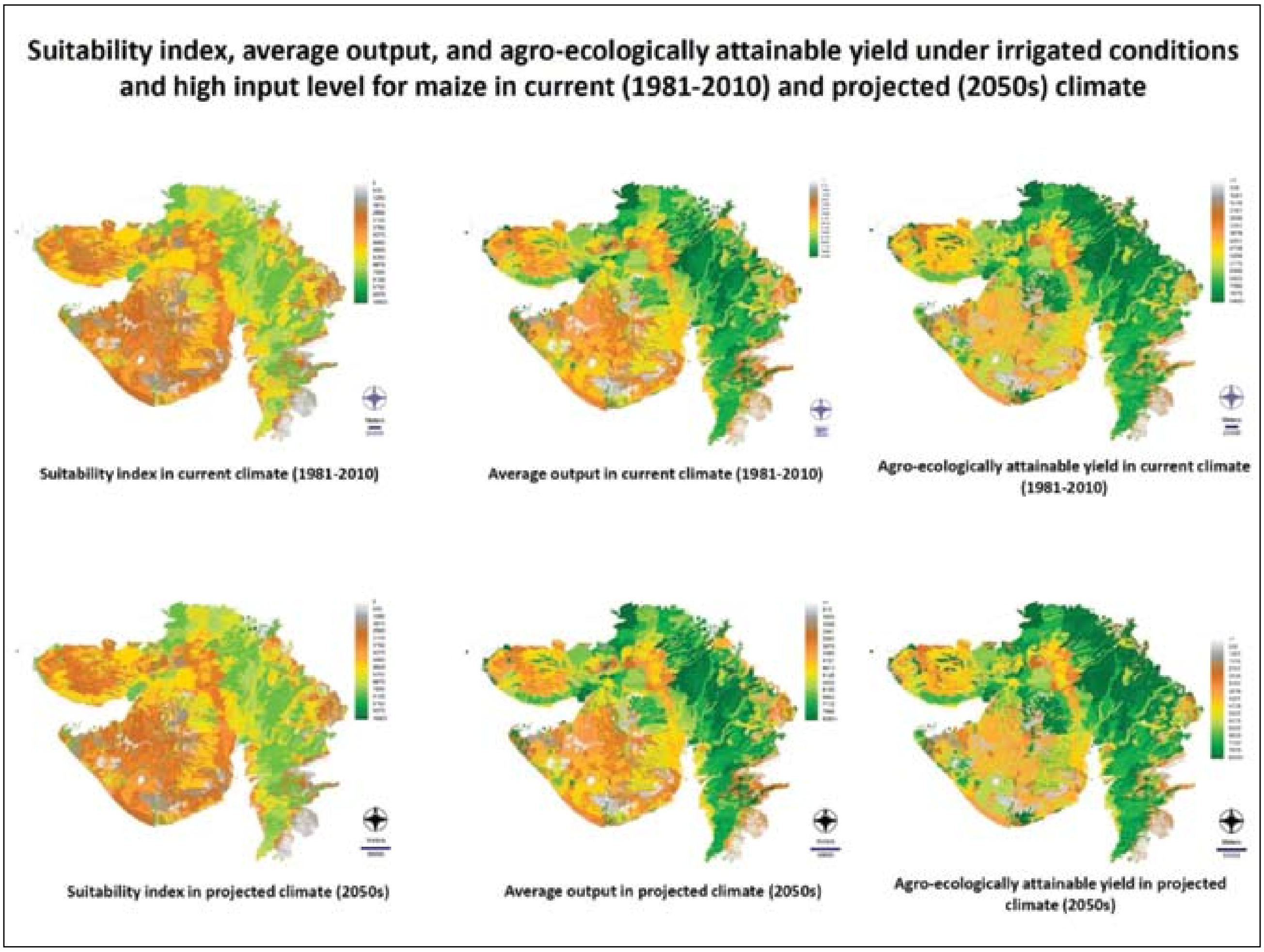

Figure 4.30: Climate Change Impacts on Crop Suitability and Attainable Yield of Maize under Irrigated Conditions Across Gujarat

7A Castor seed: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 14538.8 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for castor seed, of which 406.3 hectares areas (2.79%) are very suitable and suitable. Kutch has no areas very suitable and suitable for castor seed. 92.1 hectare (22.67%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 95.9 hectares (23.60%) in central Gujarat, 186.8 hectares (45.97%) in south Gujarat, and 31.5 hectares (7.75%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 13291 hectares areas suitable (VS+S+MS+mS+vmS) for castor seed, of which 172.5 hectares (1.3%) can be of very suitable and suitable. Kutch region has no areas very suitable and suitable for castor seed. North Gujarat region has 59 hectares (34.2%) very suitable and suitable area. Central Gujarat region has 25.7 km2 (14.9%) very suitable and suitable area, whereas, south Gujarat region has 78.6 hectares (44.83%) very suitable and suitable area. Saurashtra region will have 9.2 hectares (5.33%) very suitable and suitable area.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 714 kg/hectare, whereas, very suitable and suitable (VS+S) areas of Gujarat can give an output of 1996 kg/hectare for castor seed. Kutch region has no areas suitable for castor seed. North Gujarat region can give an average output of 1979 kg/hectare, central Gujarat region can give an average output of 1960 kg/hectare, south Gujarat region can give an average output of 2035 kg/hectare, and Saurashtra region can give an average output of 2009kg/hectare.

Projected Climate (2041–2070): Projected average output of castor seed for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 645 kg/hectare castor seed, whereas, very suitable and suitable (VS+S) areas can give an average output of 2011 kg/hectare. Kutch region has no areas very suitable and suitable for castor seed. North Gujarat region can give an average output of 2090 kg/hectare. Central Gujarat region can give an average output of 1976 kg/hectare from very suitable and suitable class, whereas, south Gujarat region can give an average output of 1986 kg/hectare yield from very suitable and suitable areas. Saurashtra region can give an average output of 1993 kg/hectare of yield by the very suitable and suitable class.

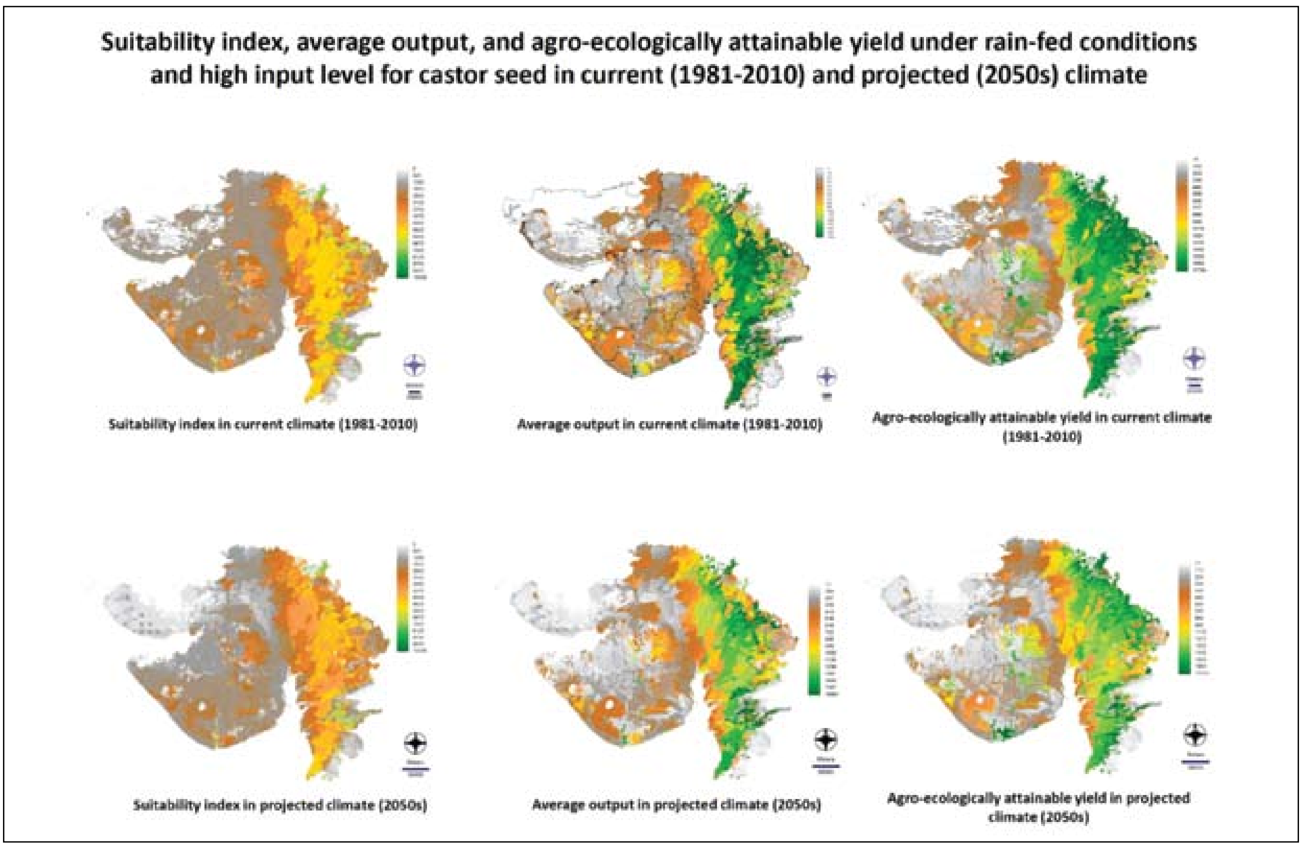

Figure 4.31: Climate Change Impacts on Crop Suitability and Attainable Yield of Castor Seed under Rain-Fed Conditions Across Gujarat

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 88.088 tons of castor seed from areas suitable (VS+S+MS+mS+vmS) for castor seed. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 7.322 tons (8.31 of total production) output of castor seed. Kutch region has no areas suitable for castor seed. North Gujarat region can produce 1.639 tons (22.38%), central Gujarat region can produce 1.693 tons (23.12%), south Gujarat region can produce 3.421 tons (46.72%), and Saurashtra region can produce 0.569 tons (7.77%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 74.4 tons of castor seed from areas suitable (VS+S+MS+mS+vmS) for castor seed whereas very suitable and suitable can give a yield of 3.136 tons (4.22% of total production). Kutch region has no areas very suitable and suitable for castor seed. North Gujarat region can produce 1.109 tons (35.36%) of yield. Central Gujarat region can produce 0.457 tons (14.57%) from very suitable and suitable class, whereas, south Gujarat region can produce 1.406 tons (44.83%) from very suitable and suitable areas. Saurashtra region can produce 0.164 tons (5.23%) from very suitable and suitable class.

7B Castor Seed: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for castor seed, of which 961 hectares areas (6.21%) are very suitable and suitable. Kutch has 14.6 hectares (1.52%) areas very suitable and suitable for castor seed. 392.5 hectare (40.84%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 224.9 km^2 (23.40%) in central Gujarat, 275.4 km^2 (28.66%) in south Gujarat, and 53.6 km^2 (5.58%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 15467.7 hectares areas suitable (VS+S+MS+mS+vmS) for castor seed, of which 290 hectares (1.87%) areas are very suitable and suitable. Kutch region has 0.4 hectare (0.14%) areas very suitable and suitable for castor seed. North Gujarat region has 175.2 hectares (60.41%) very suitable and suitable areas. Central Gujarat region has 48.4 hectares (16.69%) very suitable and suitable areas, whereas, south Gujarat region has 48.7 hectares (16.79%) very suitable and suitable areas. Saurashtra region will have 17.3 hectares (5.97%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 1103 kg/hectare, whereas, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 2210 kg/hectare castor seed. Kutch region can give an average output of 2186 kg/hectare castor seed. North Gujarat region can give an average output of 2254 kg/hectare, central Gujarat region can give an average output of 2198 kg/hectare, south Gujarat region can give an average output of 2177 kg/hectare, and Saurashtra region can give an average output of 2233 kg/hectare.

Projected Climate (2041–2070): Projected average output of castor seed for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 963 kg/hectare castor seed, whereas, very suitable and suitable can give an average output of 2187 kg/hectare. Kutch region can give an average output of 2097 kg/hectare. North Gujarat region can give an average output of 2242 kg/hectare. Central Gujarat region can give an average output of 2211 kg/hectare from very suitable and suitable class, whereas, south Gujarat region can give an average output of 2193 kg/hectare from very suitable and suitable areas. Saurashtra region can give an average output of 2194 kg/hectare from very suitable and suitable class.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 140.935 tons of castor seed from areas suitable (VS+S+MS+mS+vmS) for castor seed. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 19.174 tons (13.6% of total production) output of castor seed. Kutch region can produce 0.288 tons (1.50%) of castor seed. North Gujarat region can produce 7.964 tons (41.54%), central Gujarat region can produce 4.449 tons (23.20%), south Gujarat region can produce 5.396 tons (28.14%), and Saurashtra region can produce 1.077 tons (5.62%).

Projected Climate (2041–2070_ENSAMBLE MEAN RCP4.5): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 123.172 tons of castor seed from areas suitable (VS+S+MS+mS+vmS for castor seed, whereas, very suitable and suitable (VS+S) areas can produce 5.809 tons (4.72% of total production). Kutch region can produce 0.008 tons (0.14%) for castor seed. North Gujarat region can produce 3.535 tons (60.85%). Central Gujarat region can produce 0.963 tons (16.58%) from very suitable and suitable class, whereas, south Gujarat region can produce 0.962 tons (16.56%) from very suitable and suitable areas. Saurashtra region can produce 0.341 tons (5.87%) from very suitable and suitable class.

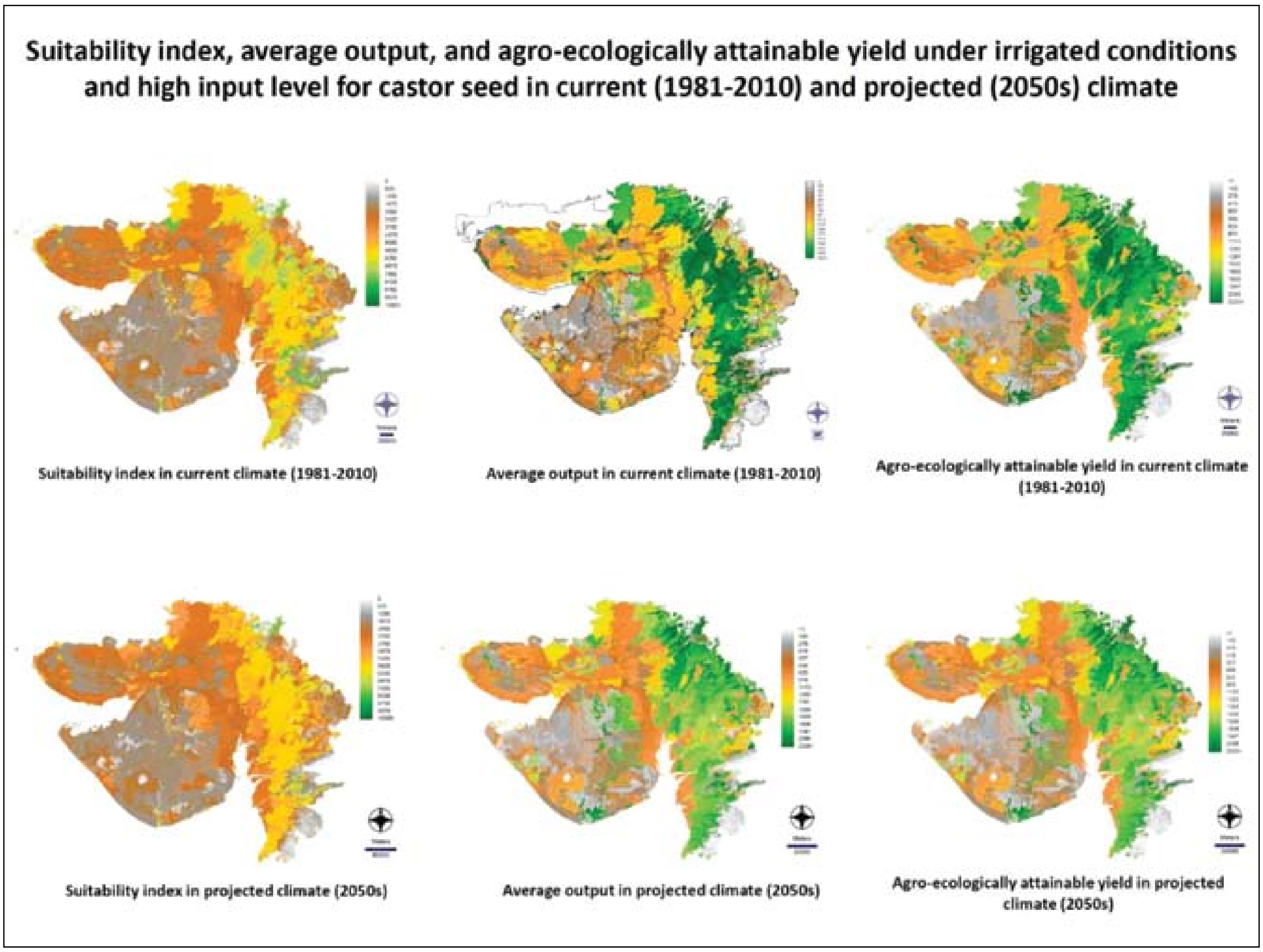

Figure 4.32: Climate Change Impacts on Crop Suitability and Attainable Yield of Castor Seed under Irrigated Conditions Across Gujarat

8A Potato: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 3 hectare area of Gujarat is suitable (VS+S+MS+mS+vmS) for potato, of which no area falls under very suitable and suitable class under rain-fed conditions.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have no areas suitable (VS+S+MS+mS+vmS) for potato under rain-fed conditions.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat could give an output of 646 kg/hectare potato, as no area falls under very suitable and suitable class.

Projected Climate (2041–2070): Projected average output of potato for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have no areas suitable (VS+S+MS+mS+vmS) for potato under rain-fed conditions.

Agro-Ecologically Attainable Yield (tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 1700 tons of potato from areas suitable (VS+S+MS+mS+vmS) for potato. However, no area falls under very suitable and suitable class under rain-fed conditions.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat under rain-fed conditions, no areas are suitable (VS+S+MS+mS+vmS) for potato.

8B Potato: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 6148.6 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for potato, of which 2.5 hectares areas (0.04%) are very suitable and suitable. 2.5 hectare (100%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for potato.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat will have 152.2 hectares areas for potato. However, no region of the state has the area under very suitable and suitable class for the cultivation of potato.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 2336 kg/ hectare whereas very suitable and suitable (VS+S) areas of Gujarat can give an average output of 8109 kg/hectare potato. North Gujarat region can give an average output of 8109 kg/hectare. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for potato.

Projected Climate (2041–2070): Projected average output of potato for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 2467 kg/hectare (VS+S+MS+mS+vmS) for potato cropping. However, no region of the state has the area under very suitable and suitable class for the cultivation of potato.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 163.118 tons of potato from areas suitable (VS+S+MS+mS+vmS) for potato. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 0.18 tons (0.11% of total production) of potato. North Gujarat region can produce 0.18 tons (100%). Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for potato.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 4.005 tons of potato from areas suitable (VS+S+MS+mS+vmS) for potato. However, no region of the state has an area under very suitable and suitable class and does not sustain potato cultivation.

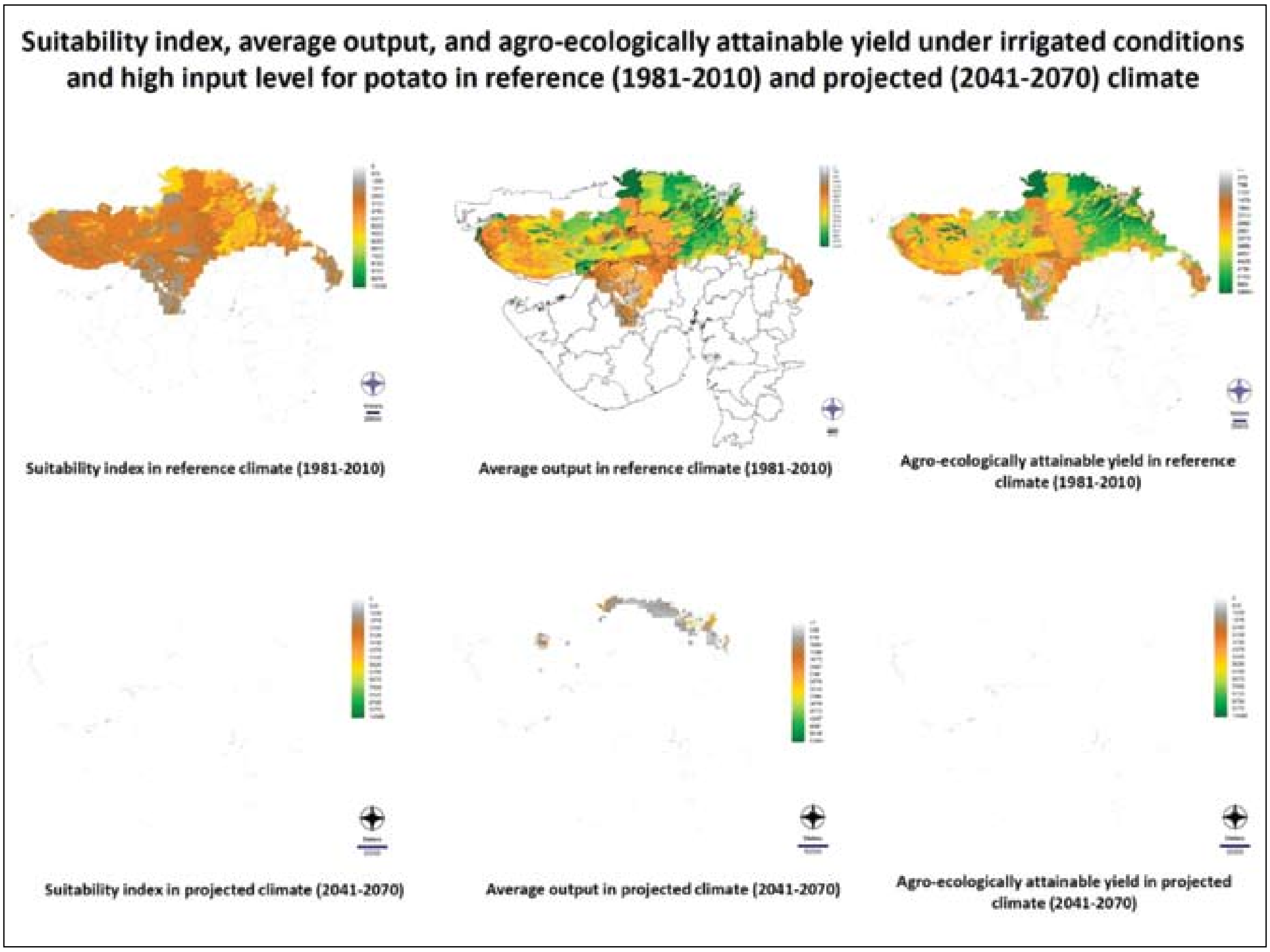

Figure 4.33: Climate Change Impacts on Crop Suitability and Attainable Yield of Potato under Irrigated Conditions Across Gujarat

9A Mango: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 8667.4 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for mango. However, no areas of the state are very suitable and suitable for mango under rain-fed conditions.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 5772.7 hectares areas suitable

(VS+S+MS+mS+vmS) for mango, whereas, very suitable and suitable (VS+S) areas 3.1 hectares (0.05). However, no other areas of the state are very suitable and suitable for mango under rain-fed conditions except 2.8 hectares (90.32%) area of south Gujarat and 0.3 hectares (9.68%) area of Saurashtra.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 978 kg/ hectare for mango. Gujarat has no areas very suitable and suitable for mango under rain-fed conditions.

Projected Climate (2041–2070): Projected average output of mango for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas can give an average output of 1093 kg/ hectare for Mango. Whereas, very suitable and suitable (VS+S) areas can give an average output of 8371 kg/hectare. South Gujarat can give an average output of 8460 kg/hectare and Saurashtra can give an average output of 8282kg/hectare under very suitable and suitable conditions. Kutch, north, and cental region have no areas very suitable and suitable for mango under rain-fed conditions.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state could produce a total of 71.601 tons of mango from areas suitable (VS+S+MS+mS+vmS) for mango. Given the rain-fed conditions, no areas of the state are very suitable and suitable for mango.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 52.382 tons of mango from areas suitable (VS+S+MS+mS+vmS) for mango, whereas, very suitable and suitable (VS+S) areas can produce 0.235 tons (0.45% of total production). South Gujarat can produce 0.215 tons (91.49%) and Saurashtra can produce 0.02tons (8.51%), whereas, Kutch, north, and central Gujarat couldn't get any production from the areas very suitable and suitable for mango under rain-fed conditions.

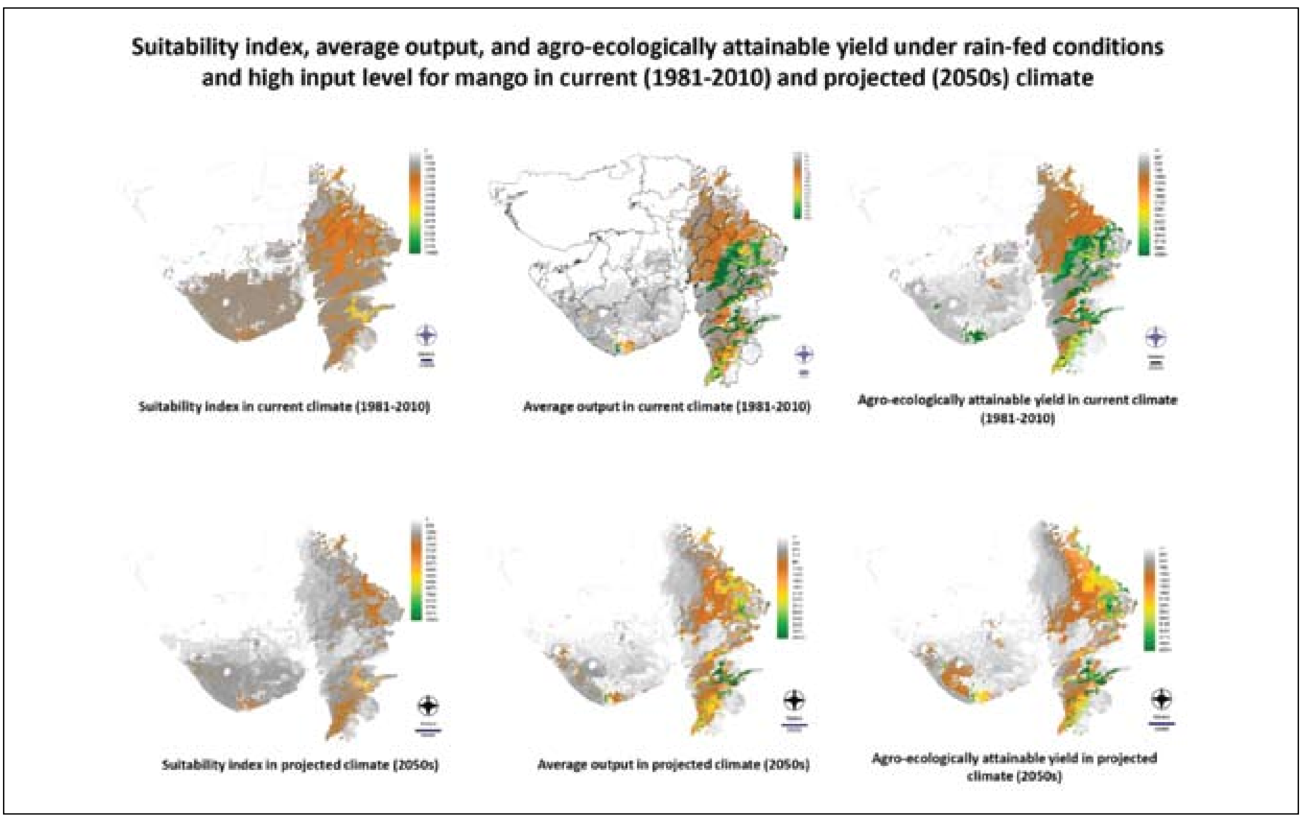

Figure 4.34: Climate Change Impacts on Crop Suitability and Attainable Yield of Mango under Rain-Fed Conditions Across Gujarat

9B Mango: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for mango, of which 6024.8 hectares areas (38.94%) are very suitable and suitable (VS+S). Kutch has 578.4 hectares (9.6%) areas very suitable and suitable for mango. 1747 hectare (29%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 1850.6 hectares (30.72%) in central Gujarat, 1101.3 hectares (18.28%) in south Gujarat, and 747.5 hectares (12.41%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that 10683.6 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for mango, of which 3152.1 hectares areas (29.5%) are very suitable and suitable. Kutch has 70.3 hectares (2.23%) areas very suitable and suitable for mango. 1008.5 hectare (31.99%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 777 hectares (24.65%) in central Gujarat, 729.3 hectares (23.14%) in south Gujarat, and 567 hectares (17.99%) in Saurashtra.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give average output of 7139 kg/ hectare for Mango, whereas, very suitable and suitable (VS+S) areas can give an average output of 10710 kg/ hectare. Kutch region can give average output of 10310 kg/hectare, north Gujarat region can give average output of 11365 kg/hectare, central Gujarat region can give average output of 10609 kg/hectare, south Gujarat region can give average output of 10681 kg/hectare, and Saurashtra region can give average output of 10587 kg/hectare.

Projected Climate (2041–2070): Projected average output of mango for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 6259 kg/ hectare, whereas, very suitable and suitable (VS+S) areas can give an average output of 10235 kg/ hectare. Kutch region can give average output of 9741 kg/hectare, north Gujarat region can give average output of 11003 kg/hectare, central Gujarat region can give average output of 10093 kg/hectare, south Gujarat region can give average output of 10282 kg/hectare, and Saurashtra region can give average output of 10056 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state could produce a total of 939.966 tons of mango from areas suitable (VS+S+MS+mS+vmS) for mango, whereas, very suitable and suitable area could produce 586.154 tons (62.36% of total production). Very suitable and suitable (VS+S) areas of Kutch region can produce 53.672 tons (9.16%), north Gujarat region can produce 178.696 tons (30.49%), central Gujarat region can produce 176.689 tons (30.14%), south Gujarat region can produce 105.871 tons (18.06%), and Saurashtra region can produce 71.226 tons (12.15%) of mango.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 567.834 tons of mango from areas suitable (VS+S+MS+mS+vmS) for mango, whereas, very suitable and suitable (VS+S) areas can produce 295.429 tons (52.03% of total production). Very suitable and suitable (VS+S) areas of Kutch region can produce 616.3 tons (2.09%), north Gujarat region can produce 99.876 tons (33.81%), central Gujarat region can produce 70.587 tons (23.89%), south Gujarat region can produce 67.492 tons (22.85%), and Saurashtra region can produce 51.311 tons (17.37%) of mango.

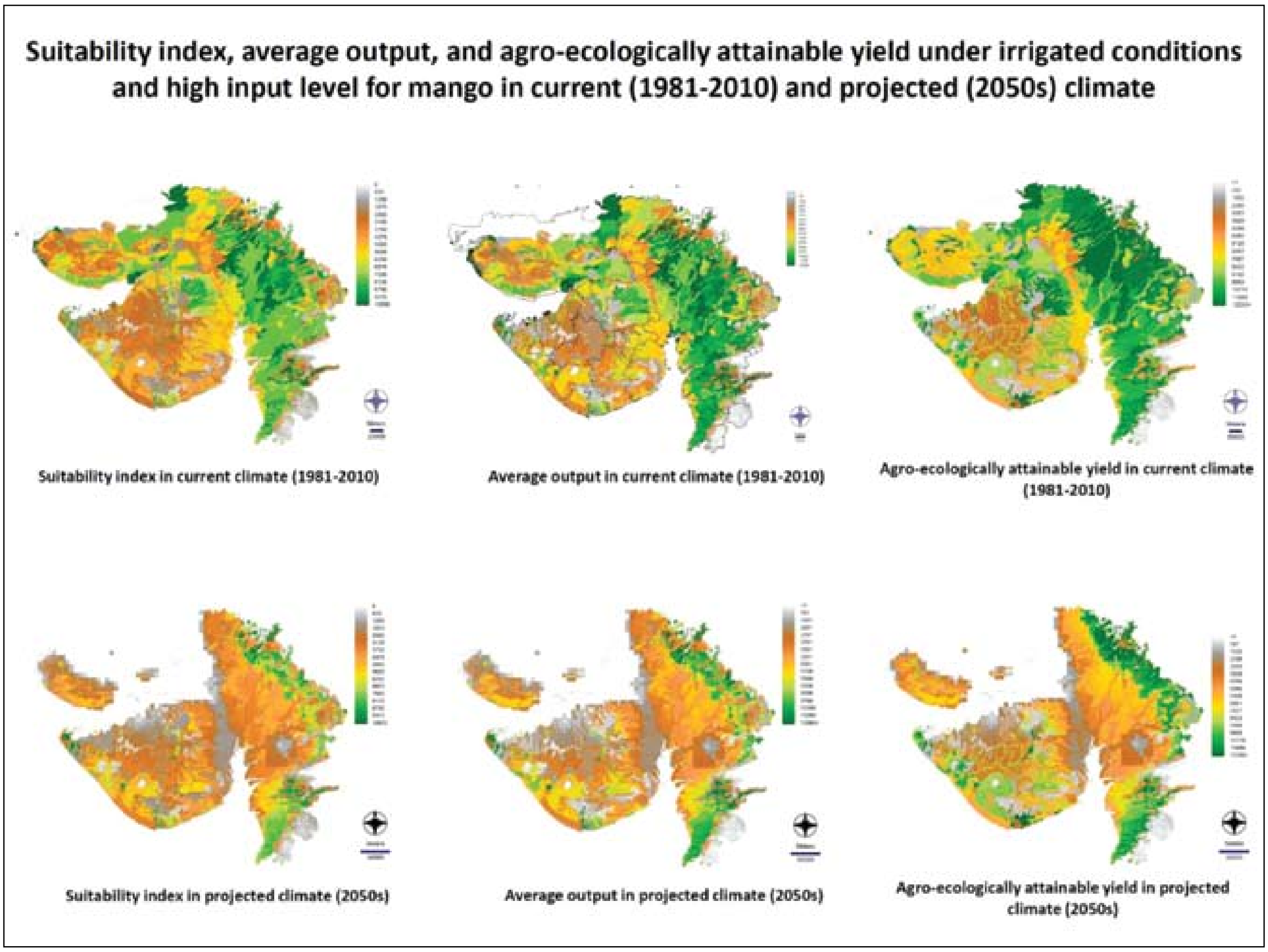

Figure 4.35: Climate Change Impacts on Crop Suitability and Attainable Yield of Mango under Irrigated Conditions Across Gujarat

10A Mustard-Rabi: Rain-fed

Suitability Index (*000 Hectare)

Reference climate (1981–2010) and projected climate(2041–2070_ENSAMBLE MEAN RCP 4.5 for 2041–2070) crop suitability analysis for mustard indicated that, no area of Gujarat is suitable (VS+S+MS+mS+vmS) for mustard under rain-fed conditions.

10B Mustard-Rabi: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 14704 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for mustard, of which 56.9 hectares (0.39%) areas are very suitable and suitable. North Gujarat region has 55.6 hectares (97.72%) and central Gujarat region has 1.3 hectares (2.28%).

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that 5139.1 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for mustard, of which 0.008 hectares (0.016%) areas are very suitable and suitable. Only 0.008 hectares (0.016%) areas north Gujarat region is very suitable and suitable for mustard cultivation.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable

(VS+S+MS+mS+vmS) areas can give an average output of 534 kg/ hectare for mustard, whereas, very suitable and suitable (VS+S) areas can give an average output of 1399 kg/ hectare. Very suitable and suitable (VS+S) areas of north Gujarat region can give an average output of 1552 kg/hectare mustard, central Gujarat region can give an average output of 1245 kg/hectare.

Projected Climate (2041–2070): Projected average output of mustard for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give average output of 241 kg/ hectare for mustard, whereas, very suitable and suitable (VS+S) areas can give average output of 1558 kg/ hectare. Very suitable and suitable (VS+S) areas of north Gujarat region can give an average output of 1558 kg/hectare mustard.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state could produce a total of 70.071 tons of mustard from areas suitable (VS+S+MS+mS+vmS) for mango, whereas, very suitable and suitable area could produce 0.792 tons (1.13% of total production). The very suitable and suitable (VS+S) areas of north Gujarat region can produce 0.777 tons (98.11%) and central Gujarat region can produce 0.015 tons (1.89%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 14.673 tons of mustard from areas suitable (VS+S+MS+mS+vmS), whereas, very suitable and suitable (VS+S) areas can produce 0.012 tons (0.082% of total production). Very suitable and suitable (VS+S) areas of north Gujarat region can produce 0.017 tons (100%) mustard.

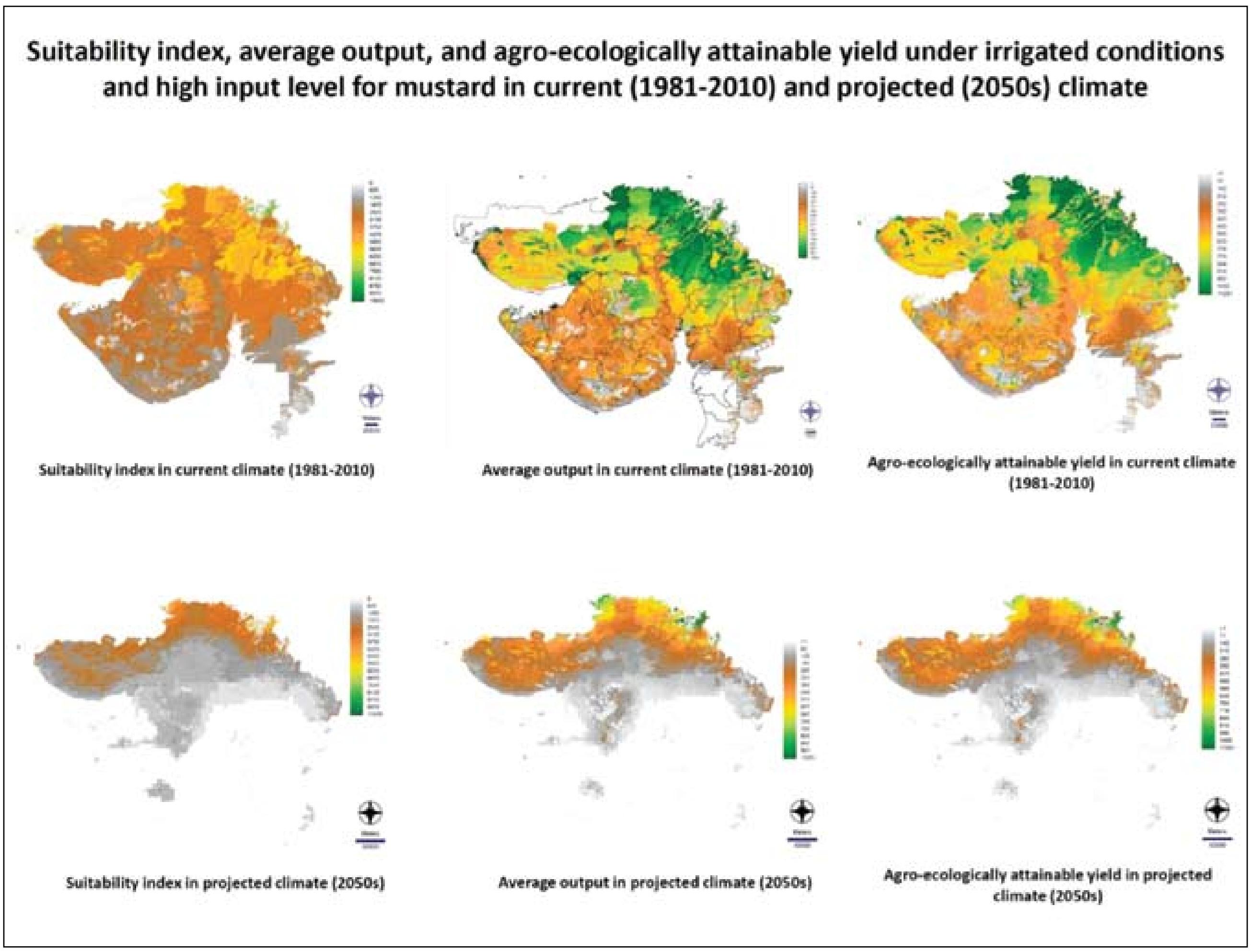

Figure 4.36: Climate Change Impacts on Crop Suitability and Attainable Yield of Mustard-Rabi under Irrigated Conditions Across Gujarat

11A Pigeon Pea: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 14922 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for pigeon pea, of which 1130.8 hectares (7.58%) areas (7.57%) are very suitable and suitable. Kutch region has no areas very suitable and suitable for pigeon pea. 429.5 hectare (37.98%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 406.4 hectares (35.94%) in central Gujarat, 256.8 hectares (22.71%) in south Gujarat and 38.1 hectares (3.37%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 13502.9 hectares areas suitable (VS+S+MS+mS+vmS) for pigeon pea, of which 455.4 hectares (2.47%) areas are very suitable and suitable. Kutch region has no areas very suitable and suitable for pigeon pea. North Gujarat region has 213.6 hectares (46.90%) very suitable and suitable areas. Central Gujarat region has 119.2 hectares (26.17%) very suitable and suitable areas, whereas, south Gujarat region has 109 hectares (23.94%) very suitable and suitable (VS+S) areas and Saurashtra region has 13.6 hectares (2.99%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, the suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 801 kg/hectare, out of which very suitable and suitable (VS+S) areas of Gujarat can give an average output of 1982 kg/hectare pigeon pea. Kutch region has no areas very suitable and suitable for pigeon pea. North Gujarat region can give an average output of 1975 kg/hectare pigeon pea, central Gujarat can give an average output of 1960 kg/hectare, south Gujarat can give an average output of 2012 kg/hectare, and Saurashtra can give an average output of 1983 kg/hectare.

Projected Climate (2041–2070): Projected average output of pigeon pea for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 729 kg/hectare pigeon pea, whereas, very suitable and suitable can give an average output of 1983 kg/hectare. Kutch region has no areas very suitable and suitable for pigeon pea. North Gujarat region can give an average output of 2043 kg/hectare from very suitable and suitable class, central Gujarat can give an average output of 1965 kg/hectare, south Gujarat can give an average output of 1982 kg/hectare, and Saurashtra can give an average output of 1943 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 101.069 tons of pigeon pea from areas suitable (VS+S+MS+mS+vmS) for pigeon pea. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 20.131 tons (19.92% of total production) of pigeon pea from areas very suitable and suitable. Kutch region has no areas very suitable and suitable for pigeon pea. North Gujarat can produce 7.633 tons (37.92%), central Gujarat can produce 7.168 tons (35.61%), south Gujarat region can produce 4.65 tons (23.1%), and Saurashtra region can produce 0.68 tons (3.38%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 84.947 tons of pigeon pea from areas suitable (VS+S+MS+mS+vmS) for pigeon pea. A total of 8.219 tons (9.68%) of pigeon pea can be produced from very suitable and suitable areas. Kutch region has no areas very suitable and suitable for pigeon pea. North Gujarat region can produce 3.927 tons (47.78%). Central Gujarat region can produce 2.109 tons (25.66%) from very suitable and suitable class, south Gujarat can produce 1.945 tons (23.66%), and Saurashtra can produce 0.238 tons (2.90%).

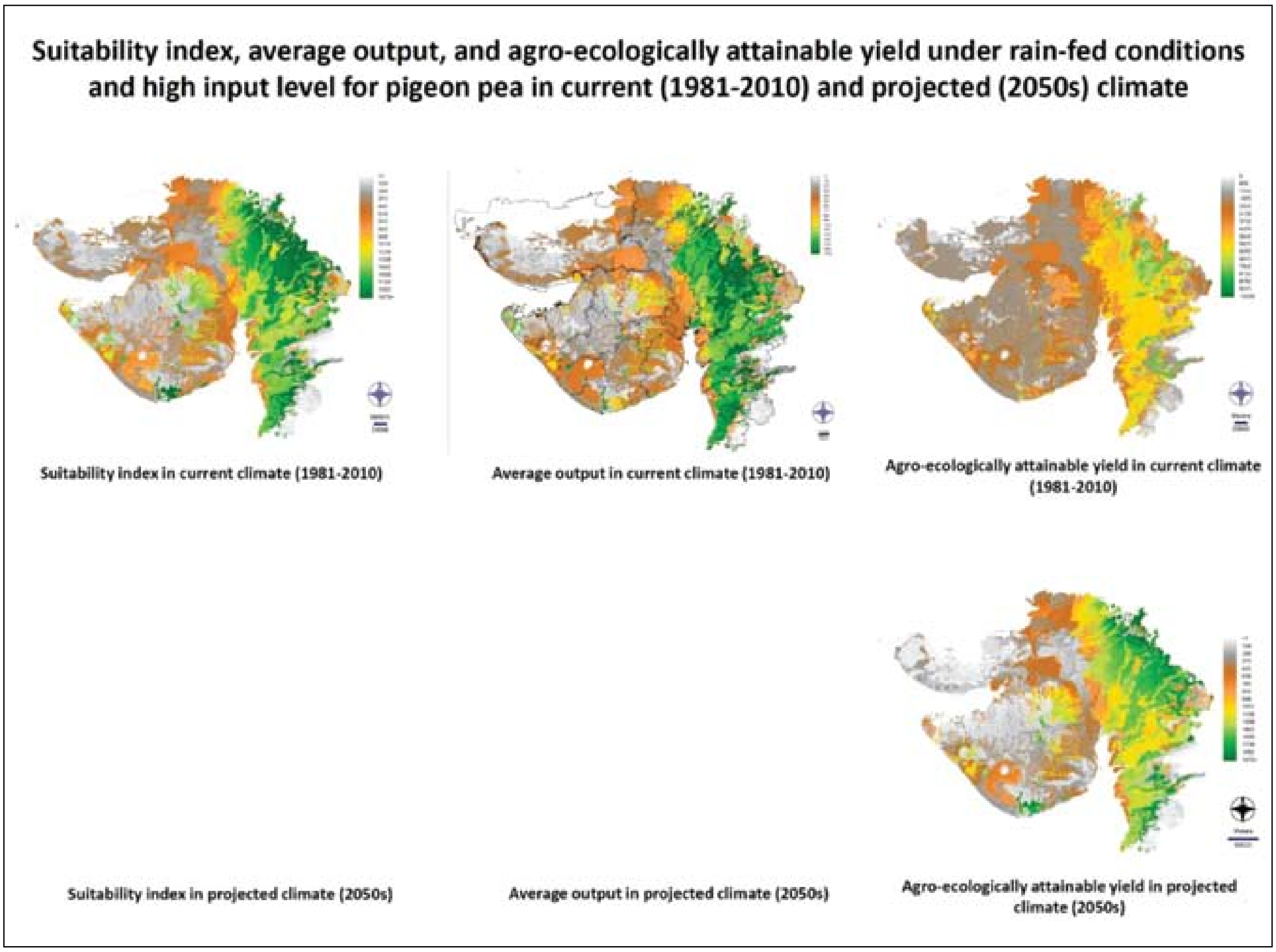

Figure 4.37: Climate Change Impacts on Crop Suitability and Attainable Yield of Pigeon Pea under Rain-Fed Conditions Across Gujarat

11B Pigeon Pea: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for pigeon pea cultivation, of which 2499.9 hectares areas (16.16%) are very suitable and suitable. Kutch region has 63.6 hectares (2.54%) areas very suitable and suitable for pigeon pea. 1091.3 hectare (43.65%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 744.9 hectares (29.8%) in central Gujarat region, 348.6 hectares (13.94%) in south Gujarat region, and 251.5 hectares (10.06%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, 15467.7 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for pigeon pea, of which 1031.3 hectares areas (6.67%) are very suitable and suitable. Kutch region has 3.5 hectares (0.34%) areas very suitable and suitable for pigeon pea. 662 hectare (64.19%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 249.9 hectares (24.23%) in central Gujarat region, 0.824 hectares (7.99%) in south Gujarat region, and 0.335 hectares (3.25%) in Saurashtra region.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 1245 kg/ hectare for pigeon pea, whereas, very suitable and suitable (VS+S) areas can give an average output of 2219 kg/ hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 2135 kg/hectare, north Gujarat region can give average output of 2355 kg/hectare, central Gujarat region can give average output of 2238 kg/hectare, south Gujarat region can give average output of 2181 kg/hectare, and Saurashtra region can give average output of 2187 kg/hectare pigeon pea.

Projected Climate (2041–2070): Projected average output of pigeon pea for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give average output of 1088 kg/ hectare, whereas, very suitable and suitable (VS+S) areas can give average output of 2176 kg/ hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 2094 kg/hectare, north Gujarat region can give average output of 2260 kg/hectare, central Gujarat region can give average output of 2193 kg/hectare, south Gujarat region can give average output of 2180 kg/hectare, and Saurashtra region can give average output of 2151 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state could produce a total of 159.445 tons of pigeon pea from areas suitable (VS+S+MS+mS+vmS), whereas, very suitable and suitable area could produce 51.146 tons (32.08% of total production). The very suitable and suitable (VS+S) areas of Kutch region can produce 1.222 tons (2.39%), north Gujarat region can produce 23.127 tons (45.22%), central Gujarat region can produce 15.004 tons (29.34%), south Gujarat region can produce 6.843 tons (13.38%), and Saurashtra region can produce 4.95 tons (9.68%) of pigeon pea.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 139.426 tons of pigeon pea from areas suitable (VS+S+MS+mS+vmS),

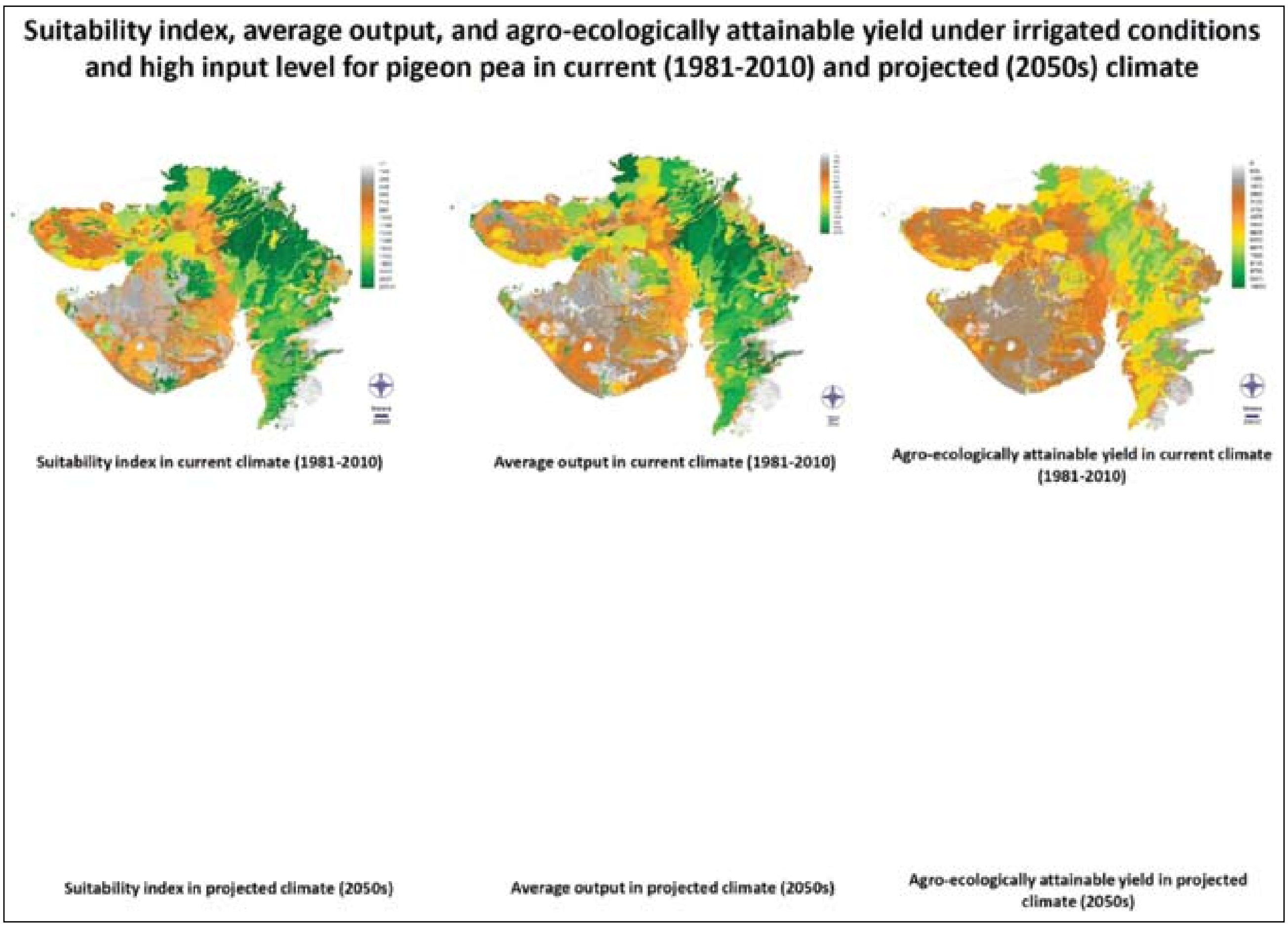

Figure 4.38: Climate Change Impacts on Crop Suitability and Attainable Yield of Pigeon Pea under Irrigated Conditions Across Gujarat

whereas, very suitable and suitable (VS+S) areas can produce 20.725 tons (14.86% of total production). Very suitable and suitable (VS+S) areas of Kutch region can produce 0.066 tons (0.32%), north Gujarat region can produce 13.463 tons (64.96%), central Gujarat region can produce 4.931 tons (23.79%), south Gujarat region can produce 1.617 tons (7.8%), and Saurashtra region can produce 0.648 tons (3.13%) of pigeon pea.

12A Sesamum: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15480.6 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sesamum, of which 2030 hectare (13.11%) areas are very suitable and suitable. Kutch region has no very suitable and suitable (VS+S) areas for sesamum. 730.9 hectare (36%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 720.2 hectares (35.48%) in central Gujarat region, 524.7 hectares (25.85%) in south Gujarat region, and 54.2 hectares (8.73%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, 15452.8 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sesamum, of which 847.9 hectares (5.49%) areas are very suitable and suitable. Kutch region has no very suitable and suitable (VS+S) areas for sesamum. 342.8 hectare (40.43%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 222.6 hectares (25.57%) in central Gujarat region, 247.6 km^2 (29.2%) in south Gujarat region, and 34.9 km^2 (4.12%) in Saurashtra region.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 1396 kg/ hectare for sesamum, whereas, very suitable and suitable (VS+S) areas can give an average output of 2666 kg/ hectare. very suitable and suitable (VS+S) areas of Kutch region can give average output of 2628 kg/hectare, north Gujarat region can give average output of 2617 kg/hectare, central Gujarat region can give average output of 2576 kg/ hectare, south Gujarat region can give average output of 2738 kg/hectare, and Saurashtra region can give average output of 2772 kg/hectare of sesamum.

Projected Climate (2041–2070): Projected average output of sesamum for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give average output of 1233 kg/ hectare for sesamum, whereas, very suitable and suitable (VS+S) areas can give average output of 2617 kg/ hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 2419 kg/hectare, north Gujarat region can give average output of 2675 kg/hectare, central Gujarat region can give average output of 2600 kg/hectare, south Gujarat region can give average output of 2724 kg/hectare, and Saurashtra region can give average output of 2669 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference rain-fed climatic conditions of Gujarat, the state could produce a total of 184.528 tons of sesamum from areas suitable (VS+S+MS+mS+vmS), whereas, very suitable and suitable area could produce 48.199 tons (26.12% of total production). There are no very suitable and suitable (VS+S) areas in Kutch region, very suitable and suitable (VS+S) areas of north Gujarat region can produce 17.216 tons (35.72%), central Gujarat region can produce 16.699 tons (34.65%), south Gujarat region can produce 12.93 tons (26.83%), and Saurashtra region can produce 1.353 tons (2.81%) of sesamum.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 162.192 tons of sesamum from areas suitable (VS+S+MS+mS+vmS), whereas, very suitable and suitable (VS+S) areas can produce 20.369 tons (12.56% of total production). Kutch region has no very suitable and suitable areas. Very suitable and suitable (VS+S) areas of north Gujarat region can produce 8.252 tons (40.51%), central Gujarat region can produce 5.208 tons (25.57%), south Gujarat region can produce 6.071 tons (29.81%), and Saurashtra region can produce 0.838 tons (4.11%) of sesamum.

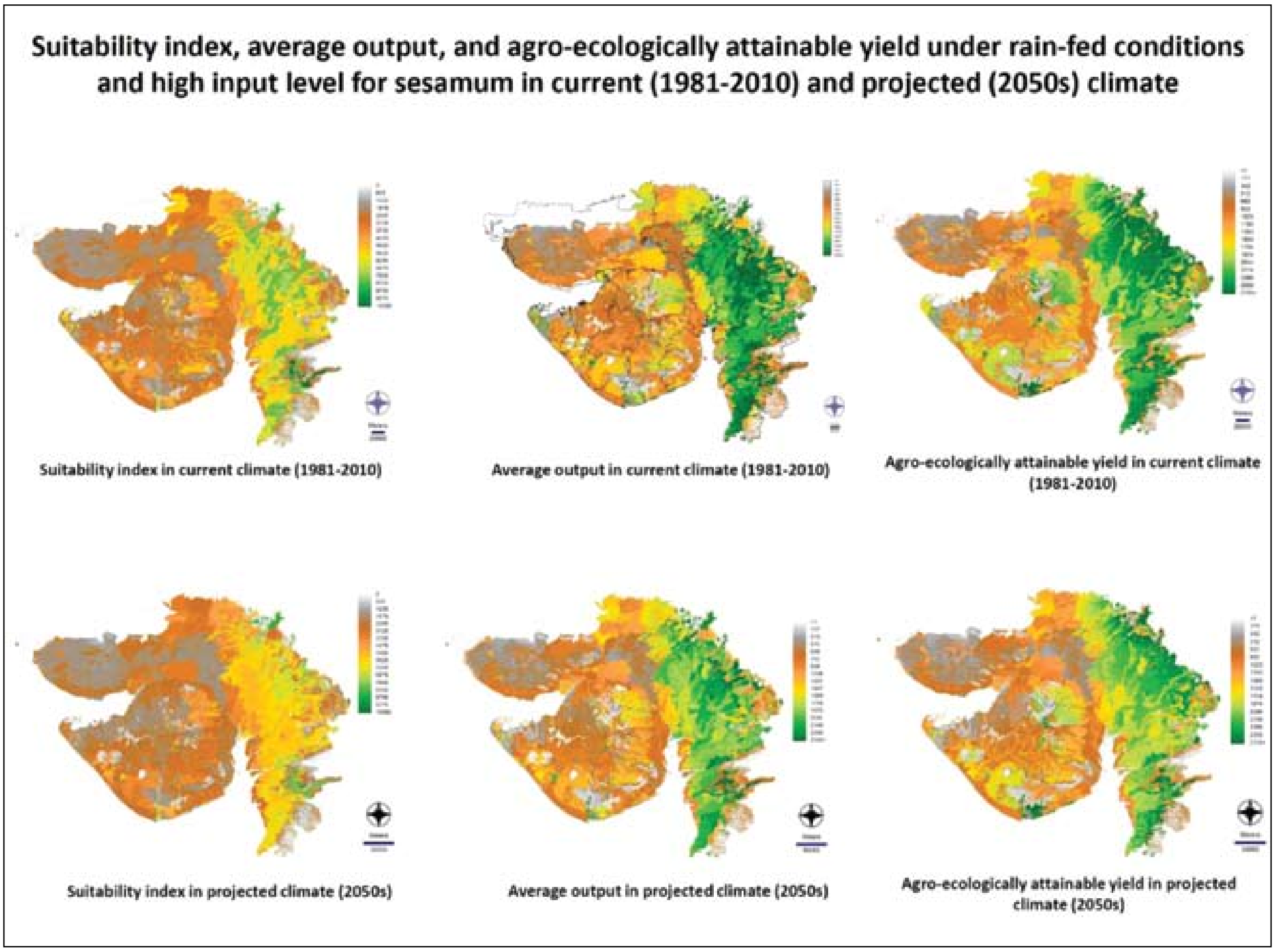

Figure 4.39: Climate Change Impacts on Crop Suitability and Attainable Yield of Sesamum under Rain-Fed Conditions Across Gujarat

12B Sesamum: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sesamum, of which 4060.4 hectares (26.25%) areas are very suitable and suitable. Kutch region has 198.8 hectares (4.9%) areas very suitable and suitable for sesamum. 1244.7 hectare (30.65%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 1302.1 hectares (32.07%) in central Gujarat region, 960.2 hectare (23.65%) in south Gujarat region, and 354.6 km2 (8.73%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, 154.677 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) cultivation of sesamum, of which 23.493 hectares areas (15.19%) are very suitable and suitable. Kutch region has 0.466 hectares (1.98%) areas very suitable and suitable for sesamum.

1060.3 hectare (45.13%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 651.3 hectares (27.72%) in central Gujarat region, 414.4 hectares (17.64%) in south Gujarat region, and 176.7 km2 (7.52%) in Saurashtra region.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give an average output of 2100 kg/ hectare for sesamum, whereas, very suitable and suitable (VS+S) areas can give an average output of 3087 kg/ hectare. very suitable and suitable (VS+S) areas of Kutch region can give average output of 2988 kg/hectare, north Gujarat region can give average output of 3248 kg/hectare, central Gujarat region can give average output of 3063 kg/ hectare, south Gujarat region can give average output of 3049 kg/hectare, and Saurashtra region can give average output of 3088 kg/hectare of sesamum.

Projected Climate (2041–2070): Projected average output of sesamum for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, given the irrigated conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas can give average output of 1882 kg/ hectare for sesamum, whereas, very suitable and suitable (VS+S) areas can give average output of 2997 kg/ hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 2895 kg/hectare, north Gujarat region can give average output of 3114 kg/hectare, central Gujarat region can give average output of 2992 kg/hectare, south Gujarat region can give average output of 3015 kg/hectare, and Saurashtra region can give average output of 2971 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference irrigated climatic conditions of Gujarat,

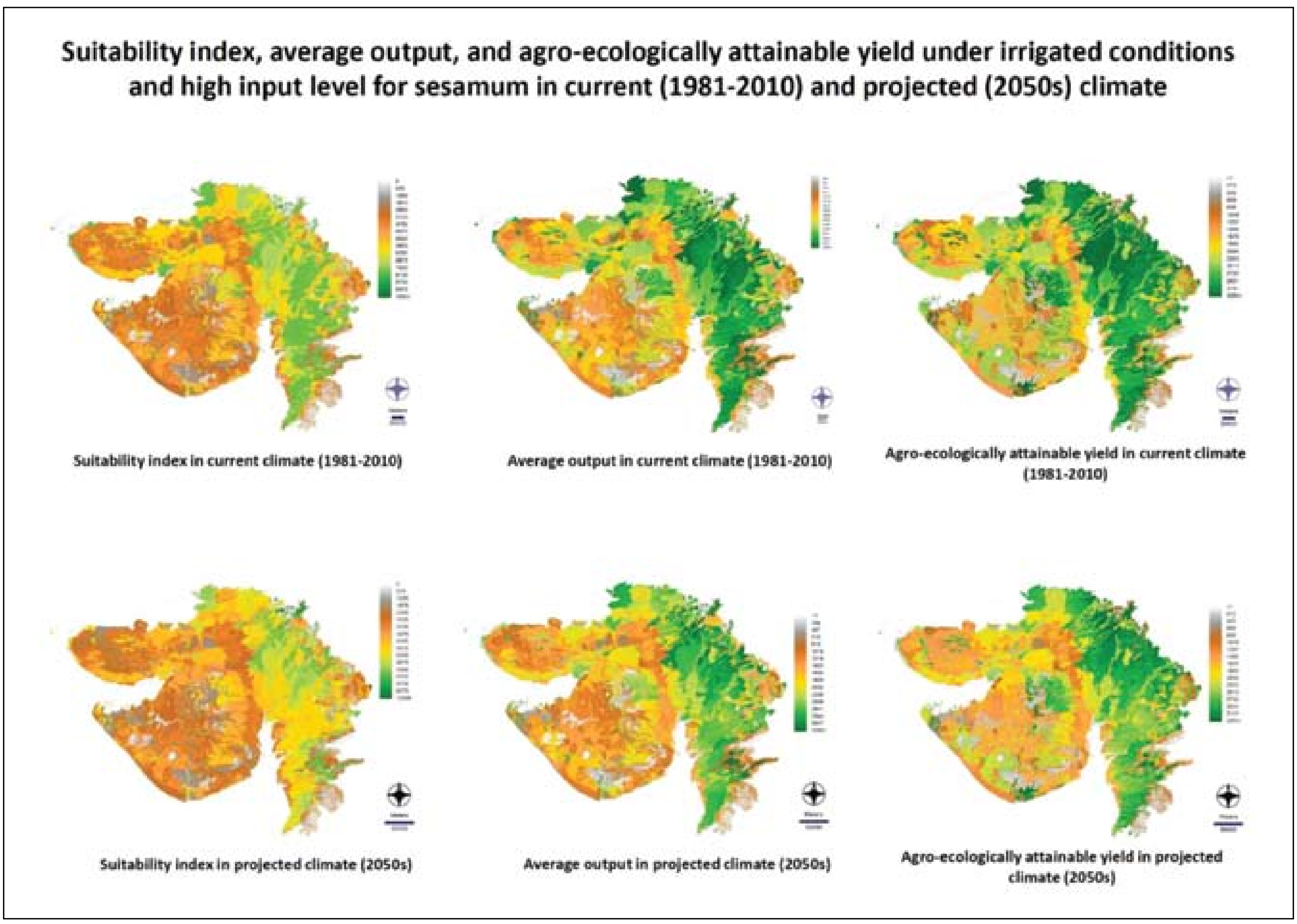

Figure 4.40: Climate Change Impacts on Crop Suitability and Attainable Yield of Sesamum under Irrigated Conditions Across Gujarat

the state could produce a total of 278.046 tons of sesamum from suitable areas (VS+S+MS+mS+vmS), whereas, very suitable and suitable area could produce 113.831 tons (40.94% of total production). Very suitable and suitable (VS+S) areas of Kutch region can produce 5.344 tons (4.69%), north Gujarat region can produce 36.382 tons (31.96%), central Gujarat region can produce 35.898 tons (31.54%), south Gujarat region can produce 26.352 tons (23.15%), and Saurashtra region can produce 9.855 tons (8.66%) of sesamum.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat the state can produce a total of 249.563 tons of sesamum from suitable areas (VS+S+MS+mS+vmS), whereas, very suitable and suitable area can produce 64.436 tons (25.82% of total production). Very suitable and suitable (VS+S) areas of Kutch region can produce 1.214 tons (1.88%), north Gujarat region can produce 29.716 tons (46.12%), central Gujarat region can produce 17.537 tons (27.22%), south Gujarat region can produce 11.244 tons (17.45%), and Saurashtra region can produce 4.725 tons (7.33%) of sesamum.

13A Sorghum: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15480.7 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sorghum, of which 6386 hectares (41.25%) areas are very suitable and suitable. Kutch has 73.8 hectares (1.16%) areas very suitable and suitable for sorghum. 1629.1 hectare (25.51%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat, 2139.5 hectares (33.50%) in central Gujarat, 1170 hectare (18.32%) in south Gujarat and 1373.6 hectares (21.51%) in Saurashtra.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, Gujarat will have 15473.3 hectares areas suitable (VS+S+MS+mS+vmS) for sorghum, of which 7026.9 hectares (45.41%) areas are very suitable and suitable. Kutch region has 196.6 hectares (2.8%) areas very suitable and suitable for sorghum. North Gujarat region has 1934.7 hectares (27.53%) very suitable and suitable areas. Central Gujarat region has 2140 hectare (30.45%) very suitable and suitable areas, whereas, south Gujarat region has 1192.6 km2 (16.97%) very suitable and suitable areas, and Saurashtra region has 1563 hectare (22.24%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, Gujarat can give an average output of 4175 kg/hectare from suitable (VS+S+MS+mS+vmS) areas, out of which very suitable and suitable (VS+S) areas of Gujarat can give an average output of 5845 kg/hectare of sorghum. Kutch can give an average output of 5392 kg/hectare sorghum. North Gujarat region can give an average output of 6345 kg/hectare, central Gujarat can give an average output of 6022 kg/hectare, south Gujarat can give an average output of 5888 kg/hectare, and Saurashtra can give an average output of 5577 kg/hectare.

Projected Climate (2041–2070): Projected average output of sorghum for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, Gujarat can give an average output of 4451 kg/hectare from the suitable (VS+S+MS+mS+vmS) areas, whereas, 6089 kg/hectare from very suitable and suitable areas. Kutch region can give an average output of 5532 kg/hectare. North Gujarat region can give an average output of 6591 kg/hectare from very suitable and suitable class, central Gujarat can give an average output of 6309 kg/hectare, south Gujarat can give an average output of 6194 kg/hectare, and Saurashtra can give an average output of 5819 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the historic agro-ecological conditions of Gujarat, the state could produce a total of 570.555 tons of sorghum from areas suitable (VS+S+MS+mS+vmS) for sorghum cultivation. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat could give 343.515 tons (60.21% of total production) of sorghum from areas very suitable and suitable. Kutch can produce 3.580 tons (1.04%), north Gujarat can produce 93.026 tons (27.08%), central Gujarat can produce 115.966 tons (33.76%), followed by south Gujarat region with 61.998 tons (18.05%), and Saurashtra region with 68.945 tons (20.07%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 607.46 tons of sorghum from areas suitable (VS+S+MS+mS+vmS) for sorghum cultivation. A total of 394.384 tons (64.92 % of total production) of sorghum can be produced from very suitable and suitable areas. Kutch region can produce 9.786 tons (2.48%), north Gujarat region can produce 114.763 tons (29.10%). central Gujarat region can produce 121.502 tons (30.81%) from very suitable and suitable class, south Gujarat can produce 66.484 tons (16.86%), and Saurashtra can produce 81.849 tons (20.75%).

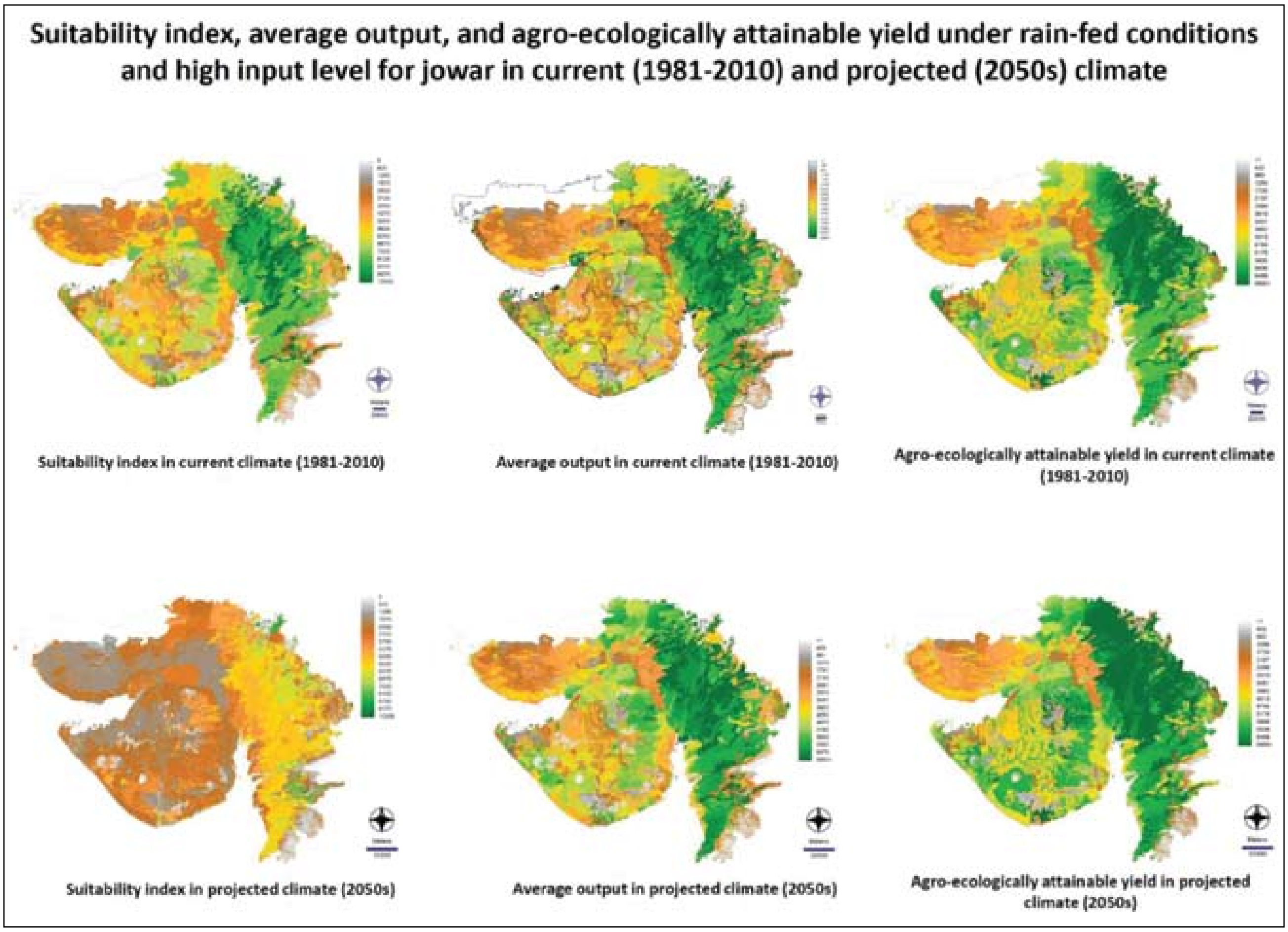

Figure 4.41: Climate Change Impacts on Crop Suitability and Attainable Yield of Sorghum under Rain-Fed Conditions Across Gujarat

13B Sorghum: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 15471 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sorghum, of which 6964.5 Hectare (45.02%) areas are very suitable and suitable. Kutch region has 795.7 hectares (11.43%) areas very suitable and suitable for sorghum. 1764.4 hectare (25.33%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 1893.9 hectares (27.19%) in central Gujarat region, 1133.3 hectares (16.27%) in south Gujarat region, and 1377.2 hectares (19.77%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that 15467.7 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for sorghum, of which 7081.7 hectares (45.78%) areas are very suitable and suitable. Kutch region has 800.2 hectares (11.30%) areas very suitable and suitable for sorghum. 1810.4 hectare (25.56%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 1901.4 hectares (26.85%) in central Gujarat region, 1149.9 hectares (16.24%) in south Gujarat region, and 1419.8 hectares (20.05%) in Saurashtra region.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, Gujarat can give an average output of 5153 kg/hectare from suitable (VS+S+MS+mS+vmS) areas, out of which very suitable and suitable (VS+S) areas of Gujarat can give an average output of 6538 kg/hectare of sorghum. very suitable and suitable (VS+S) areas of Kutch region can give average output of 6331 kg/hectare, north Gujarat region can give average output of 6982 kg/hectare, central Gujarat region can give average output of 6577 kg/hectare, south Gujarat region can give average output of 6385 kg/hectare, and Saurashtra region can give average output of 6417 kg/hectare sorghum.

Projected Climate (2041–2070): Projected average output of sorghum for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, Gujarat can give average output of 5272 kg/hectare from suitable (VS+S+MS+mS+vmS) areas, out of which very suitable and suitable (VS+S) areas of Gujarat can give average output of 6686 kg/hectare of sorghum. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 6486 kg/hectare, north Gujarat region can give average output of 7115 kg/hectare, central Gujarat region can give average output of 6732 kg/hectare, south Gujarat region can give average output of 6550 kg/hectare, and Saurashtra region can give average output of 6549 kg/hectare.

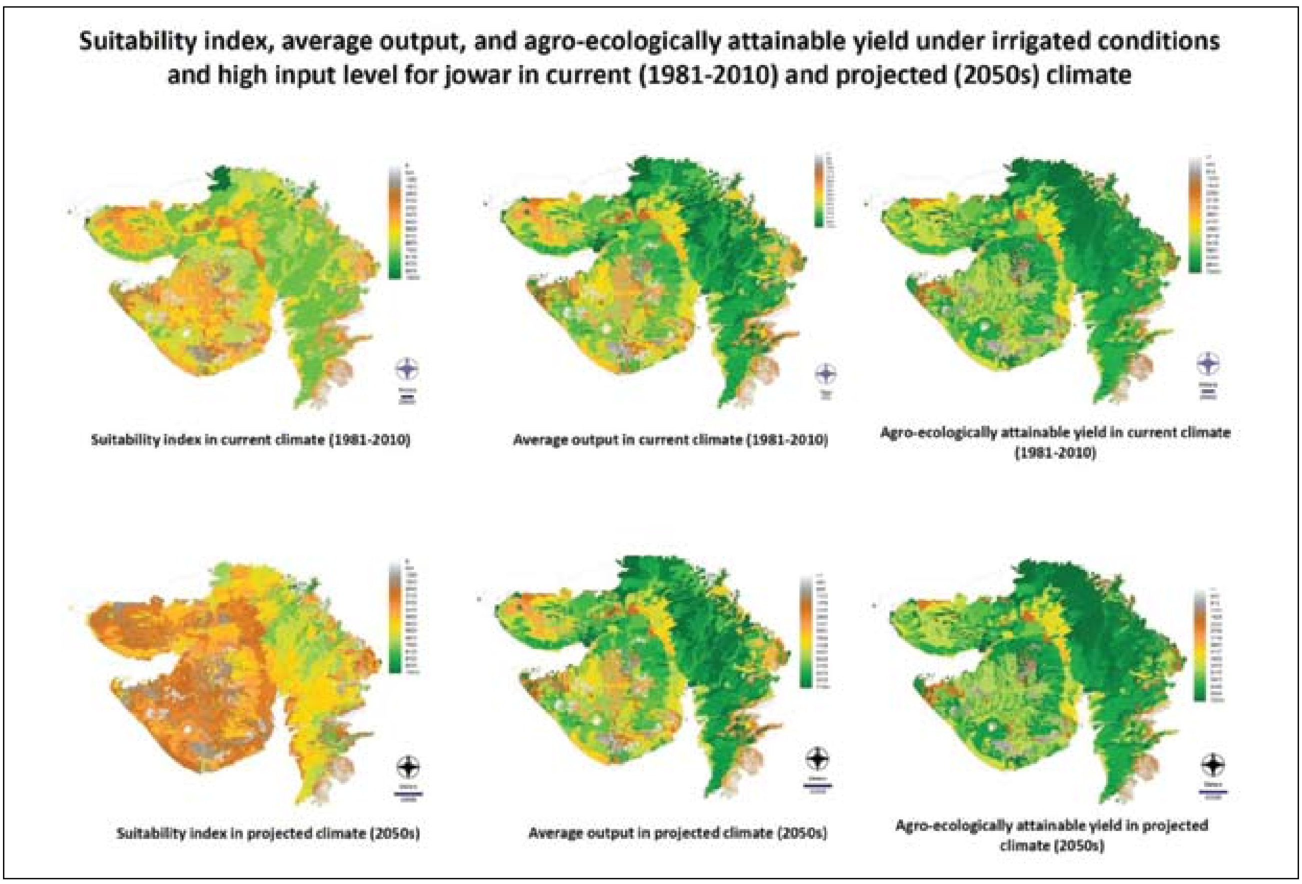

Figure 4.42: Climate Change Impacts on Crop Suitability and Attainable Yield of Sorghum under Irrigated Conditions Across Gujarat

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the historic agro-ecological conditions of Gujarat, the state could produce a total of 698.908 tons of sorghum from areas suitable (VS+S+MS+mS+vmS) for sorghum cultivation. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat could give 412.97 tons (59.09% of total production) of sorghum from areas very suitable and suitable. Very suitable and suitable (VS+S) areas of Kutch region can produce 45.339 tons (10.98%), north Gujarat region can produce 110.869 tons (26.85%), central Gujarat region can produce 11.21 tons (27.14%), south Gujarat region can produce 65.122 tons (15.76%), and Saurashtra region can produce 79.54 tons (19.26%) of sorghum.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat and given the irrigated conditions and high inputs, the state could produce a total of 714.674 tons of sorghum from areas suitable (VS+S+MS+mS+vmS) for sorghum cultivation. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat could give 429.327 tons (60.07% of total production) of sorghum from areas very suitable and suitable. Very suitable and suitable (VS+S) areas of Kutch region can produce 46.714 tons (10.88%), north Gujarat region can produce 115.922 tons (27%), central Gujarat region can produce 115.21 tons (26.84%), south Gujarat region can produce 67.789 tons (15.79%), and Saurashtra region can produce 83.692 tons (19.49%) of sorghum.

14A Cumin: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 1582.2 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for cumin, of which no areas are very suitable and suitable for cumin.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 289.3 hectares areas suitable (VS+S+MS+mS+vmS) for cumin, of which no areas are very suitable and suitable cumin.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Reference climate shows that given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 170 kg/hectare cumin. However, no areas of the state fall under very suitable and suitable class for cumin.

Projected Climate (2041–2070): Projected average output of cumin for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 172 kg/hectare cumin. However, no areas are very suitable and suitable for cumin.

Agro-Ecologically Attainable Yield (tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat and given the rain-fed conditions and high inputs, the state can produce a total of 231600 tons of cumin from areas suitable (VS+S+MS+mS+vmS) for the cultivation of cumin. However, no areas are very suitable and suitable for cumin.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat and given the rain-fed conditions and high inputs, the state has a potential of producing a total of 43400 tons of cumin from areas suitable (VS+S+MS+mS+vmS) for the cultivation of cumin. However, no areas are very suitable and suitable for cumin.

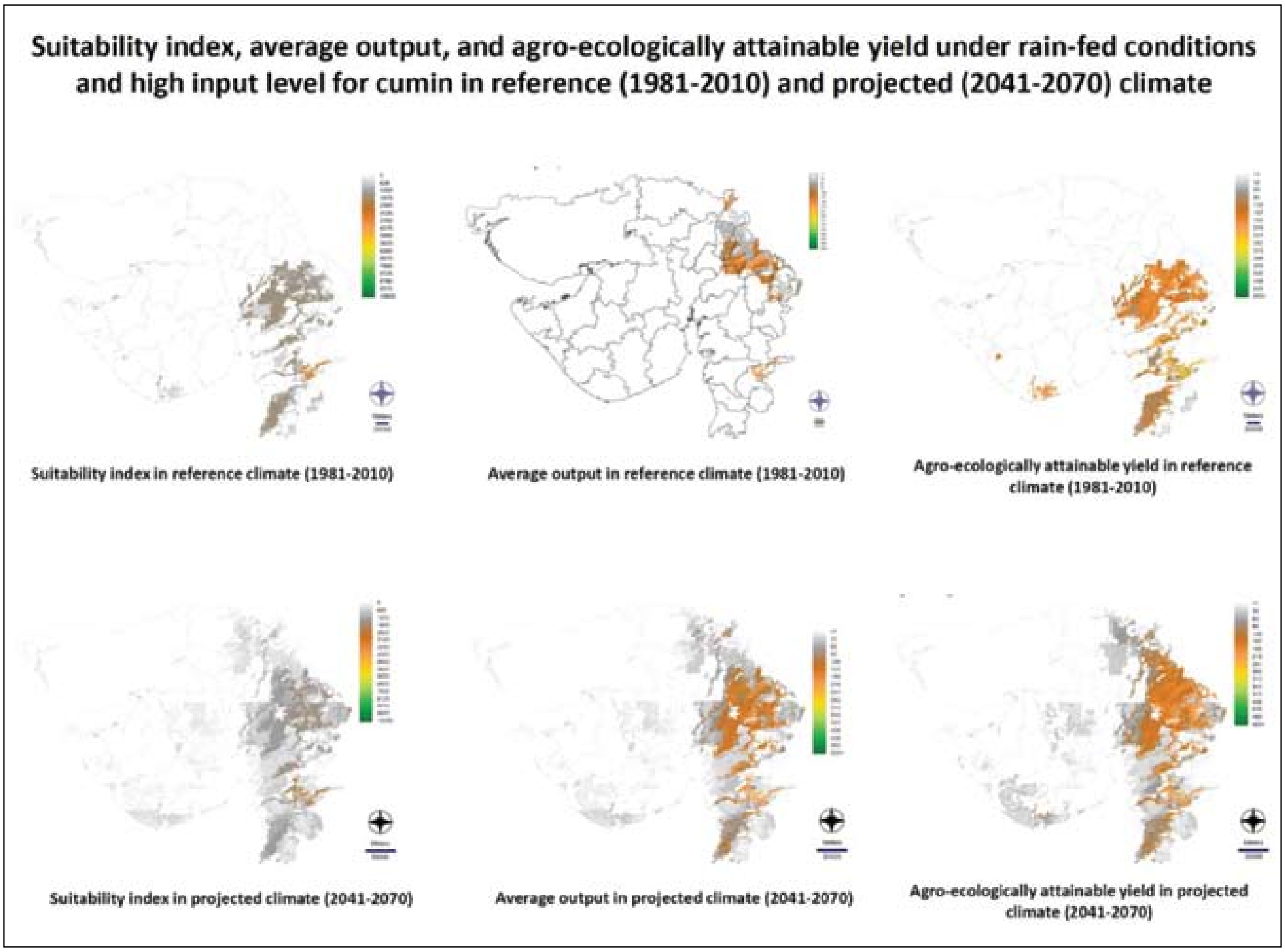

Figure 4.43: Climate Change Impacts on Crop Suitability and Attainable Yield of Cumin under Rain-Fed Conditions Across Gujarat

14B Cumin: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 10199.4 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for cumin, of which 1460.6 hectares (14.32% of total production) areas are very suitable and suitable. Kutch region has no areas very suitable and suitable for cumin. 200 hectare (13.69%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 817.8 hectares (55.99%) in central Gujarat region, 273.8 hectares (18.75%) in south Gujarat region, and 169 hectares (11.57%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that 15026.4 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for cumin, of which 825.1 hectares (23.63%) areas are very suitable and suitable. Kutch region has 85.1 hectares (12.25%) areas very suitable and suitable for cumin. 460.6 hectare (55.82%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region, 100.4 hectares (12.17%) in central Gujarat region, 123.8 hectare (15%) in south Gujarat region, and 55.2 km2 (6.69%) in Saurashtra region.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, suitable areas (VS+S+MS+mS+vmS) can give average output of 972 kg/hectare whereas very suitable and suitable (VS+S) areas of Kutch region can give average output of 903 kg/hectare, north Gujarat region can give average output of 927 kg/hectare, central Gujarat region can give average output of 948 kg/hectare, south Gujarat region can give average output of 1037 kg/hectare, and Saurashtra region can give average output of 975 kg/hectare cumin.

Projected Climate (2041–2070): Projected average output of cumin for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, given the irrigated conditions and high inputs, suitable areas (VS+S+MS+mS+vmS) can give an average output of 490 kg/hectare, whereas, very suitable and suitable (VS+S) areas can give 885 kg/hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 910 kg/hectare, north Gujarat region can give average output of 942 kg/hectare, central Gujarat region can give average output of 862 kg/hectare, south Gujarat region can give average output of 852 kg/hectare, and Saurashtra region can give average output of 859 kg/hectare.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 48.809 tons of cumin from suitable areas (VS+S+MS+mS+vmS) areas, whereas, given the irrigated conditions and high inputs very suitable and suitable areas for cumin can produce 12.685 tons (25.99% of total production). No very suitable and suitable area found could be found in Kutch for cumin production. North Gujarat region can produce 1.668 tons (13.15%), central Gujarat region can produce 6.981 tons (55.03%), south Gujarat region can produce 2.554 tons (20.13%), and Saurashtra region can produce 1.482 tons (11.68%) of cumin.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 63.465 tons of cumin from suitable (VS+S+MS+mS+vmS) areas, whereas,

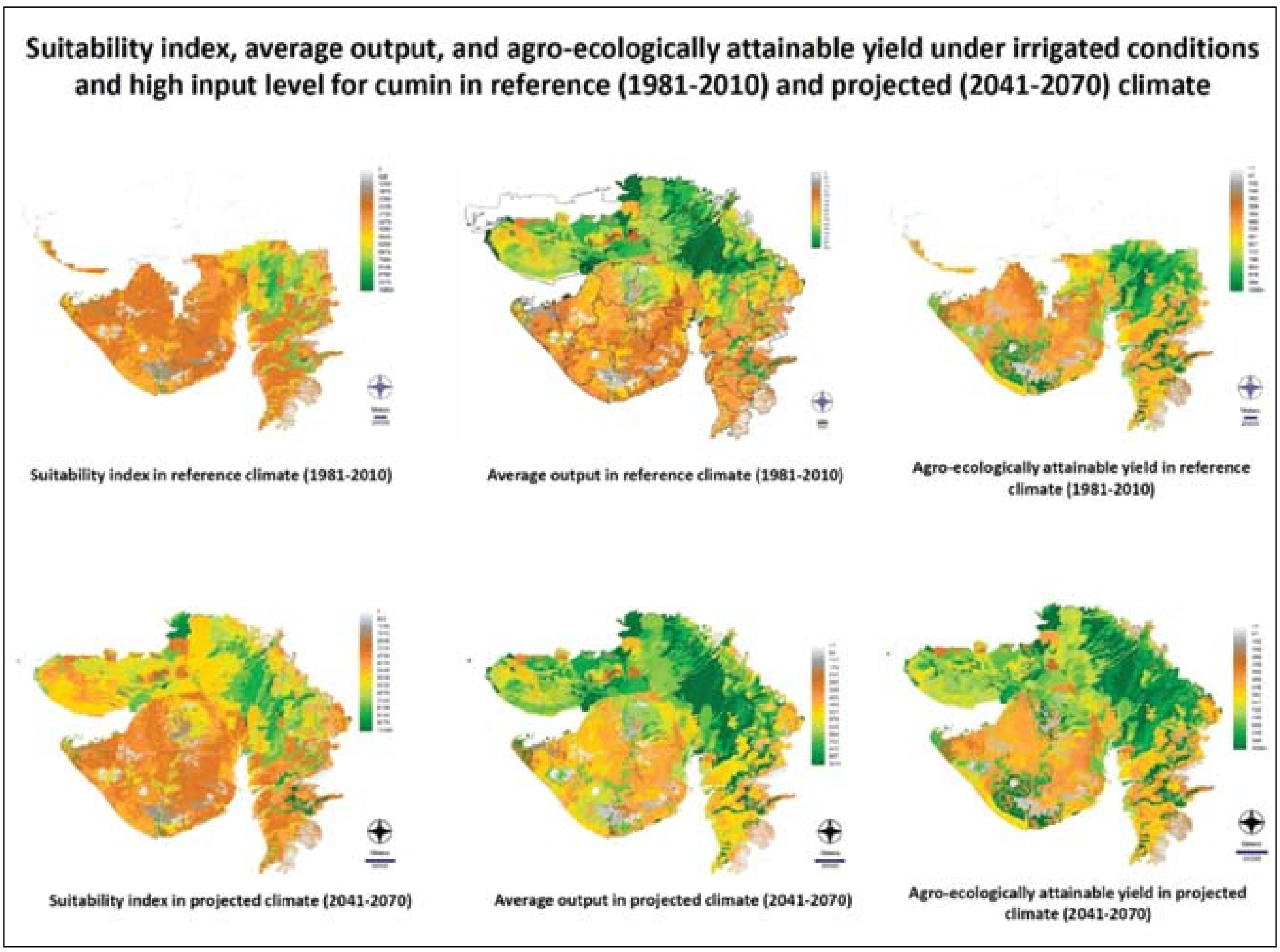

Figure 4.44: Climate Change Impacts on Crop Suitability and Attainable Yield of Cumin under Irrigated Conditions Across Gujarat

very suitable and suitable area cumin can produce 6.756 tons (10.65% of total production). Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Kutch region can produce 0.697 tons (10.32%), north Gujarat region can produce 3.904 tons (57.79%), central Gujarat region can produce 0.779 tons (11.53%), south Gujarat region can produce 0.949 tons (14.05%), and Saurashtra region can produce 0.427 tons (6.32%) of cumin.

15A Tobacco: Rain-Fed

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 12564.2 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for tobacco, of which 22 km2 hectare (0.18%) are very suitable and suitable. North Gujarat has 2.7 hectares (12.27%) areas very suitable and suitable for tobacco. 18.6 hectare (84.55%) of the very suitable and suitable (VS+S) areas happen to be in central Gujarat and 0.7 hectares (3.18%) in south Gujarat.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that Gujarat will have 6945 hectares areas suitable (VS+S+MS+mS+vmS) for tobacco, of which 18.8 hectares (0.27%) areas are very suitable and suitable. Kutch, South Gujarat, and Saurashtra region have no areas very suitable and suitable for tobacco. North Gujarat region has 14.7 hectares (78.19%) very suitable and suitable areas, whereas, central Gujarat region has only 4.1 hectares (21.81%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the rain-fed conditions and high inputs, suitable (VS+S+MS+mS+vmS) areas of Gujarat can give an average output of 159 kg/hectare tobacco whereas very suitable and suitable (VS+S) areas can give average output 478 kg/hectare. North Gujarat region can give an average output of 483 kg/hectare for tobacco, central Gujarat can give an average output of 484 kg/hectare, and south Gujarat can give an average output of 468 kg/hectare.

Projected Climate (2041–2070): Projected average output of tobacco for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, Gujarat can give an average output of 207 kg/hectare tobacco from suitable (VS+S+MS+mS+vmS) areas, whereas, very suitable and suitable can give an average output of 885 kg/hectare. North Gujarat region can give an average output of 899 kg/hectare. Central Gujarat region can give an average output of 870 kg/hectare from very suitable and suitable class.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 17.614 tons of tobacco from areas suitable (VS+S+MS+mS+vmS) for tobacco. Given the rain-fed conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can produce 0.096 tons (0.55% of total production) of tobacco from areas very suitable and suitable for tobacco. Central Gujarat can produce 0.081 tons (84.55%) for tobacco, followed by north Gujarat region with 0.012 tons (12.27%) and south Gujarat region with 0.003 tons (3.13%).

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 11.847 tons of tobacco from areas suitable (VS+S+MS+mS+vmS) for tobacco cultivation. A total of 0.151 tons (1.27% of total production) of tobacco can be produced from very suitable and suitable areas. North Gujarat region can produce 0.889 tons (78.81%). Central Gujarat region can produce 0.032 tons (21.19%) from very suitable and suitable class.

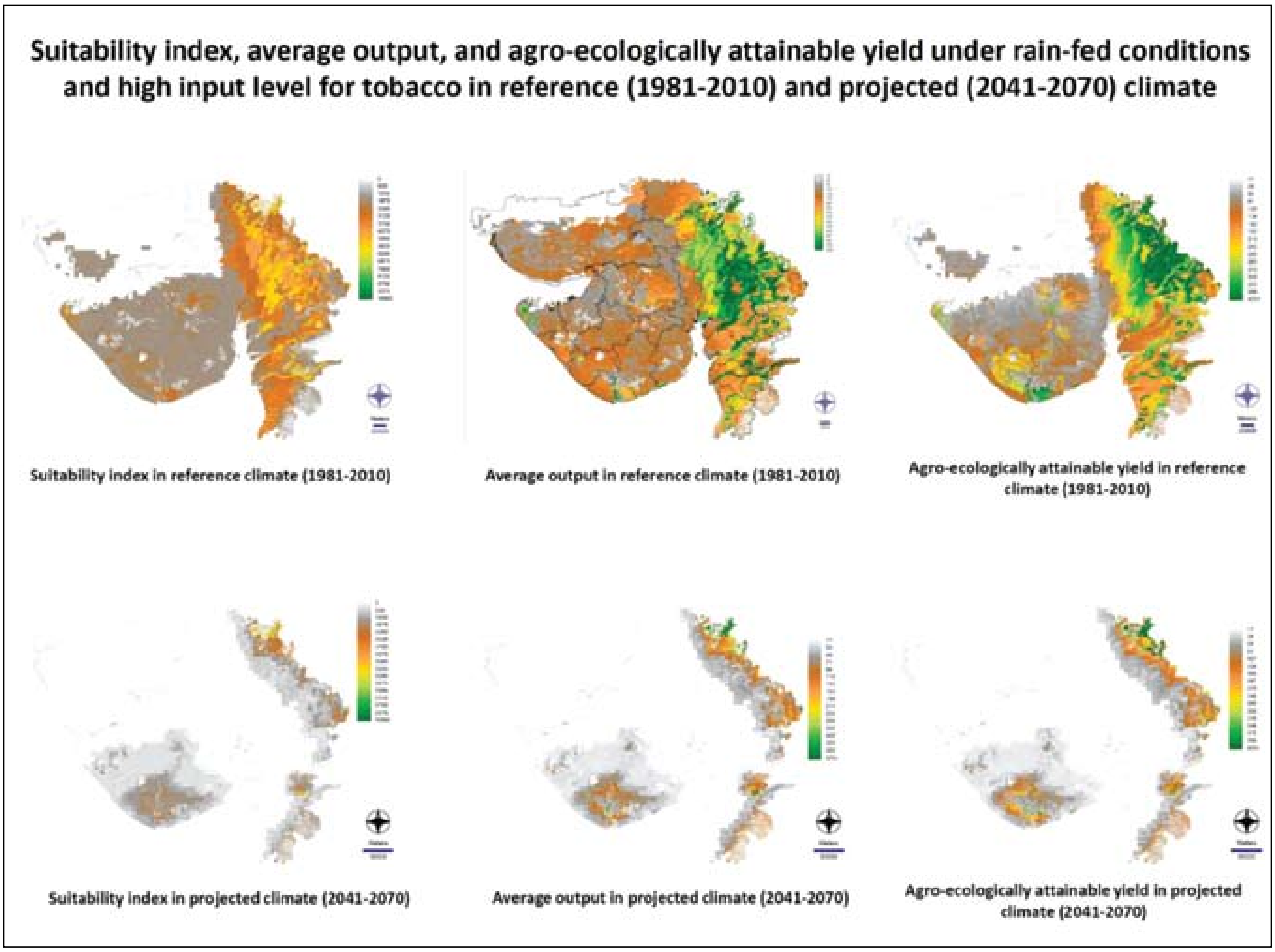

Figure 4.45: Climate Change Impacts on Crop Suitability and Attainable Yield of Tobacco under Rain-Fed Conditions Across Gujarat

15B Tobacco: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows 13097.8 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for tobacco, of which 9.8 hectares (0.07%) areas are very suitable and suitable. The entire, 9.8 hectares (100%) very suitable and suitable areas, happen to be in north Gujarat region. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, 7121.8 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for tobacco, of which 15.7 hectares (0.0.22%) areas are very suitable and suitable. The entire, 15.7 hectares (100%) of the very suitable and suitable areas, happen to be in north Gujarat region. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat and north Gujarat region can give an average output of 853 kg/hectare tobacco against suitable (VS+S+MS+mS+vmS) areas average output of 230 kg/hectare. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

Projected Climate (2041–2070): Projected average output of tobacco for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can give average output of 1000 kg/hectare tobacco against suitable (VS+S+MS+mS+vmS) areas average output of 342 kg/hectare. North Gujarat region can give an average output of 1012 kg/hectare and central Gujarat region can give an average output of 988 kg/hectare in very suitable and suitable conditions. Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the suitable (VS+S+MS+mS+vmS) areas of the state can produce a total of 25.187 tons of tobacco. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of the state can produce 0.075 tons (0.30% of total production) of tobacco. The very suitable and suitable (VS+S) areas of north Gujarat region can produce 0.075 tons (100%), Kutch, central Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 19.317 tons of tobacco can be produced from areas suitable (VS+S+MS+mS+vmS) for tobacco. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas can produce 0.143 tons (0.74% of total production) of tobacco. Very suitable and suitable (VS+S) areas of north Gujarat region can produce 0.134 tons (93.71%) of tobacco and central Gujarat region can produce 0.009 tons (6.29%) of tobacco. Kutch, Gujarat, south Gujarat, and Saurashtra regions have no areas very suitable and suitable for tobacco.

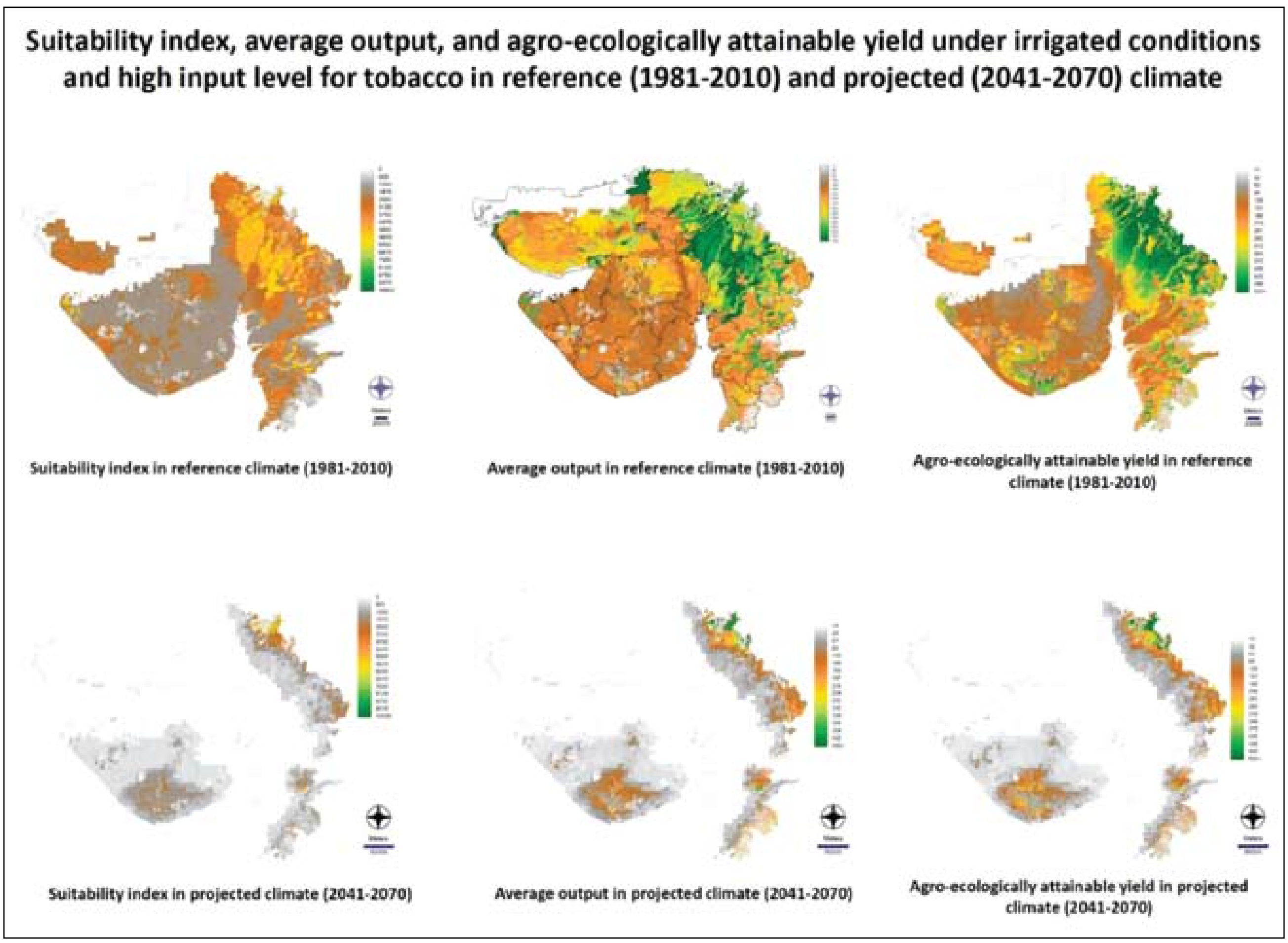

Figure 4.46: Climate Change Impacts on Crop Suitability and Attainable Yield of Tobacco under Irrigated Conditions Across Gujarat

16A Banana: Irrigated

Suitability Index (*000 Hectare)

Reference Climate (1981–2010): Reference climate shows, 2124.7 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for the cultivation of banana, of which 36 hectares areas (1.69%) are very suitable and suitable. Kutch region, central Gujarat, and south Gujarat regions have no areas very suitable and suitable for banana cultivation. 145 km2 (40.28%) of the very suitable and suitable (VS+S) areas happen to be in north Gujarat region and 215 km2 (59.72%) in Saurashtra region.

Projected Climate (2041–2070): Projected crop suitability analysis for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that 15477.4 hectares area of Gujarat is suitable (VS+S+MS+mS+vmS) for banana, of which 745.4 hectares (4.82%) areas are very suitable and suitable. Kutch region have 1 hectare (0.13%) very suitable and suitable areas, north Gujarat region have 422.2 hectare (56.64%) very suitable and suitable areas, central Gujarat region have 132.3 hectares (17.75%) very suitable and suitable areas, south Gujarat region have 124.7 hectares (16.73%) very suitable and suitable areas, Saurashtra region have 65.2 hectares (8.75%) very suitable and suitable areas.

Average Output per Unit Area (kg/ha)

Reference Climate (1981–2010): Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 6819 kg/hectare of banana against suitable (VS+S+MS+mS+vmS) areas average output of 2309 kg/hectare. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas of north Gujarat region can give an average output of 6764 kg/hectare, and Saurashtra region can give an average output of 6873 kg/hectare banana. Kutch region, central Gujarat, and south Gujarat regions have no areas very suitable and suitable for banana cultivation.

Projected Climate (2041–2070): Projected average output of banana for 2041–2070, using ENSEMBLE MEAN Climate Model with RCP 4.5, indicated that, very suitable and suitable (VS+S) areas of Gujarat can give an average output of 6836 kg/hectare of banana against suitable (VS+S+MS+mS+vmS) areas average output of 3087 kg/hectare. Very suitable and suitable (VS+S) areas of Kutch region can give average output of 6507 kg/hectare banana, north Gujarat region can give average output of 7080 kg/hectare banana, central Gujarat region can give average output of 6693 kg/hectare banana, south Gujarat region can give average output of 6823 kg/hectare banana, and Saurashtra region can give average output of 7079 kg/hectare banana.

Agro-Ecologically Attainable Yield (*00000 tons)

Reference Climate (1981–2010): Considering the reference climatic conditions of Gujarat, the state can produce a total of 38.845 tons of banana from areas suitable (VS+S+MS+mS+vmS) for the cultivation of banana. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas can produce 2.217 tons (5.17% of total production) of banana. North Gujarat region can produce 0.885 tons (39.92%) and Saurashtra region can produce 1.332 tons (60.08%) of banana. Kutch region, central Gujarat, and south Gujarat regions have no areas very suitable and suitable for banana cultivation.

Projected Climate (2041–2070): Considering the projected climatic conditions of Gujarat, the state has a potential of producing a total of 407.835 tons of banana from areas suitable (VS+S+MS+mS+vmS) for the cultivation of banana. Given the irrigated conditions and high inputs, very suitable and suitable (VS+S) areas can produce 46.74 tons (11.46% of total production) of banana. The very suitable and suitable (VS+S) areas of Kutch region can produce 0.061 tons (0.13%) of banana, north Gujarat region can produce 26.903 tons (57.56%) of banana, central Gujarat region can produce 7.967 tons (17.05%) of banana, south Gujarat region can produce 7.658 tons (16.38%) of banana, and Saurashtra region can produce 4.151 tons (8.88%) of banana.

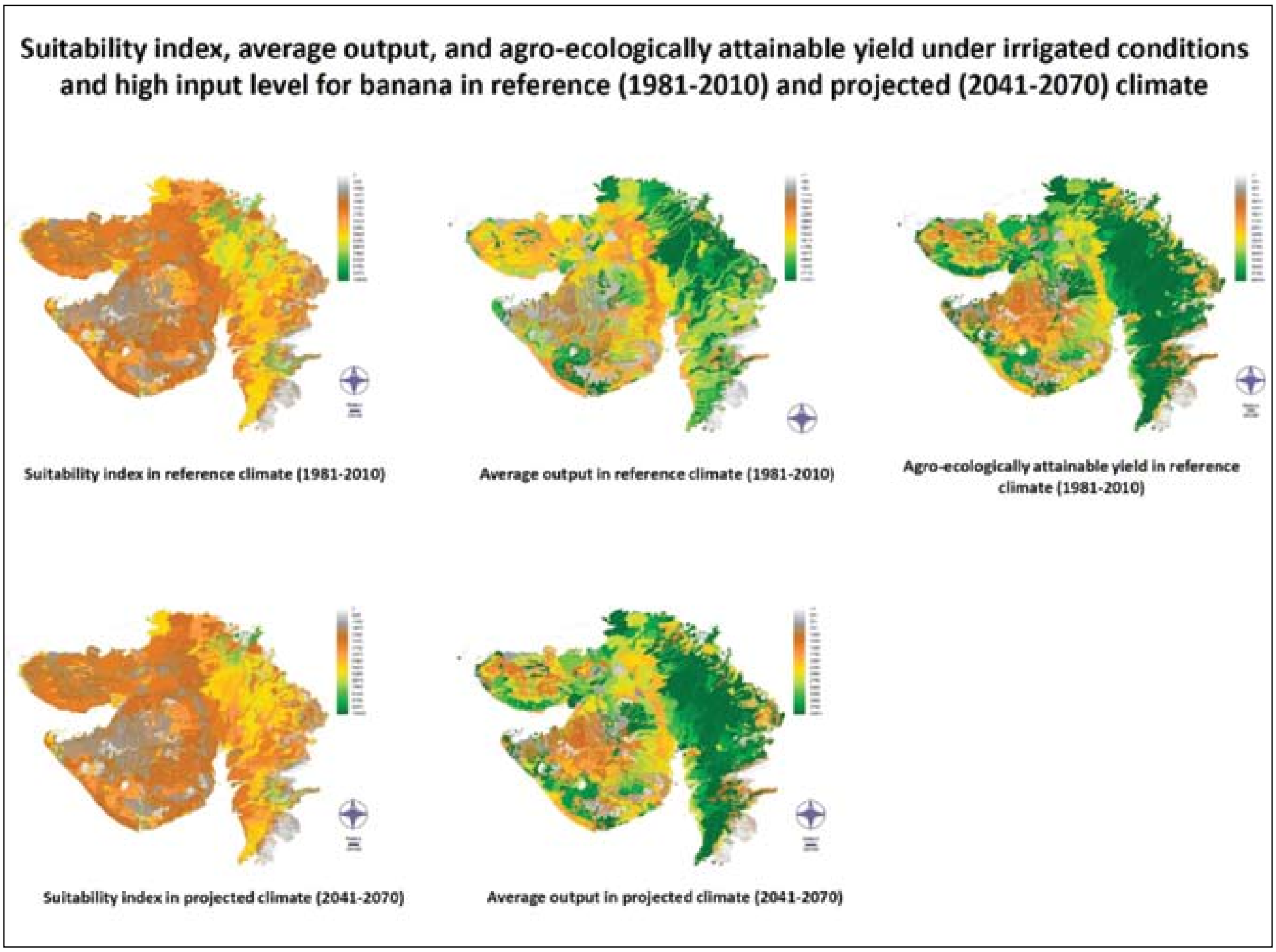

Figure 4.47: Climate Change Impacts on Crop Suitability and Attainable Yield of Banana under Irrigated Conditions Across Gujarat

4.8 Limitations

In the soil data used, Saurashtra soil is classified as shallow soil. Therefore, many classifications are showing poor crop suitability. Better datasets are needed for much robust results.

CHAPTER-5

Adaptation Options for Enhancing Livelihoods of Rural Communities

Under the common but differentiated responsibility, the state has done commendable work to mitigate climate change and has the maximum number of registered projects under the clean development mechanism in India. The state is also gearing up to adapt against climate-related impacts through various programmes such as climate smart agriculture, crop and soil management, micro-irrigation, better water resource management practices, climate smart livestock rearing, integrated coastal zone management, etc.

5.1 Micro-Irrigation to Increase Crop Production in Surendranagar District

5.1.1 Climate-Related Impacts and Adaptations as Perceived by the Stakeholders

The stakeholders percieved an increase in temperatures during summer and winter seasons. They also percieved increase in rainfall during rainy season. It is apparent that increased summer and winter temperatures influenced their natural and human assets the most. Increased temperatures has resulted into declined vegetable and wheat production reduced agricultural production due to increasing temperatures has ensued decrease in fodder availability. Also, fodder availability has been directly impacted by the temperature rise in both the seasons. Less availability of fodder has decreased livestock number, health, and milk production, which consequently led to plunge in the financial reserves of the stakeholders. Another major impact of increased temperature is the surge in heat during summers as well as winters. This climatic extreme has degraded human and livestock health severly. Declining water resources during summer and winter seasons such as availability of ground water, drinking water, and water for irrigation have further impacted agricultural production, and human and livestock health. Less availability of ground water has led to decrease in agriculture produce like cotton. Drudgery among women has increased due to scarcity of drinking water. Water quality has also lowered negatively affecting human health. Farmers of this region percieve that rainfall has increased, and it positively influenced their livelihood. Increased rainfall has increased the production of sesame, which has expanded stakeholders' financial reserves. Increasing financial reserves provide farmers the space to introduce different agriculture inputs to improve their agricultural production. Due to increased rainfall, water availability has inclined resulting increase in both drinking and ground water availability where the latter has benefitted farmers in agriculture production. Fodder availability has also increased during rainy seasons which subsequently increased milk production as well as livestock health and number.

Increased rainfall has positively influenced land conditions in the region. As soil moisture has increased agriculture production has increased as well. Communities of this region chiefly face the issue of less water availability and low agriculture production during summer and winter. They have adopted several adaptation practices such as micro-irrigation, better agricultural inputs, water resource management, water infrastructure, and diversification of production systems to increase the agriculture production. Stakeholders use fertilizers to increase soil fertility and agriculture production. Building of check dam has increased water availability during lean seasons increasing the agriculture production and fodder availability. Drip irrigation and sprinklers have increased soil moisture and improved soil quality, and also increased agriculture production. To tackle the issue of drinking water availability, water storage tanks have been installed at various places which provides drinking water to villagers, and reduces drudgery among women. Health care facilities for livestock have increased livestock health as well as milk prodcution.

Table 5.1: Climate Change Sensitivity and Adaptive Capacity Against Respective Concepts in all Three Season

Concepts	Climate variability and change	
	Sensitivity	Adaptive capacity
Agricultural production	Climate variability and change	Water resource management
	Agriculture production	Diversification of production systems
	Insects and Pest	Water resource management
	Land resources	Agriculture input
	Water resources	Water resource management
Climatic extremes	Climate variability and change	
Financial reserve	Agriculture production	
	Livestock and milk production	
	Water resources	
	Human health and education	
	Financial reserve	
Fodder availability	Climate variability and change	
	Water resources	
	Agriculture production	
	Fodder availability	
Human health and education	Climate variability and change	Water infrastructure
	Climatic extremes	
	Water resources	
	Financial reserve	
Insects and Pest	Climate variability and change	Pest control techniques
Land resources	Climate variability and change	Agricultural inputs
	Land resources	Water resource management
Livestock and milk production	Climate variability and change	Health care facilities
	Climatic extremes	Water resource management
	Fodder availability	
	Livestock and milk production	
	Water resources	

Water resources	Climate variability and change	Water infrastructure
	Water resources	Water resource management
	Land resources	
	Financial reserve	
Agricultural inputs	Agriculture production	
Water resource management	Climate variability and change	
	Land resources	
	Water resources	

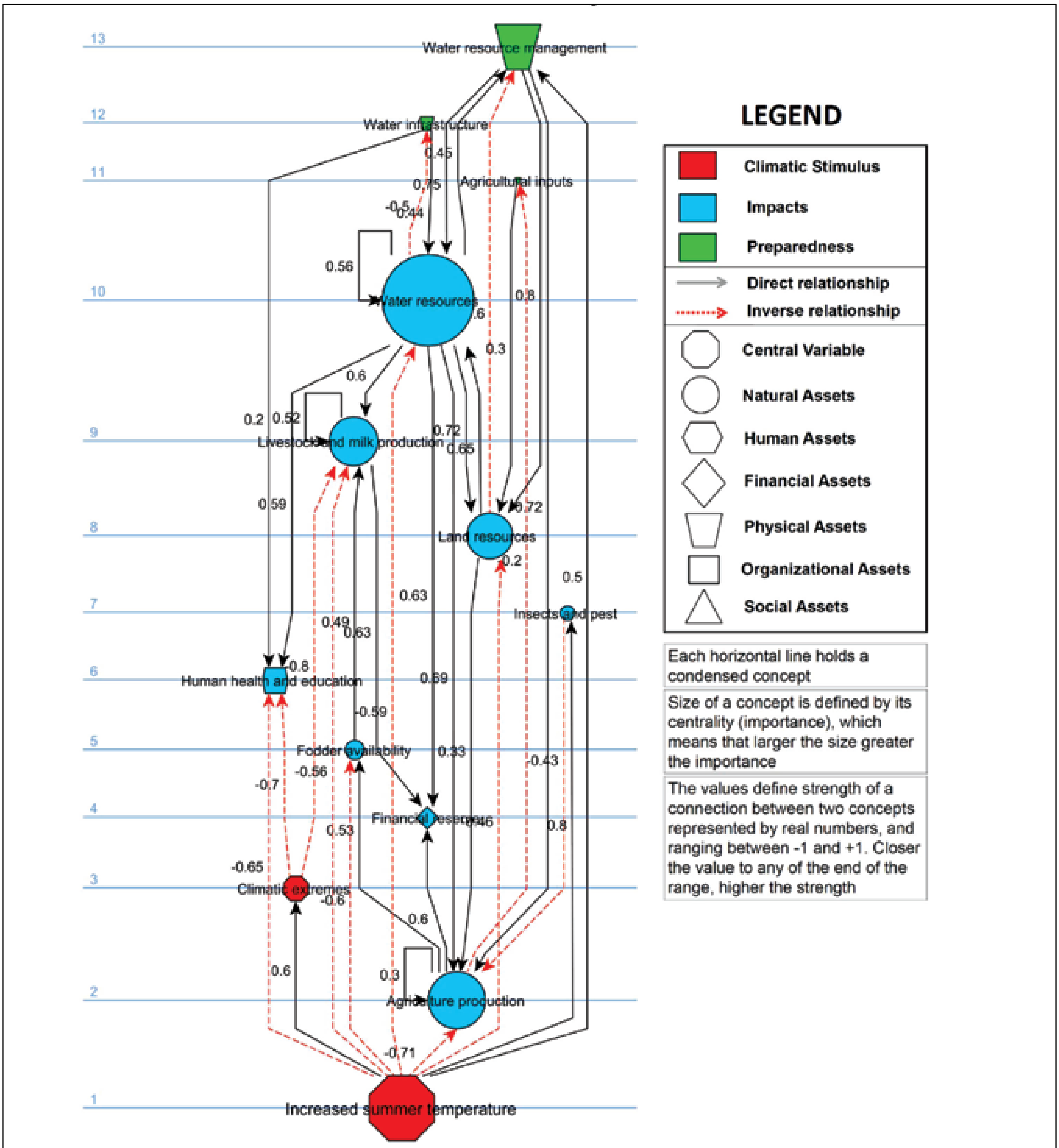

Figure 5.1: Impacts of Climate Change and Adaptations as Perceived by the Communities of Surendranagar in Summer Season

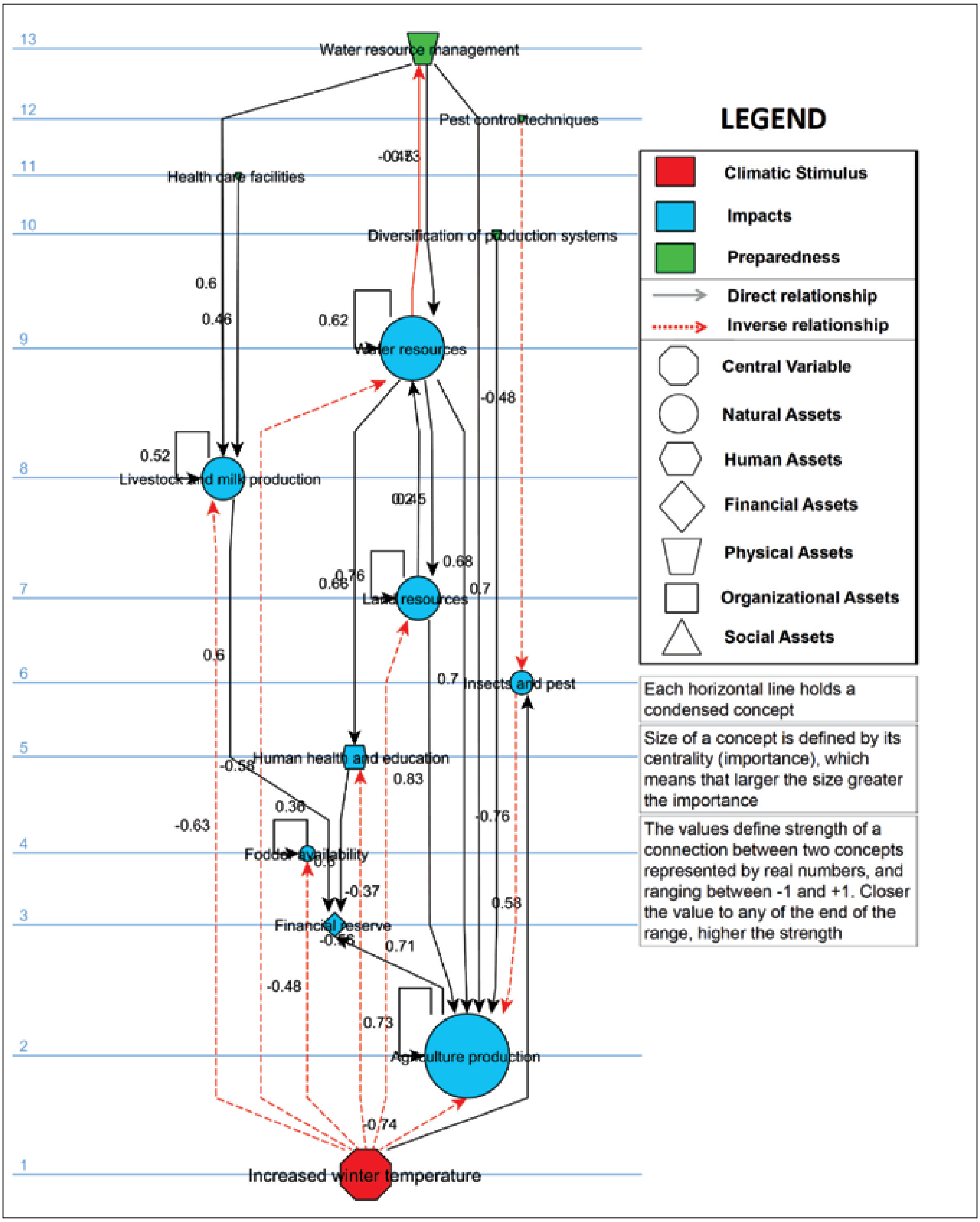

Figure 5.2: Impacts of Climate Change and Adaptations as Perceived by the Communities of Surendranagar in Winter Season

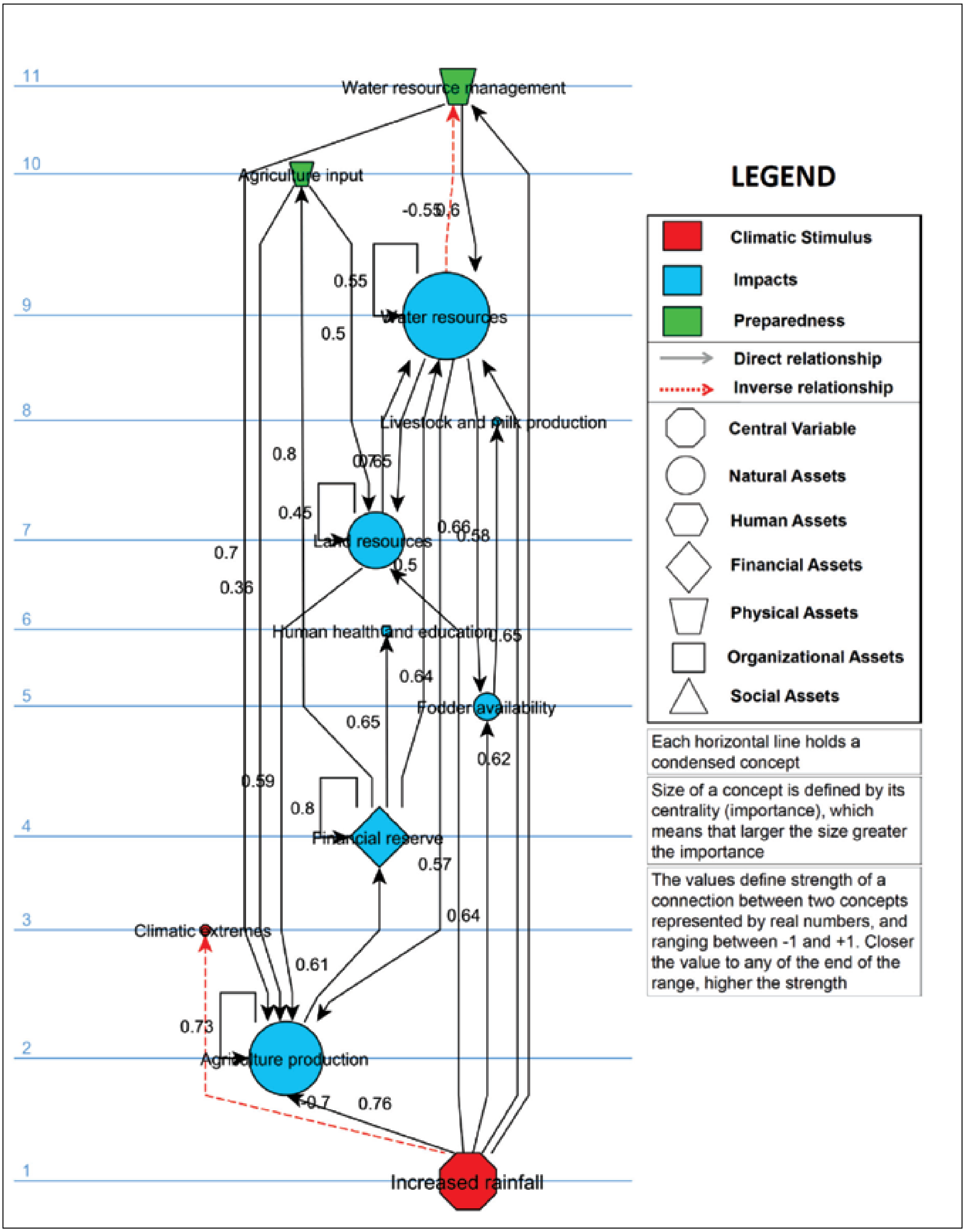

Figure 5.3: Impacts of Climate Change and Adaptations as Perceived by the Communities of Surendranagar in Rainfall Season

5.1.2 Livelihood Vulnerability to Climate Variability and Change in Surendranagar

Livelihood vulnerability was calculated for three seasons, i.e. summer, winter, and rainfall. Livelihood vulnerability to climate variability and change is dynamic and varies across seasons and sectors. The climate data reveals that exposure is highest due to increasing temperatures in winter with 0.826, marginally ahead of increasing temperatures in summer with 0.818. Exposure due to increasing rainfall variability is lowest, i.e. 0.684.

The below tables show sensitivity and adaptive capacity as perceived by the communities in Surendranagar.

Table 5.2: Sensitivity for Each Season

Livelihood Assets	Sensitivity		
	Summer	Winter	Rainfall
Agriculture production	0.44	0.447	0.676
Climatic extremes	0.6		0.7
Fodder availability	0.565	0.42	0.64
Insects and pest	0.8	0.58	
Land quality	0.462	0.565	0.555
Livestock and milk production	0.593	0.575	0.583
Water availability	0.574	0.388	0.557
Human health and education	0.675	0.566	0.645
Financial reserve	0.62	0.637	0.705

Table 5.3: Adaptive Capacity for Each Season

Livelihood Assets	Sensitivity		
	Summer	Winter	Rainfall
Agricultural inputs	0.3		0.43
Water infrastructure	0.32		
Water resource management	0.756	0.67	0.65
Diversification of production systems		0.7	
Health care facilities		0.46	

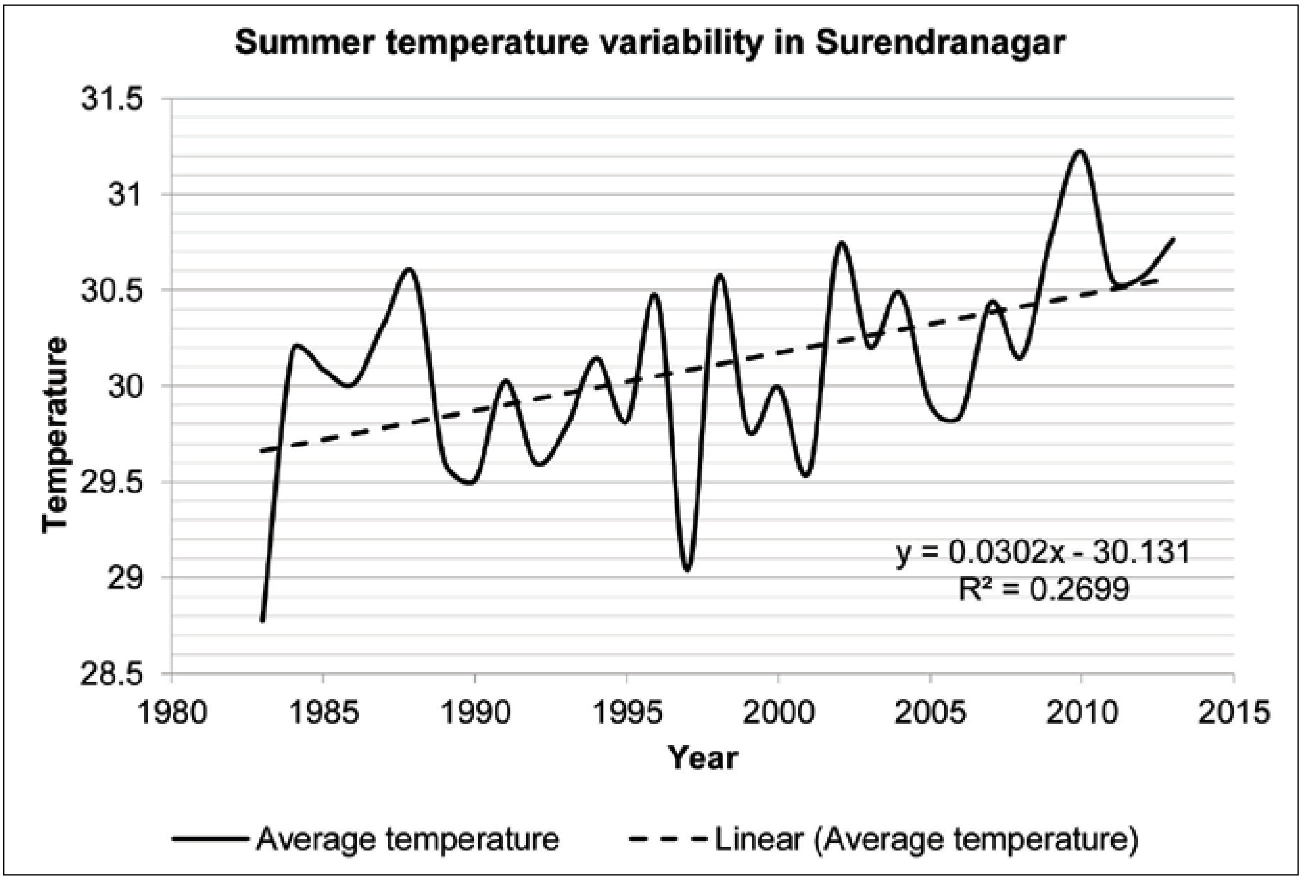

Figure 5.4: Summer Temperature Variability

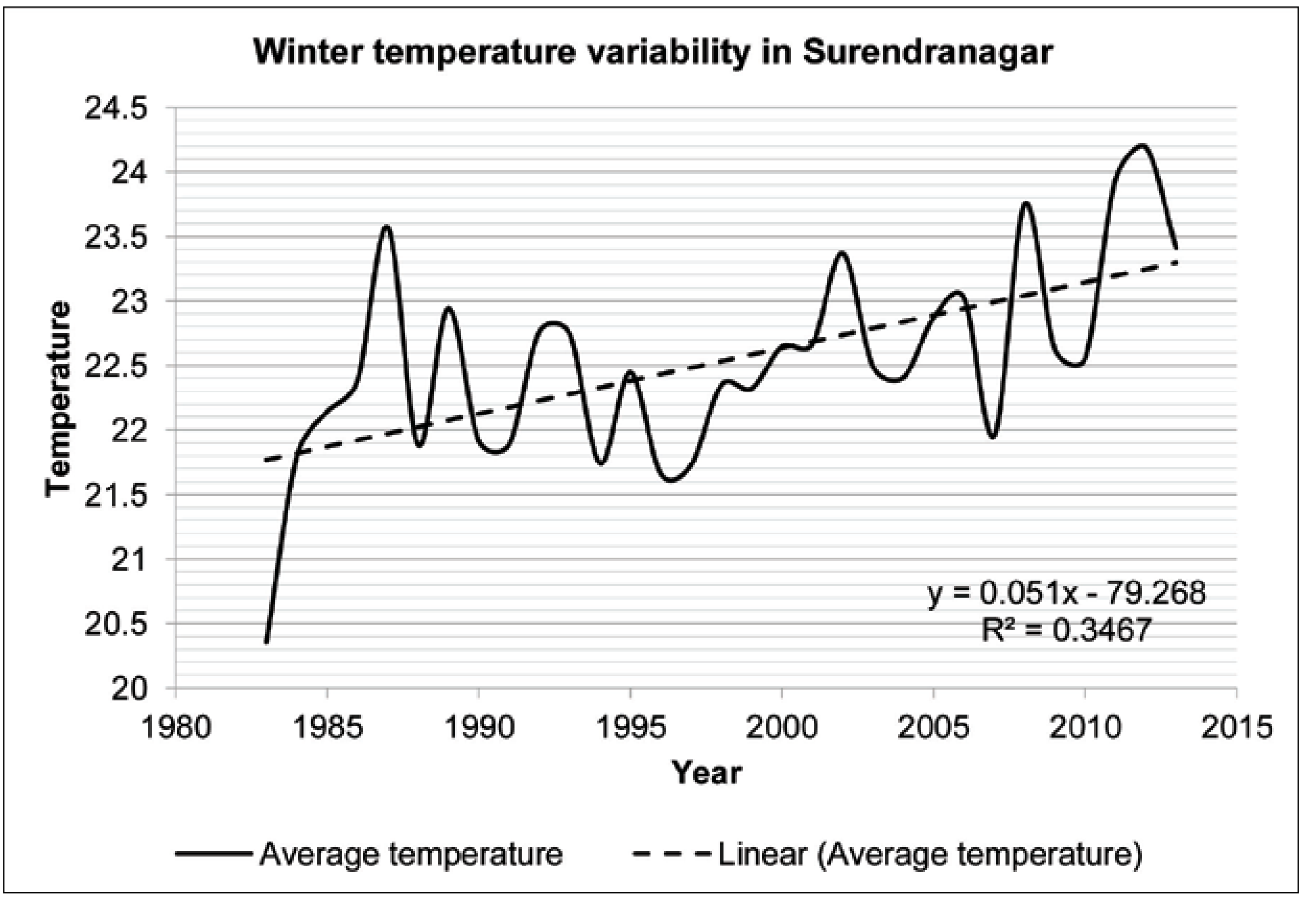

Figure 5.5: Winter Temperature Variability

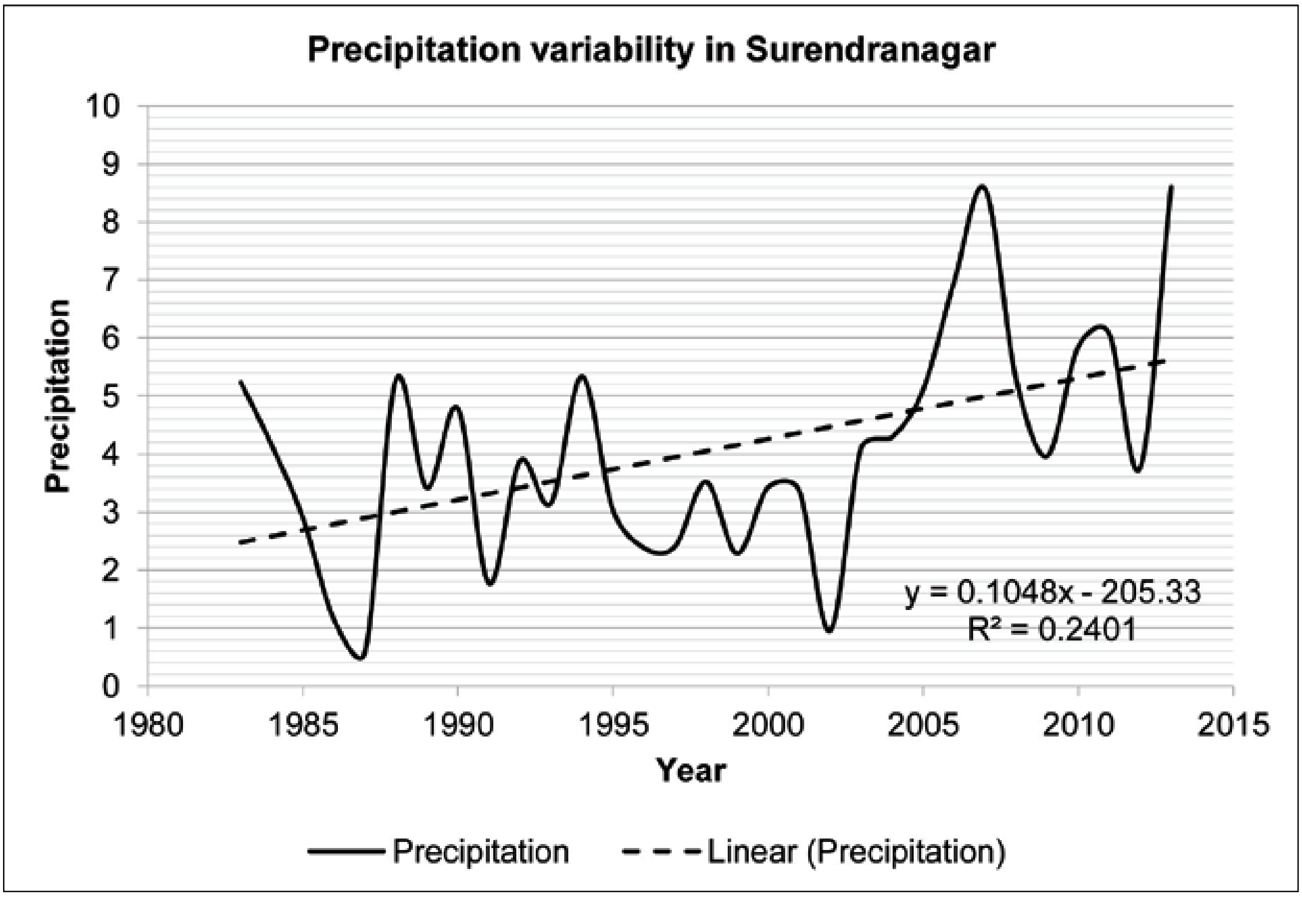

Figure 5.6: Precipitation Variability

Table 5.4: Mean Precipitation and Temperature in Surendrnagar for Reference Climate, and Change for Projected Climates Using Different Models

Years	Models	Precipitation (mm)	Temperature (ºC)
Reference climate (1981-2010)	CRU	598.75	27.26
Projected climate 2050s	GFDL	552.48	28.80
	HadGEM	747.82	29.12
	IPSL	668.71	29.62
	MIROC	557.96	28.76
	NorESM	585.24	28.66
	E-MEAN	622.44	29.00
Projected climate 2080s	GFDL	623.39	29.41
	HadGEM	787.43	29.93
	IPSL	712.76	30.23
	MIROC	564.97	29.50
	NorESM	684.01	28.72
	E-MEAN	674.51	29.54

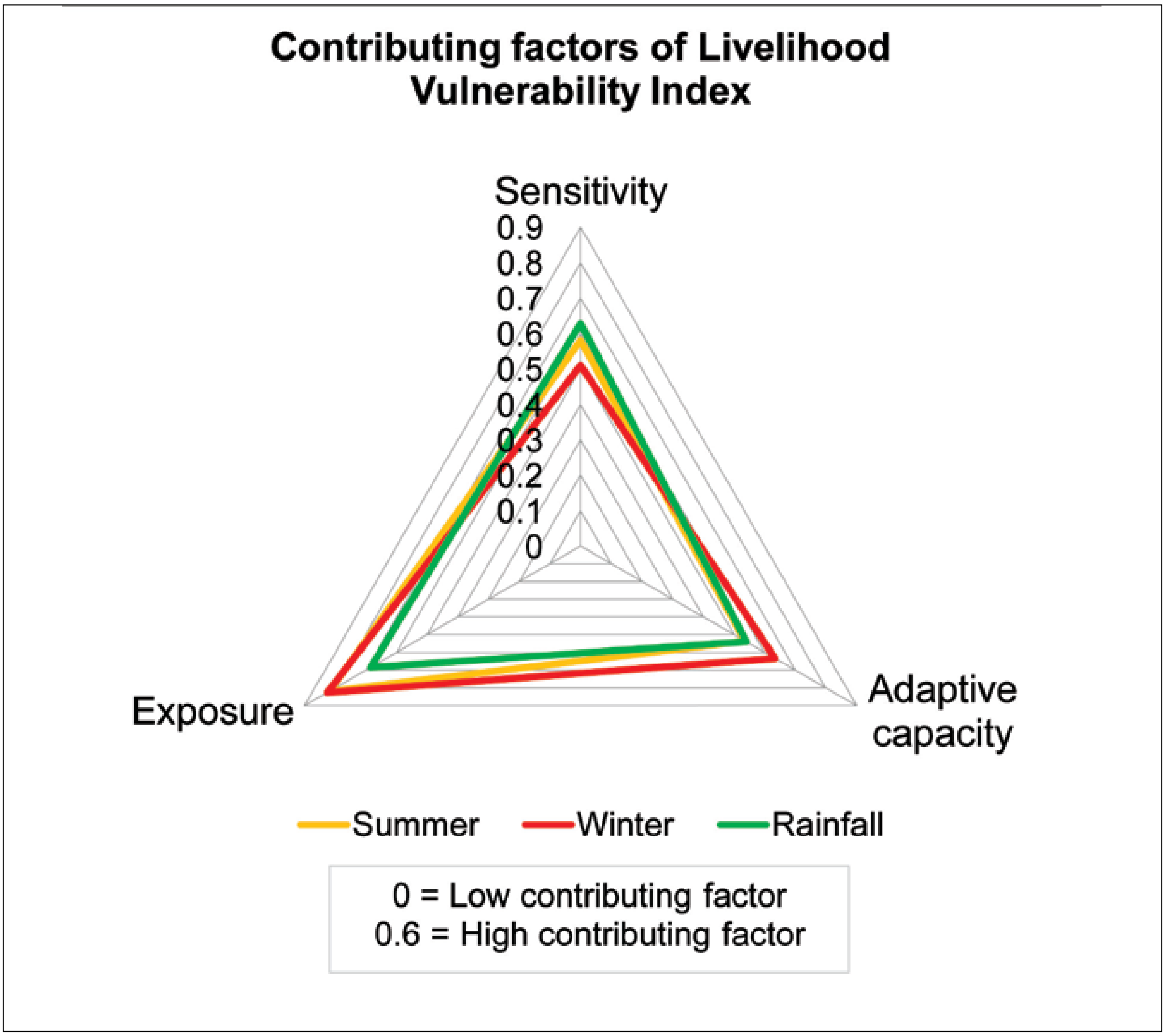

Figure 5.7: Contributing Factors of the Livelihood Vulnerability Index to Climate Variability and Change

Overall sensitivity of livelihoods to increasing summer and winter temperature is 0.580 and 0.510, while for increasing rainfall variability is 0.628. Overall adaptive capacities during rainfall and summer seasons are 0.540 and 0.535 respectively, whereas, adaptive capacity during winter season is 0.634. Sensitivity, adaptive capacity, and exposure to climate variability and change vary across seasons, hence, communities in study area exhibit different vulnerability. The livelihood vulnerability index to climate variability and change in Surendranagar is highest during rainfall season, i.e.0.060, followed by summer season with 0.037. Livelihood vulnerability index is least during rainfall, i.e. -0.102. Communities perceived themselves to be vulnerable to increasing temperatures.

5.1.3 Scenarios

To understand the effectiveness of the adaptations, scenarios have been modeled under future climate change. To generate future climate change scenario with present adaptations, all three central concepts were scaled up to their maximum activation level, which is 1, adaptation interventions were also scaled up to their maximum activation level.

i. Scenarios Generated for Increased Summer Temperature:

In order to understand effectiveness of the adaptation interventions; agriculture inputs, water infrastructure, and water resource management, intended for reducing the negative impacts incurred on; water resources, agricultural production, land resources, livestock and milk production, human health, and fodder availability. A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that agricultural production, livestock and milk production, fodder availability, water and land resources, and financial reserves show positive change till 20 iterations. However, these concepts along with agriculture inputs, water infrastructure, and water resource management show recurring positive and negative change post 20 iterations. While, human health remain shows negative change.

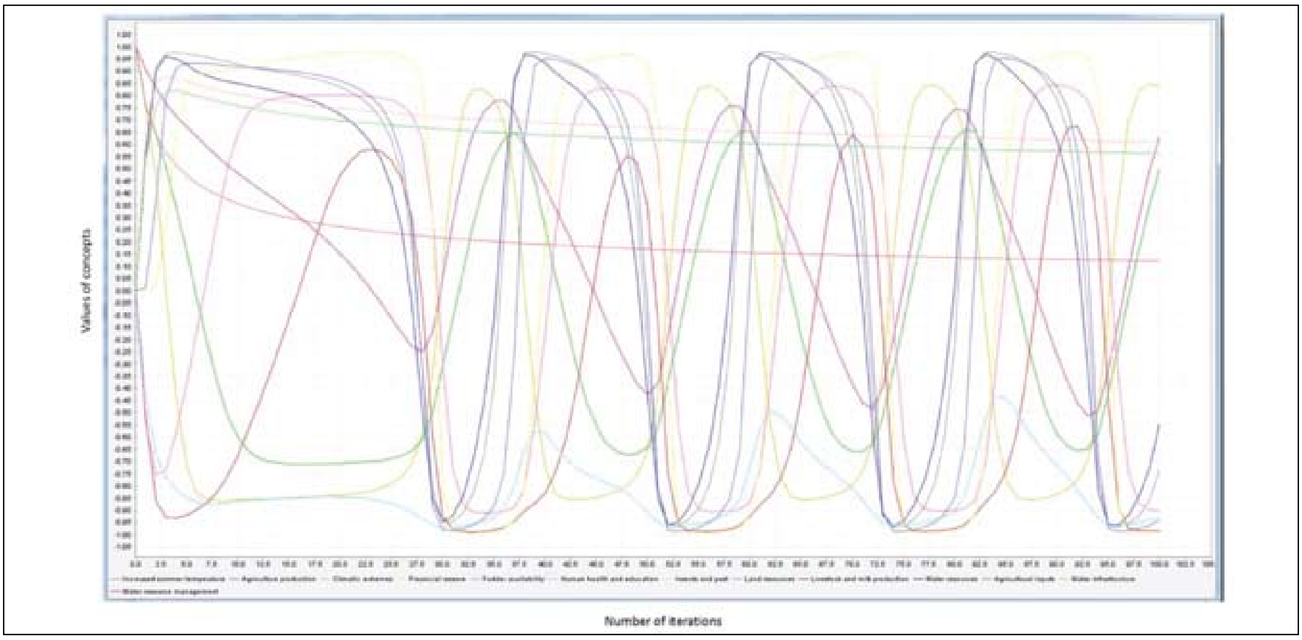

Figure 5.8: Simulations for Increased Summer Temperature

ii. Scenarios Generated for Increased Winter Temperature:

In order to understand effectiveness of the adaptation interventions; diversification of production systems, healthcare facilities, pest control techniques, and water resource management, intended for reducing

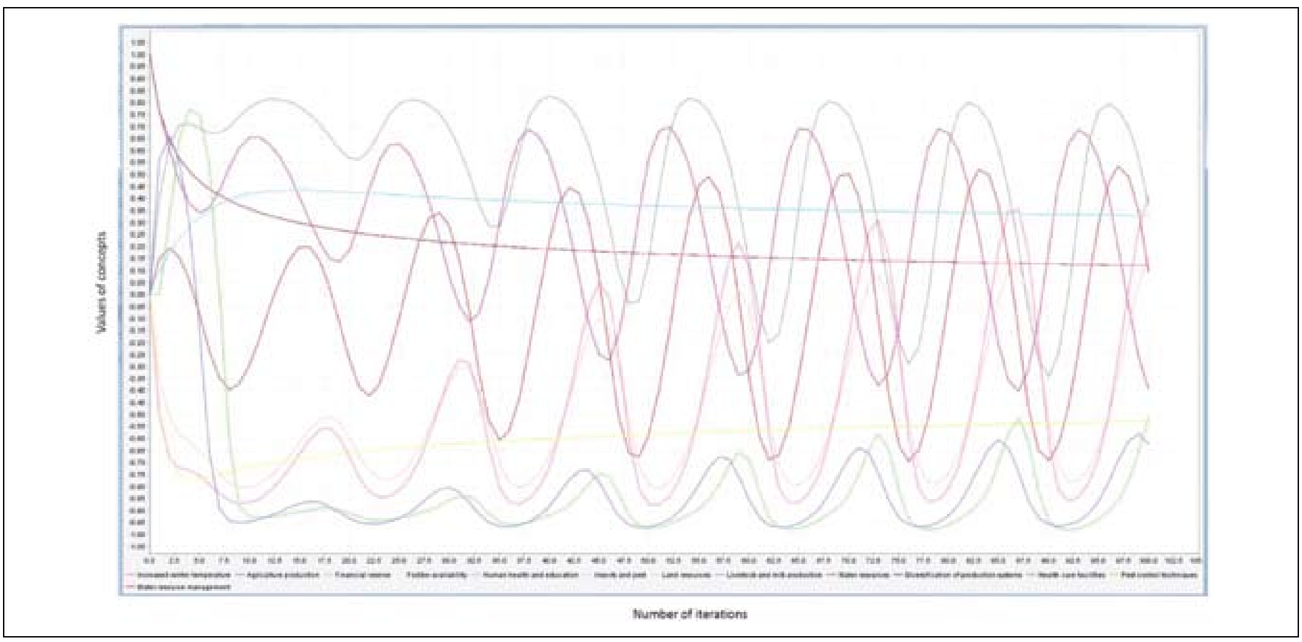

Figure 5.9: Simulations for Increased Winter Temperature

the negative impacts incurred on; agricultural production, land and water resources, livestock and milk production, human health and education, fodder availability, financial reserves, and insects and pests. A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that agricultural production, fodder availability, and financial reserves shownegative change, whereas, land and water resources, livestock and milk production, human health and education showrecurring positive and negative change.

iii. Scenarios Generated for Increased Rainfall:

In order to understand effectiveness of the adaptation interventions; agriculture inputs and water resource management, intended for reducing the negative impacts incurred on; agricultural production, land and

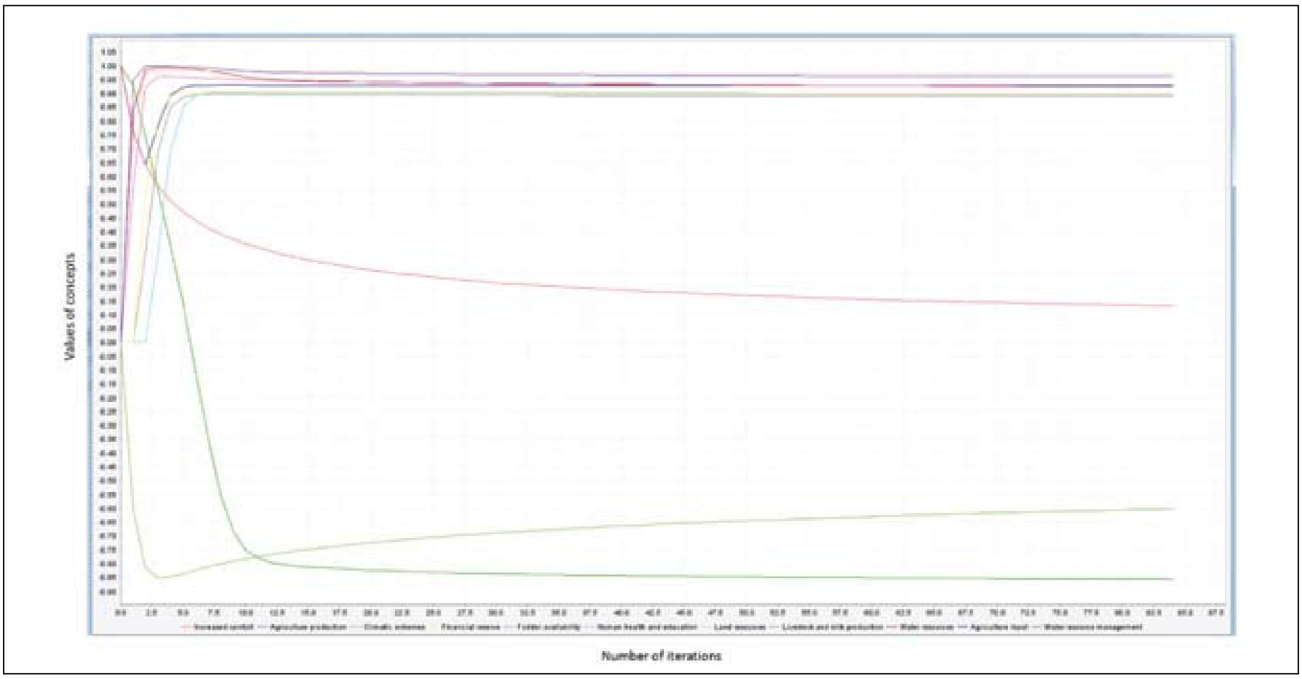

Figure 5.10: Simulations for Increased Rainfall

Drip irrigation set-up

water resources, and fodder availability, livestock and milk production, human health and education, and financial reserves. A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that given these adaptations, agricultural production, land and water resources, fodder availability, livestock and milk production, human health and education, and financial reserves converge on positive side. Climatic extremes and water resource management converge on negative side.

5.2 Water Budgeting in Mahesana District

5.2.1 Climate-Related Impacts and Adaptations as Perceived by the Stakeholders

Stakeholders perceived increased temperatures during summer and winter seasons, and also increase in amount of rainfall in the last decade, which has impacted their livelihood prospect. Increase temperatures have caused a negative impact chiefly on agriculture production and water resources, followed by fodder availability, human and livestock health. Increased summer temperature has decreased the agriculture production, whereas, rainfall variability has helped in increasing the production as stated by the community. Agriculture production has also declined due to pest proliferation due to increased temperatures, and causing crop failure. Soil fertility and soil moisture have notably declined due to increased temperatures, increasing the soil hardness which again reduces the agriculture production. Stakeholders also perceived that increased temperatures have also lessened the water availability hence they are facing difficulty in procuring water for drinking purposes. Declining water availability has reduced people's financial reserves as less water sources also lessens the agriculture productivity as well as negatively affects human health. Declining ground water level has reduced drinking water availability significantly. Increase in temperatures has also reduced the availability of fodder which has resulted into decline in livestock health. Moreover, with poorer health of livestock milk production decreases, further reducing the financial reserves of stakeholders. Increasing summer and winter temperatures also deteriorate human health. Financial reserves have largely been impacted by decrease in agriculture production, water availability and deteriorating human health as stated by people.

In order to avert the unfavorable impacts occurring in all three seasons, stakeholders have adopted various adaptation practices. They have benefitted from agricultural inputs, water resource management, water infrastructure and diversification of production systems. Majorly these practices have helped to increase agricultural production. The utilization of fertilizers and manure has notably surged their agriculture produce and it has also helped them to increase soil fertility and reduce soil hardness. Many farmers use drip irrigation system and sprinklers in their farms to optimally utilize water. Regular water supply through these micro-irrigation practices has helped to increase agriculture production.

Shift in cropping pattern as well as usage of hybrid seed have increased the farm produce. Regular spraying of insecticides and pesticides has reduced pest invasion in crops, though it reduces financial reserves of the farmers. The health care facilities have advance effect on human health. Livestock feed has increased livestock health and milk production. Villagers have made considerable amount of efforts in organizing vaccination programs, this along with the sanitation measures taken up have resulted into boosting the livestock health. However, the health care facilities for human and livestock put a burden on the stakeholders' financial reserves. In the pursuance of acquiring adequate water supply both for agricultural as well as domestic purposes, water resource management and several other water structures have been introduced. Tube well boring and construction of irrigation canal resolves the water scarcity problems. Awareness generation among the people to conserve water has also led to increase water availability.

Table 5.5: Climate Change Sensitivity and Adaptive Capacity Against Respective Concepts in all Three Season

Concepts	Climate variability and change	
	Sensitivity	**Adaptive capacity**
Agricultural production	Climate variability and change	Agricultural inputs
	Water resources	Diversification of production systems
	Land resources	Water infrastructure
	Insects and Pest	Water resource management
	Agriculture production	
Financial reserve	Agriculture production	Health care facilities
	Human health	Water infrastructure
	Livestock and milk production	Agricultural inputs
	Financial reserve	Pest control techniques
Fodder availability	Climate variability and change	Health care facilities
Land resources	Climate variability and change	Agricultural inputs
	Land resources	
Livestock and milk production	Climate variability and change	Health care facilities
	Fodder availability	Livestock feed
	Livestock and milk production	
Social capital	Financial reserve	
Water resources	Climate variability and change	Water infrastructure
	Water resources	Water resource management
Human health and education	Climate variability and change	Health care facilities
	Financial reserve	
Insects and pests	Climate variability and change	Pest control techniques

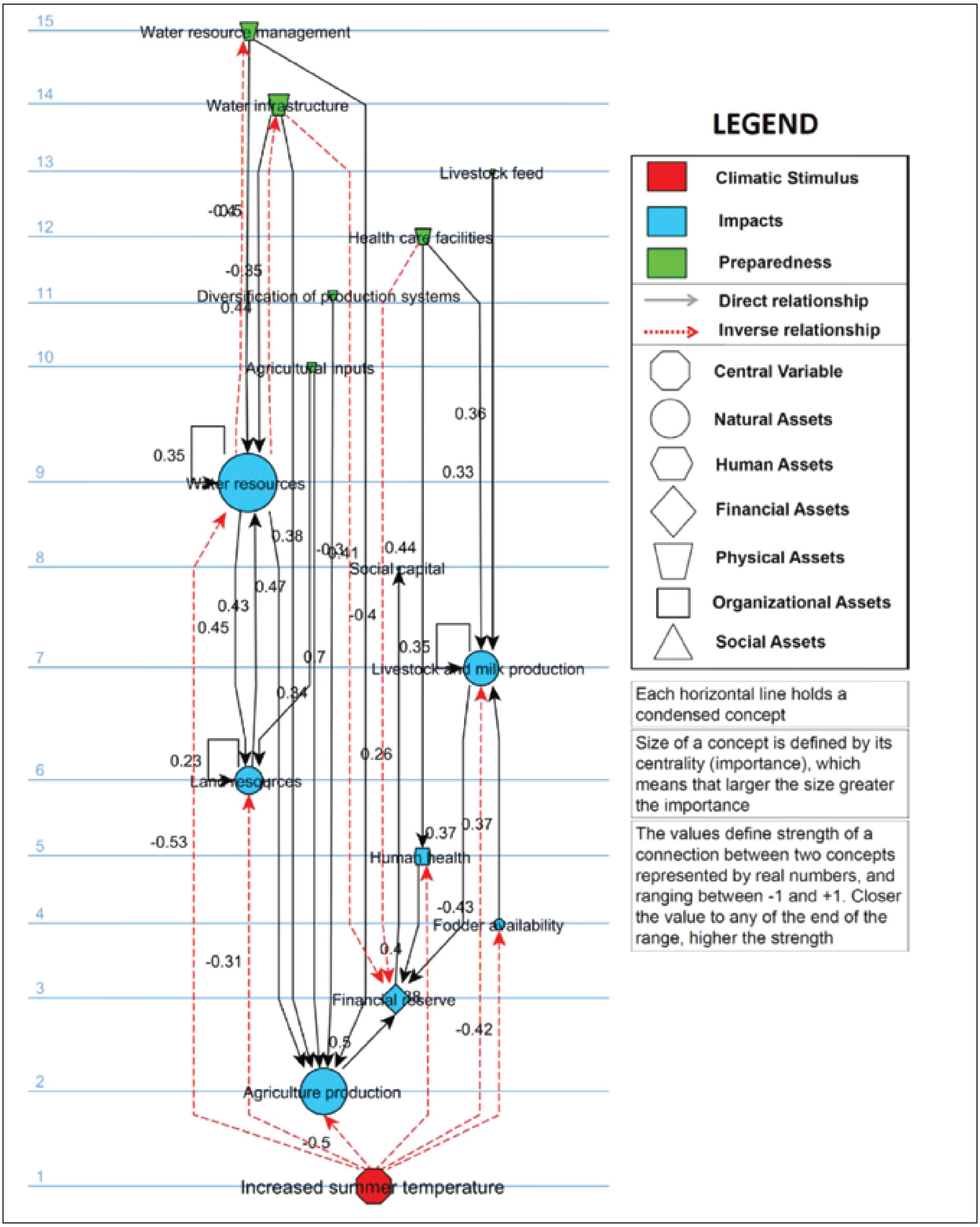

Figure 5.11: Impacts of Climate Change and Adaptations as Perceived by the Communities of Mahesana in Summer Season

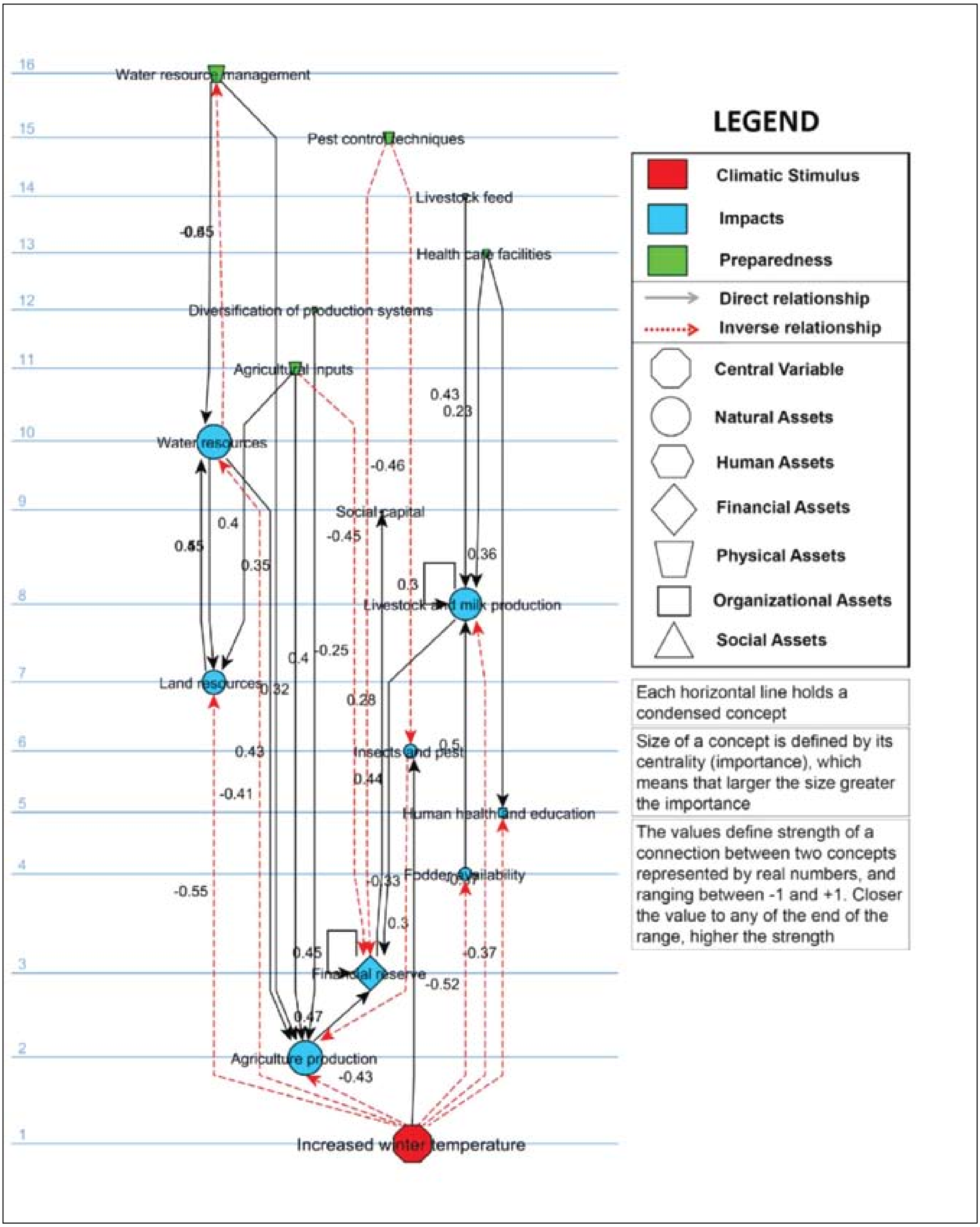

Figure 5.12: Impacts of Climate Change and Adaptations as Perceived by the Communities of Mahesana in Winter Season

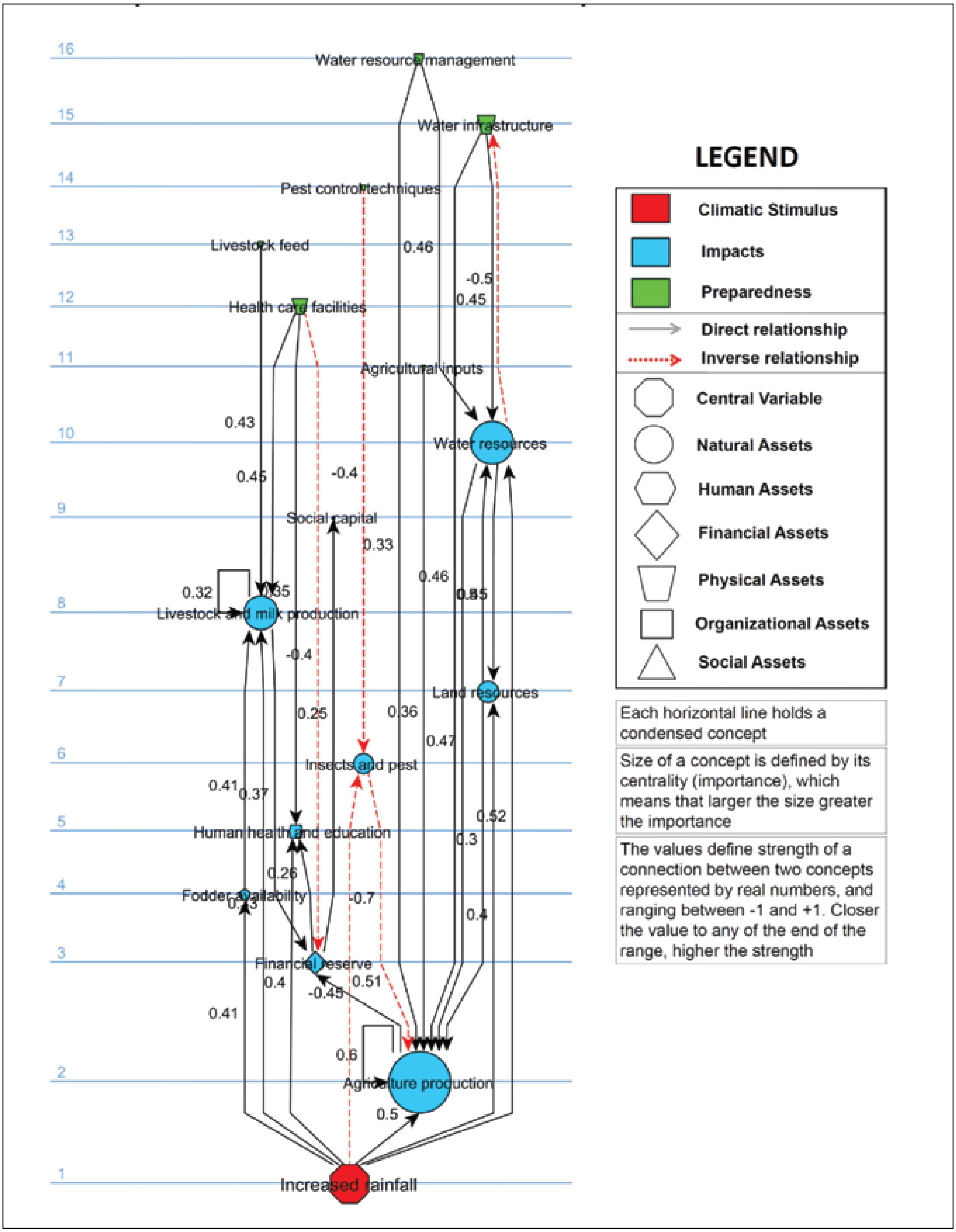

Figure 5.13: Impacts of Climate Change and Adaptations as Perceived by the Communities of Mahesana in Rainfall Season

5.2.2 Livelihood Vulnerability to Climate Variability and Change in Mahesana

Vulnerability to climate variability and change varies across time and sector. The climate data reveals that exposure is highest due to increasing temperatures in summer with 0.743, followed by increasing temperatures in winter with 0.719. Exposure due to increasing rainfall variability is lowest, i.e. 0.681.

The below tables show sensitivity and adaptive capacity as perceived by the communities in Mahesana.

Table 5.6: Ensitivity for Each Season

Livelihood Assets	Sensitivity		
	Summer	Winter	Rainfall
Agriculture	0.505	0.396	0.232
Fodder availability	0.415	0.52	0.41
Land quality	0.27	0.475	0.4
Livestock and milk production	0.383	0.388	0.353
Water availability	0.440	0.405	0.515
Financial reserve	0.394	0.412	0.423
Human health	0.377	0.37	0.33
Social capital	0.26	0.28	0.25
Insects and pest		0.38	0.425

Table 5.7: Adaptive Capacity for Each Season

Livelihood Assets	Sensitivity		
	Summer	Winter	Rainfall
Agricultural inputs	0.355	0.36	0.355
Diversification of production systems	0.7	0.4	
Health care facilities	0.385	0.295	0.397
Livestock feed	0.36	0.425	0.43
Water infrastructure	0.452		0.46
Water resource management	0.41	0.35	0.39

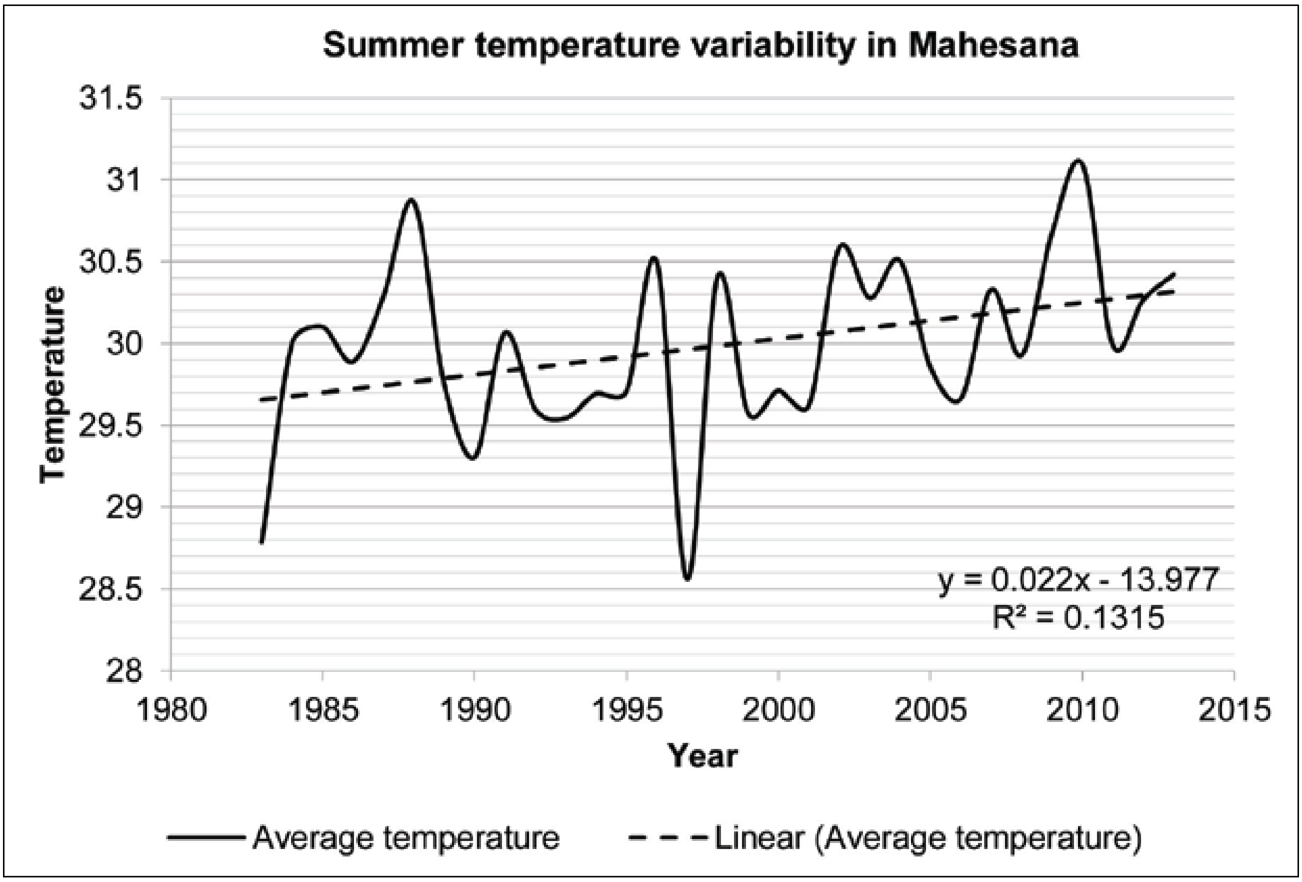

Figure 5.14: Summer Temperature Variability

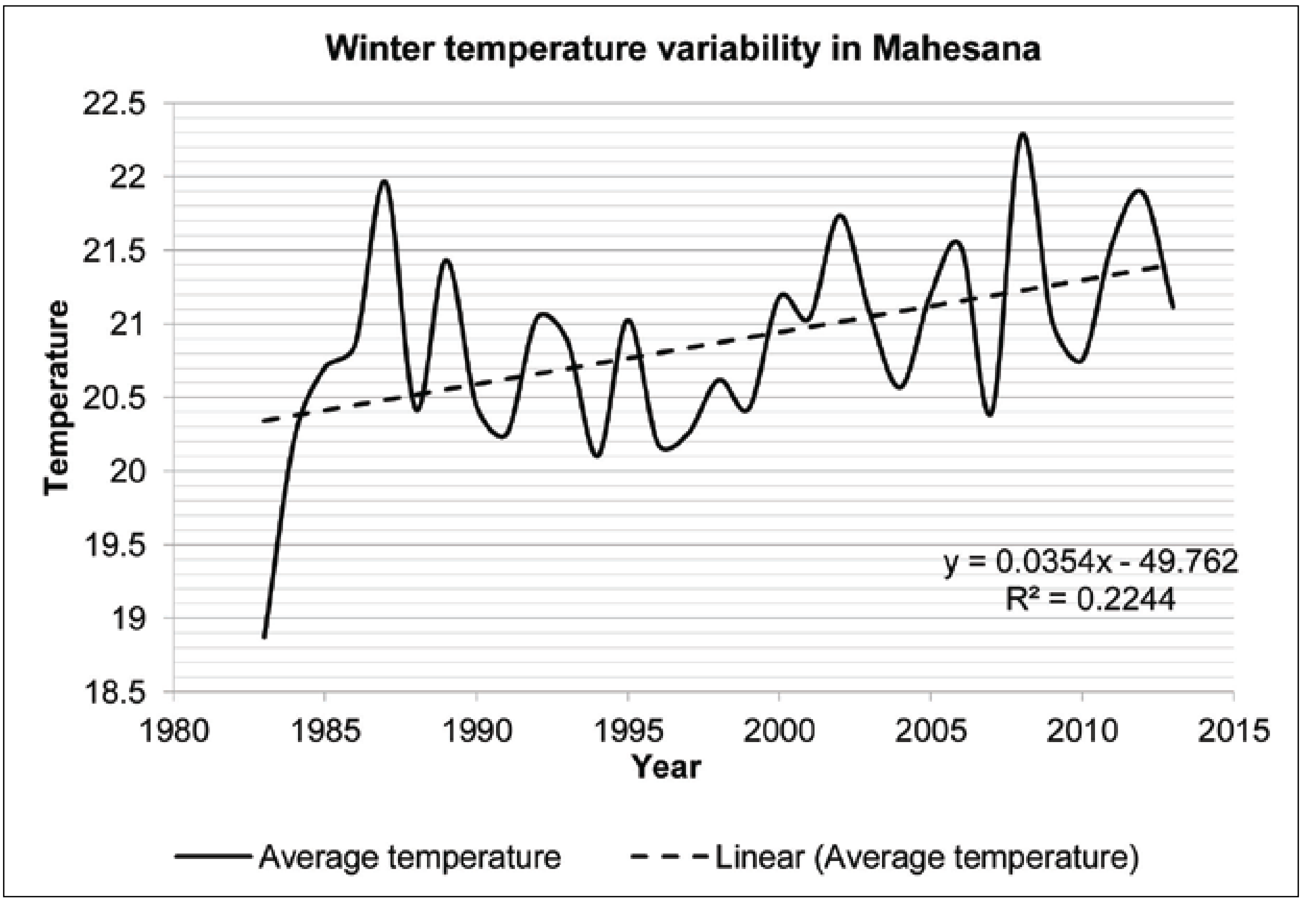

Figure 5.15: Winter Temperature Variability

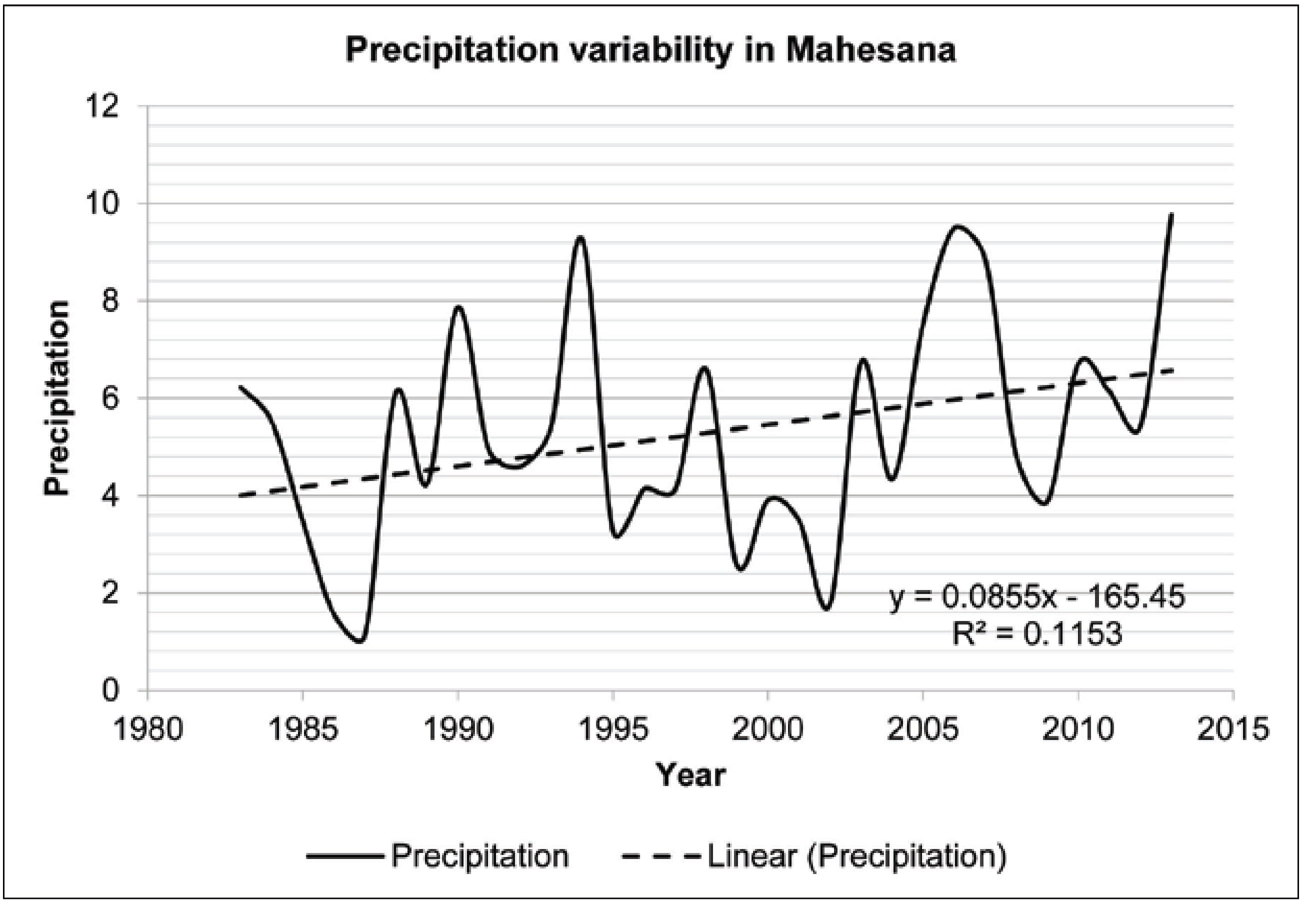

Figure 5.16: Precipitation Variability

Table 5.8: Mean Precipitation and Temperature in Mahesana for Reference Climate, and Change in for Projected Climates Using Different Models

Years	Models	Precipitation (mm)	Temperature (ºC)
Reference climate (1981-2010)	CRU	644.79	27.05
Projected climate 2050s	GFDL	630.86	28.79
	HadGEM	878.99	29.12
	IPSL	720.42	29.46
	MIROC	666.23	28.47
	NorESM	679.19	28.54
	E-MEAN	715.14	28.87
Projected climate 2080s	GFDL	661.52	29.35
	HadGEM	916.01	29.86
	IPSL	831.63	30.04
	MIROC	674.26	29.23
	NorESM	794.79	28.64
	E-MEAN	775.65	29.44

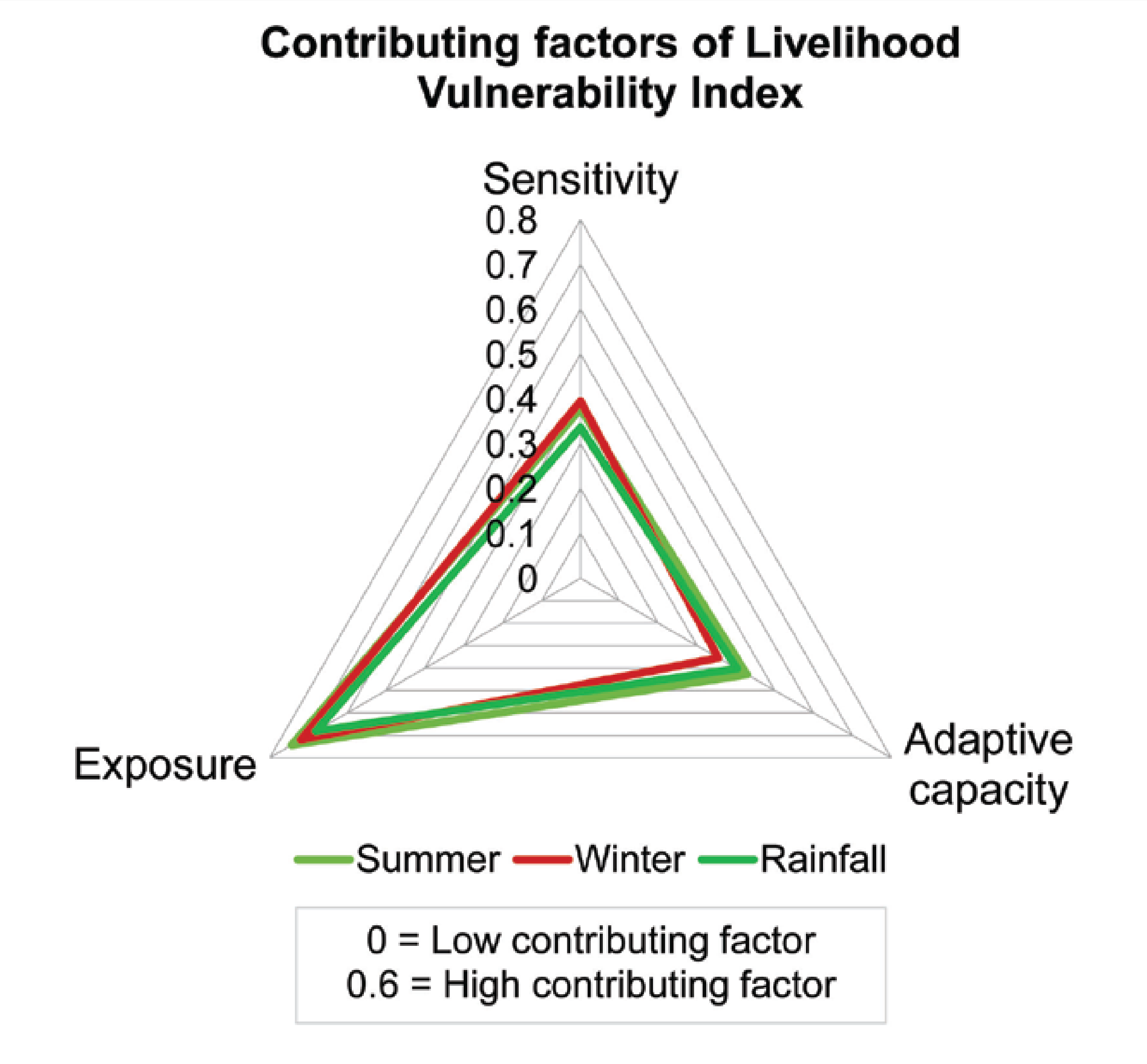

Figure 5.17: Contributing Factors of the Livelihood Vulnerability Index to Climate Variability and Change

Overall sensitivity of livelihoods to increasing summer and winter temperature is 0.378 and 0.395 respectively, while sensitivity for increasing rainfall variability is 0.336. Overall adaptive capacities during rainfall and summer seasons are 0.402 and 0.428 respectively, whereas, adaptive capacity during winter season is 0.355. Sensitivity, adaptive capacity and exposure to climate variability and change vary across different seasons hence, communities in study area exhibit different vulnerability. The livelihood vulnerability index to climate variability and change in Mahesana is highest during winter season, i.e. 0.028, followed by summer season with -0.036. Livelihood vulnerability index is least during rainfall, i.e. -0.044. Communities perceive themselves to be more vulnerable to increasing temperatures as compared to rainfall variability.

5.2.3 Scenarios

To understand the effectiveness of the adaptations, scenarios have been modeled under future climate change. To generate future climate change scenario with present adaptations, all three central concepts were scaled up to their maximum activation level, which is 1, adaptation interventions were also scaled up to their maximum activation level.

i. Scenarios Generated for Increased Summer Temperature:

In order to understand effectiveness of the adaptation interventions; agriculture inputs, diversification of production systems, healthcare facilities, livestock feed, water infrastructure, and water resource management, intended for reducing the negative impacts incurred on; agricultural production, land and water resources, fodder availability, livestock and milk production, human health, and financial reserves.A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that given these adaptations the major benefit that has been seen is on human health which converges on positive side. Fodder availability, and livestock and milk production converges on negative side. Other concepts show recurring positive and negative changes.

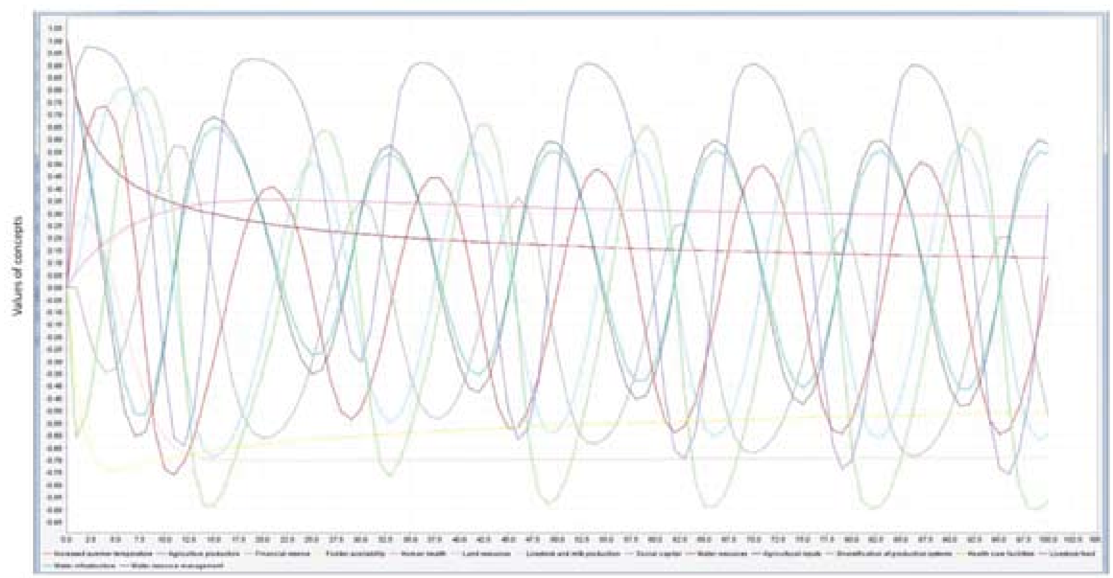

Figure 5.18: Simulation for Increased Summer Temperature

ii. Scenarios Generated for Increased Winter Temperature:

In order to understand effectiveness of the adaptation interventions; agriculture inputs, diversification of production systems, healthcare facilities, livestock feed, pest control techniques, and water resource

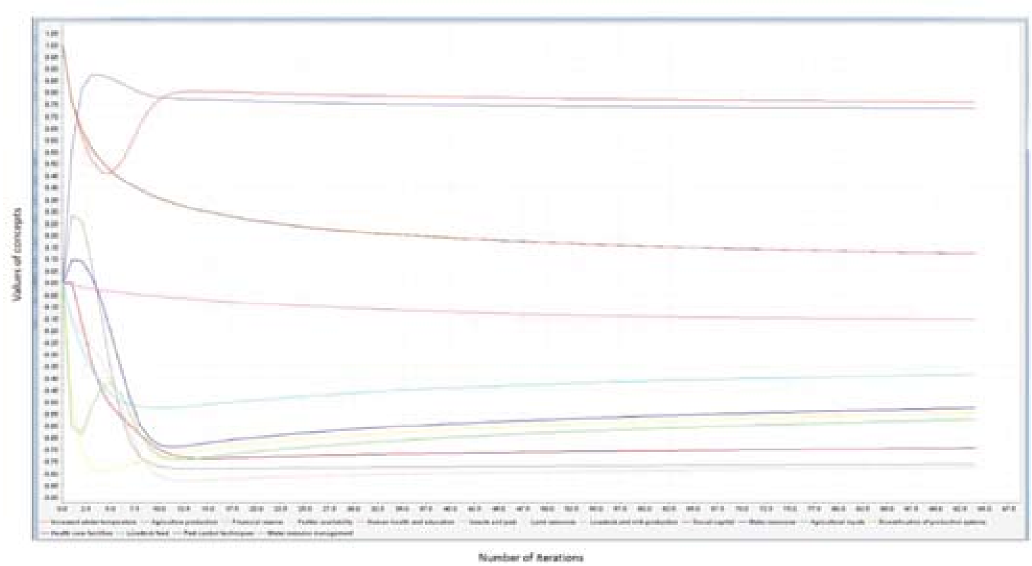

Figure 5.19: Simulation for Increased Winter Temperature

management, intended for reducing the negative impacts incurred on; agricultural production, land and water resources, fodder availability, livestock and milk production, human health and education, social capital, and financial reserve. A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that given these adaptations agricultural production converges on positive side. Human health and education shows very less negative change, whereas, insects and pests show medium negative change. All other concepts such as land and water resources, fodder availability, livestock and milk production, social capital, and financial reserve converge on negative side, indicating high negative change.

iii. Scenarios Generated for Increased Rainfall:

In order to understand effectiveness of the adaptation interventions; agriculture inputs, water infrastructure and water resource management, intended for increasing the positive impacts incurred

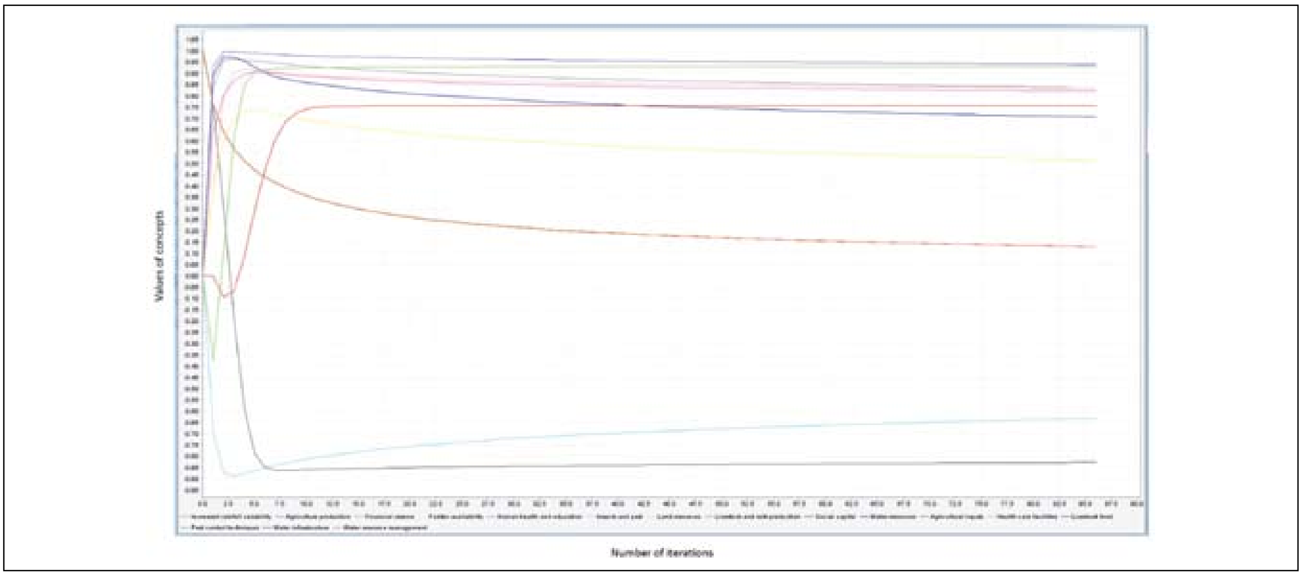

Figure 5.20: Simulation for Increased Rainfall

Water budgeting map of Mahiyal village

on; agricultural production, land and water resources, fodder availability, livestock and milk production, human health and education, and financial reserve due to increased rainfall. Insects and pest show high negative change. A future scenario is developed by activating values of the adaptation interventions to 1, whereas, values of the rest of the concepts were set to 0. The simulation results show that given these adaptations, agricultural production, land and water resources, fodder availability, livestock and milk production, human health and education, and financial reserve converge on positive side indicating high positive change, with fodder availability indicating medium positive change, whereas, insects and pests, and water infrastructure converge on negative side indicating negative change.

5.3 Participatory Irrigation Management (PIM) and Resilience to Climate Variability and Change in Mahesana District of Gujarat

5.3.1 Climate-Related Impacts and Adaptations as Perceived by the Stakeholders

The stakeholders perceived increased temperatures and irregular rainfall as components of climate variability and change. This change chiefly affects water resources, agricultural production, human health, and productivity of livestock negatively. Climate variability and change decreases water availability, soil moisture, as well as soil fertility, which eventually decrease the agriculture production. Irregular rainfall causes groundwater table to plummet and gives rise to water scarcity for irrigation and drinking purposes. Drudgery among women increases as they have to fetch water from far places for everyday activities, which results in deteriorating their health. Many stakeholders declared that clouds during summer and winter seasons increase pest proliferation and cause crop failure, eventually reducing the agriculture production and income. They also perceived that water logging in fields because of eradicate rainfall during monsoon season causes pest invasion. Increase in temperature during summer reduces fodder availability which negatively impacts livestock health, consequently decreasing the milk production. They emphasized that excessive fog during winter also reduces the agriculture production. They emphasized that due to reducing agriculture and milk production, their financial reserves also decrease, pushing them into poverty. They also perceived that due to increase in deforestation activities, temperature also increases.

The stakeholders perceived that various interventions taken up under the participatory irrigation management (PIM) such as farmers' co-operative, kisan club, capacity building and awareness generation programme, and other technical services, which help them to tackle water scarcity problems, increase agriculture production, and resolve health related issues. Production enhancement measures such as use of fertilizers, organic manure, vermi-compost, and pesticides help farmers to increase agriculture production and reduce crop failure. Farmers are also indulged in land leveling with the assistance from kisan club so as to increase cropping area and to enhance crop production. Plantation activities have also been initiated to tackle the issue of deforestation. Check dams and farm ponds have been constructed to increase water availability for irrigation purpose. Tube wells and wells have been built to increase water availability for irrigation and drinking purpose, which have not only reduced drudgery among women but have also decreased crop failure occurring due to water scarcity, and increased agriculture production. Use of drip irrigation helps farmers to decrease soil hardness, and reduce crop failure, eventually increasing the agriculture production. Farmers also use sprinklers to optimize the use of water so as to enhance crop production. Sustainable agriculture practices such as crop rotation, multi cropping, and organic farming help to reduce crop failure and increase agriculture production. Farmers also perceived that electrification services such as solar power and regular supply of electricity help them in operating motor to extract water from wells and tube wells for their agriculture fields, hence, increasing the crop production. Adaptation measures recommended by the stakeholders such as better employment opportunities for woman, higher education for children, and provision of market facility will increase the quality of life. Better management of natural resource will reduce crop failure and enhance agriculture production, and increase communities' resilience.

Table 5.9: Climate Change Sensitivity and Adaptive Capacity Against Respective Concepts

Concepts	Climate variability and change	
	Sensitivity	**Adaptive capacity**
Agricultural production	Climate variability and change	Agricultural techniques
	Agriculture production	Participatory irrigation management (PIM)
	Climatic extremes	Water infrastructure
	Water availability	Water resource management
	Soil quality	Electrification
		Production enhancement
Climatic extremes	Climate variability and change	Water infrastructure
	Livestock and milk production	Production enhancement
Deforestation	Climate variability and change	
Human health	Climate variability and change	Agricultural techniques
	Human health	Participatory irrigation management (PIM)
	Livestock and milk production	Water infrastructure
Livestock and milk production	Climate variability and change	Water infrastructure
		Water resource management
		Electrification
Water resources	Climate variability and change	Water infrastructure
		Water resource management
		Electrification
Land resources	Climate variability and change	Participatory irrigation management (PIM)
Financial reserves	Agriculture production	
	Human health	
	Livestock and milk production	
	Water availability	

Table 5.10: Sensitivity and Adaptive Capacity to Climate Variability and Change

Assets sensitive to climate variability and change		Assets providing adaptive capacity	
Livelihood Assets	**Sensitivity**	**Livelihood Assets**	**Adaptive capacity**
Agriculture production	0.635	Agricultural techniques	0.55
Livestock and milk production	0.615	Water infrastructure	0.439
Water availability	0.6	Water resource management	0.641
Soil quality	0.397	Electrification	0.625
Human health	0.51	Production enhancement	0.439
Financial reserves	0.678	Participatory irrigation management (PIM)	0.429

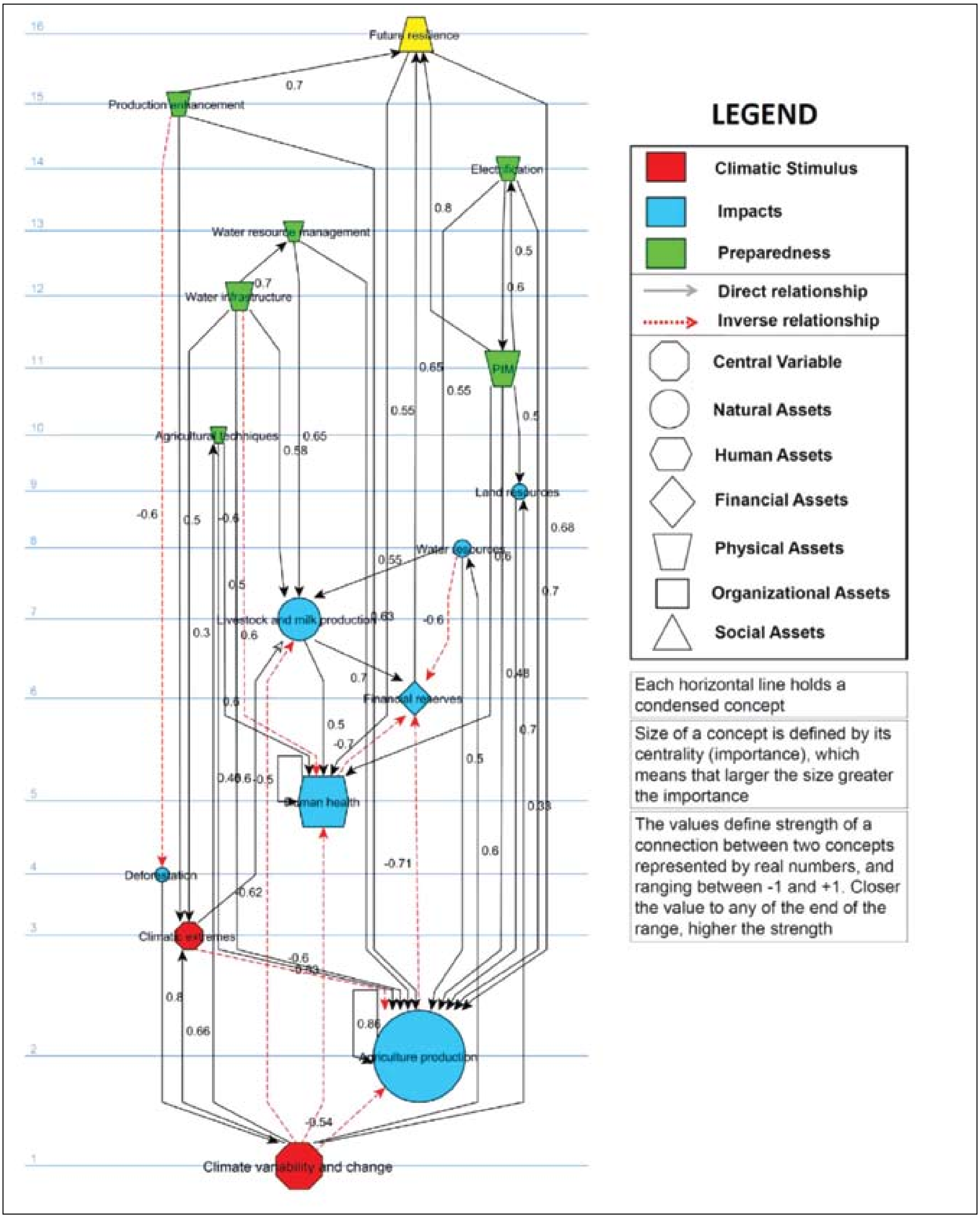

Figure 5.21: Impacts of Climate Variability and Change, and Adaptations as Perceived by the Communities of Mahesana

5.3.2 Scenarios

To understand the effectiveness of the adaptations, scenarios have been modeled under future climate change. To generate future climate change scenario with present adaptations, the central concept was scaled up to its maximum activation level, which is 1, adaptation interventions were also scaled up to their maximum activation level.

i. Scenario Generated for Climate Variability and Change:

In order to understand effectiveness of the adaptation interventions; better agricultural techniques, participatory irrigation management (PIM), water infrastructure, water resource management,

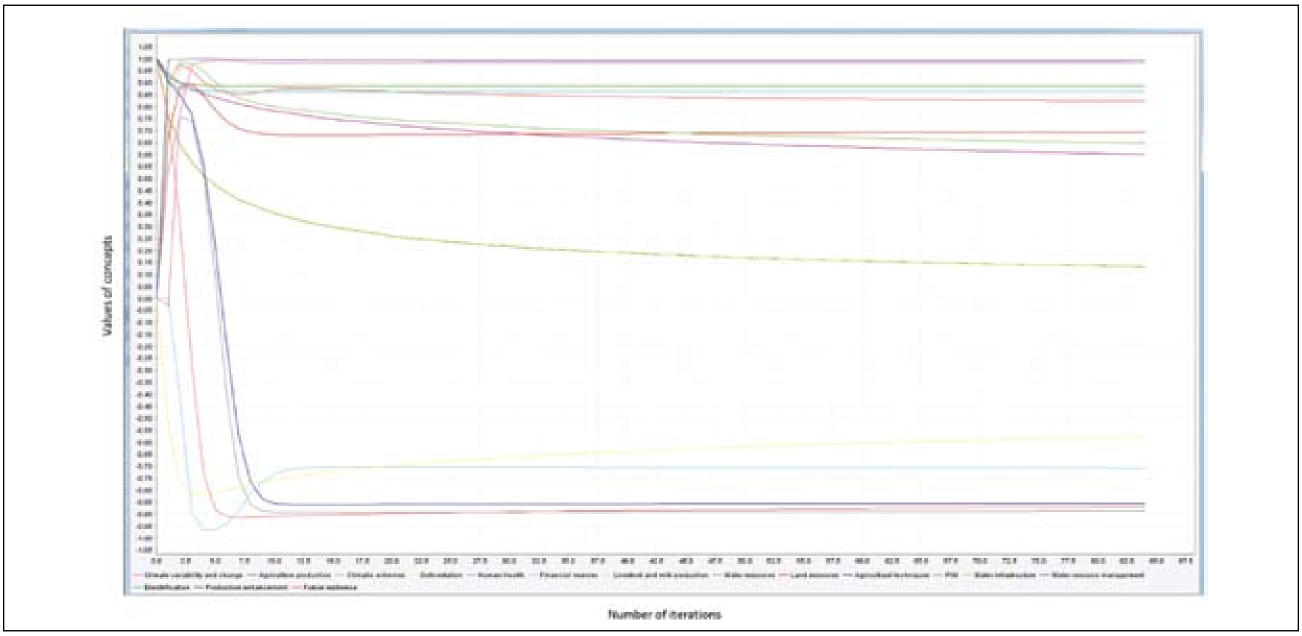

Figure 5.22: Simulations for Climate Variability and Change

A tube well built under PIM

electrification, production enhancement, and other future resilience, intended for reducing the negative impacts incurred on; agricultural production, land and water resources, fodder availability, livestock and milk production, deforestation, human health, and financial reserve due to increased climate variability and change. The simulation results show that given these adaptations, the major benefits are seen on agricultural production, land resources, human health, water resources, fodder availability, and livestock and milk production. These concepts converge on positive side indicating positive change. However, climatic extremes also converge on positive side and show high positive change. Deforestation and financial reserves converge on negative side indicating negative change. Adaptation measures; better agricultural techniques, production enhancement, and other future resilience also converge on negative side.

5.4 Wadi Schemes and Resilience to Climate Variability and Change in Valsad District of Gujarat

5.4.1 Climate-Related Impacts and Adaptations as Perceived by the Stakeholders

The stakeholders perceived that climate variability and change have chiefly impacted agriculture and water, which subsequently have influence on various factors like, soil, fodder availability, human health, and financial reserves. They perceived that due to increased summer temperature agriculture production has notably decreased. Cashew bud dries up due to heat and causes crop failure, which reduces the production. Increasing crop failure and rotting of cashew bud have negatively impacted their financial reserves, and also reduced employment for landless labours working in wadi. Due to less horticulture production, landless labours working in wadi are being affected the most as there is serious reduction in employment opportunities at co-operatives. Increased temperatures also cause health problems for humans, hindering work efficiency and reducing their financial reserves. It also affects livestock health. They also perceived that soil has been impacted the most in all three seasons, but soil hardness increases the most during summer season. Rainfall has become irregular, leading to crop failure and surge in pest invasion. The stakeholders also perceive that water availability has declined due to climate variability change. Lack of water availability has increased soil hardness which affects agriculture production. Due to reduced sources of water, farmers find it difficult to protect their crop from heat which affects their financial reserve. This has negatively impacted the horticulture production as well as vegetable production resulting into less income for farmers and lesser employment for landless labours. Reduced water availability causes cutback in fodder availability, affecting livestock health. Water scarcity also increases drudgery among women. Extreme rainfall over a short period of time causes surface water runoff, and increases soil erosion.

The stakeholders identified pesticides and fertilizers, alcohol addiction, financial loss, poverty, and pest invasion as chief resilience reducers. Excessive use of pesticides and chemical fertilizers has decreased agriculture production and income, increased health problems and soil hardness. Also, pest invasion decreases resilience by crop failure, causing financial loss to farmers. Alcohol addiction is also a matter of concern as it reduces income and also alcoholics indulge in unproductive expenses, which lead to financial burden and pushing them into poverty. Other key resilience reducers as perceived by people involved in value chain and enterprising are the sluggish efforts by farmers in farms after withdrawal of BAIF, causing vegetable and horticulture production to go down. Also less number of staff in co-operatives has affected organizational structure causing disruption in the value chain and enterprising of horticulture production.

The wadi programme has played a very significant role in developing possibilities of agriculture in steep hilly regions of Valsad, which has benefitted farmers as they have started horticulture production which has given them financial security and has reduced their dependency on market. Farmers have also started using chemical fertilizers extensively to increase agriculture and horticulture production. However, it negatively affects soil quality in longer time. Landless labours working in wadi also have an advantage due to increase in horticulture production as they get more employment at co-operatives and cashew-mango processing units. The stakeholders perceived that it has significantly reduced their migration for employment opportunities away from their region and improved quality of life, securing their financial reserves, which is otherwise being negatively impacted by degrading soil, reducing agriculture and horticulture production, fodder availability, and diminishing human and livestock health. There are different services being implemented under the wadi programme which have enhanced people's resilience. The stakeholders have been benefitted immensely from the wadi programme as it has increased the production of mango and cashew crops, and surged stakeholders' financial reserves. Farmers are able to cultivate even during lean seasons and have steady source of income, which has increased their self-dependency.

Various eco-restoration measures like cultivation on fallow land and soil-moisture conservation have reduced chances of drought. Farmers have also implemented various agriculture techniques such as crop rotation and land leveling, which have increased agriculture production and income, and have reduced crop failure, soil hardness, and soil erosion. Use of better agriculture inputs such as hybrid seeds and vermi-composting has increased their resilience, by increasing soil quality and agriculture production, resulting in more income for farmers. Various extension services like women self-help groups (SHG), government schemes, training and capacity building, kisan bank, and education programs, which have helped to increase stakeholders' resilience against climate variability and change. Skill development and training programs for landless labours working in wadi have not only helped to increase horticulture production but also helped in the processing plant, increasing their income and reducing migration. Awareness programs carried out by BAIF Development Research Foundation, a Pune-based organization, along with several soil conservation measures take up by farmers have helped to increase soil quality and fertility, have increased agriculture production and financial reserves. Another measure which has increased their resilience is interference of religious groups which reduced alcohol addiction among men of this region.

The stakeholders also suggested various resilient measures which could be taken up in future, which could be also helpful in tackling impacts of climate variability and change, so as to create a better livelihood. Reduction in the use of chemical fertilizers will improve soil quality and human health. People involved in value chain and enterprising believe that introduction of sustainable agriculture techniques as well as training farmers will help in increasing agriculture production, livestock health, and income, which will reduce migration. Watershed development will benefit farmers as it will increase water availability, improve horticulture production, and reduce crop failure. This will also reduce soil hardness which will subsequently increase soil fertility and agriculture production. Bio-gas plant will also increase soil fertility and agriculture production.

Table 5.11: Concepts Showing Impacts of Climate Variability and Change, Resilience Enhancers, and Concepts Recommended by Wadi Owners

Concepts	Climate variability and change	Resilience enhancers	Resilience reducers	Future resilience
Agricultural production	Agriculture production	Agricultural techniques	Pesticides and fertilisers	Collectivisation
	Water resources	Water management	Thin soil layer	Water management
	Land resources	Soil conservation		Physical infrastructure
	Climatic extremes	Extension services		Organic agriculture
	Pest invasion			Extension services

Water resources	Climatic extremes	Water management		Water management
		Extension services		Physical infrastructure
Land resources	Water resources	Wadi program	Pesticides and fertilisers	Water management
	Climatic extremes	Agricultural techniques		Physical infrastructure
		Soil conservation		Organic agriculture
Human health	Water resources	Water management	Pesticides and fertilisers	Water management
	Human health			Physical infrastructure
	Climatic extremes			Health and education
Deforestation	Climatic extremes			
Fodder availability	Water resources	Wadi program		
	Climatic extremes			
Financial reserve	Agriculture production	Physical infrastructure	Alcohol addiction	Collectivisation
	Land resources	Wadi program	Pesticides and fertilisers	Water management
		Agricultural techniques	Poverty	Health and education
	Climatic extremes	Soil conservation		Extension services
	Livestock health	Extension services		
Climatic extremes	Climate variability and change			
	Deforestation			
Pest invasion	Climatic extremes		Pesticides and fertilisers	Organic agriculture
Livestock health and milk production	Water resources			Physical infrastructure
	Fodder availability			
	Climatic extremes			

Table 5.12: Concepts Showing Impacts of Climate Variability and Change, Resilience Enhancers, and Concepts Recommended by Landless Labours

Concepts	Climate variability and change	Resilience enhancers	Resilience reducers	Future resilience
Agriculture production	Agriculture production	Wadi program	Pest invasion	Water management
	Water resources	Extension services	Financial loss	Pesticides
	Climatic extremes			
Water resources	Climatic extremes			Water management
Human health	Water resources	Extension services		Water management
	Human health			Health and education
	Climatic extremes			
Fodder availability	Climatic extremes			Water management
Financial reserve	Agriculture		Financial loss	Livelihood diversification
	Human health			Value chain infrastructure
	Fodder availability			Financial reserve
	Financial reserve			
	Climatic extremes			
Climatic extremes	Climate concept change			
Livestock health and milk production	Fodder availability			
Migration	Financial reserve	Wadi program		Health and education
	Migration	Wadi program		Value chain infrastructure
				Financial reserve

Table 5.13: Concepts Showing Impacts of Climate Variability and Change, Resilience Enhancers, and Concepts Recommended by People Involved in Value Chain Enterprise

Concepts	Climate variability and change	Resilience enhancers	Resilience reducers	Future resilience
Agriculture production	Agriculture production	Soil conservation	Pesticides and fertilizers	Water management
	Water resources	Agricultural techniques	Financial loss	Sustainable agriculture
	Climatic extremes	Awareness	Capacity building	Extension services

	Insects and pest	Collectivization		Climate smart livestock
	Land resources	Extension services		
Waterresources	Climatic extremes	Collectivization	Capacity building	Water management
		Wadi program		Sustainable agriculture
Human health	Water resources	Wadi program	Pesticides and fertilizers	Water management
	Climatic extremes			Sustainable agriculture
Financial reserve	Agriculture production	Agricultural techniques	Financial loss	Value chain infrastructure
	Human health	Livestock and milk production	Capacity building	Sustainable agriculture
	Financial reserve	Awareness		Extension services
		Collectivization		Solar energy
		Extension services		Climate smart livestock
		Wadi program		
Climatic extremes	Climate concept change	Wadi program		Water management
Insects and pest	Climatic extremes	Soil conservation		Sustainable agriculture
		Agricultural techniques		Extension services
Land resources	Water resources		Pesticides and fertilizers	Water management
	Climatic extremes			
Migration	Financial reserve	Awareness	Financial loss	Water management
		Collectivization	Capacity building	Value chain infrastructure
		Extension services		Sustainable agriculture
		Wadi program		Extension services
				Solar energy
				Climate smart livestock

Table 5.14: Concepts Showing Impacts of Climate Variability and Change, Resilience Enhancers, and Concepts Recommended by all Stakeholders

Concepts	Sensitivity/Resilience reducers	Adaptive capacity/ Resilience enhancers	Adaptations recommended by stakeholders
Agriculture production	Climate variability and change	Agricultural techniques	Water management
	Crop failure	Wadi program	Sustainable agriculture
	Land resources	Collectivization	Climate smart livestock
	Water resources	Soil conservation	Livelihood diversification
	Institutional support		Physical infrastructure
			Collectivisation
Crop failure	Climate variability and change	Agricultural techniques	Water management
	Crop failure	Physical infrastructure	Sustainable agriculture
			Livelihood diversification
Human health	Climate variability and change	Physical infrastructure	Water management
	Agriculture production		Sustainable agriculture
	Migration		Health and education
	Water resources		Livelihood diversification
Deforestation	Climate variability and change		
Financial reserves	Agriculture production	Agricultural techniques	Climate smart livestock
	Crop failure	Livestock and milk production	Health and education
	Institutional support	Collectivization	Livelihood diversification
		Soil conservation	Collectivisation
			Value chain infrastructure
Climatic extremes	Climate variability and change	Wadi program	
	Water resources		
Migration	Agriculture production	Wadi program	Sustainable agriculture
	Migration	Collectivization	Climate smart livestock
	Water resources		Health and education
	Institutional support		Livelihood diversification
			Value chain infrastructure
Land resources	Climate variability and change	Soil conservation	Sustainable agriculture
	Water resources		
Water resources	Climate variability and change	Collectivization	Water management
	Water resources	Physical infrastructure	
	Institutional support		

Institutional support	Institutional support		Livelihood diversification
			Value chain infrastructure
Pesticides and fertilizers			Sustainable agriculture
			Health and education

Impacts of Climate variability and change and community resilience in Valsad
As perceived by wadi owners

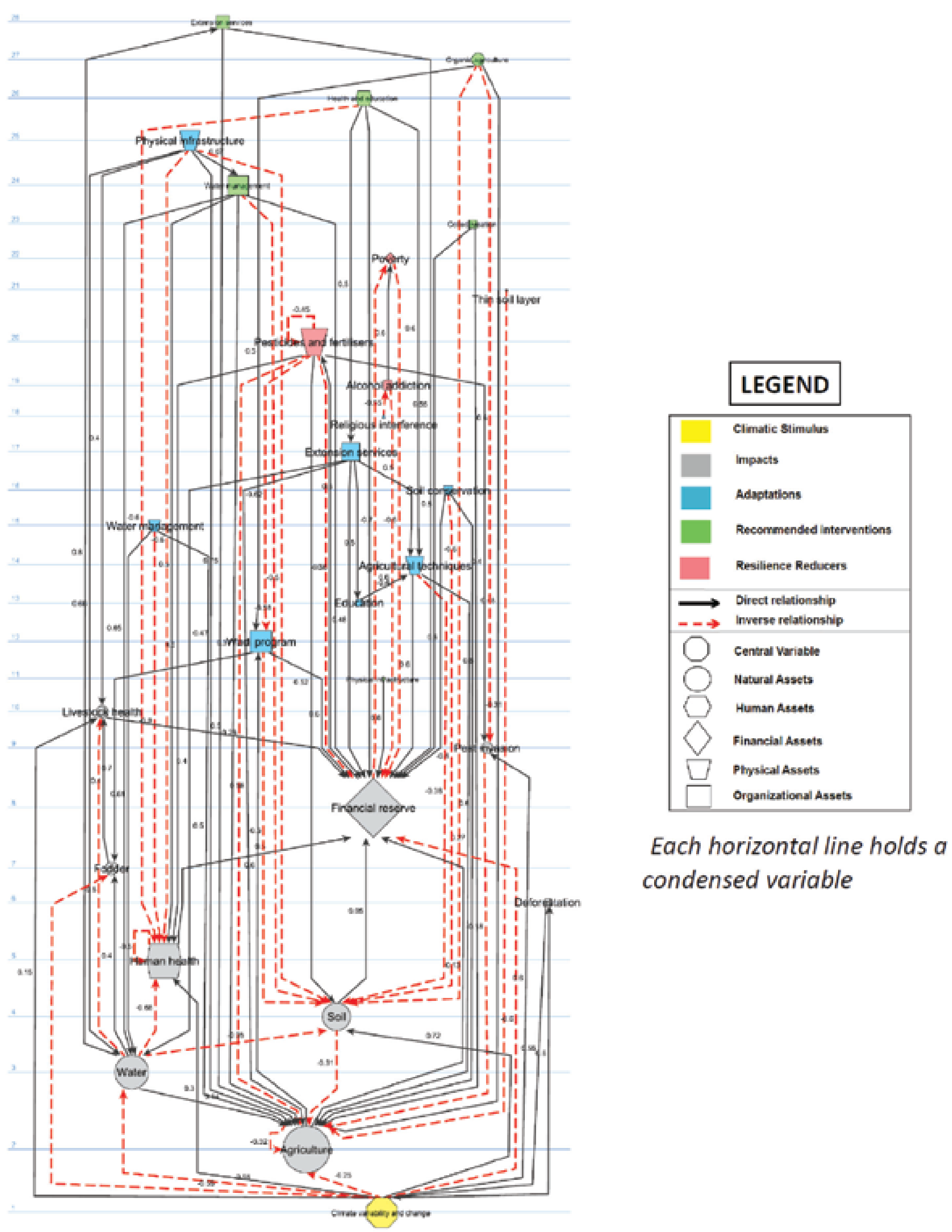

Figure 5.23: Impacts of Climate Variability and Change, and Community Resilience in Valsad as Perceived by the Wadi Owners

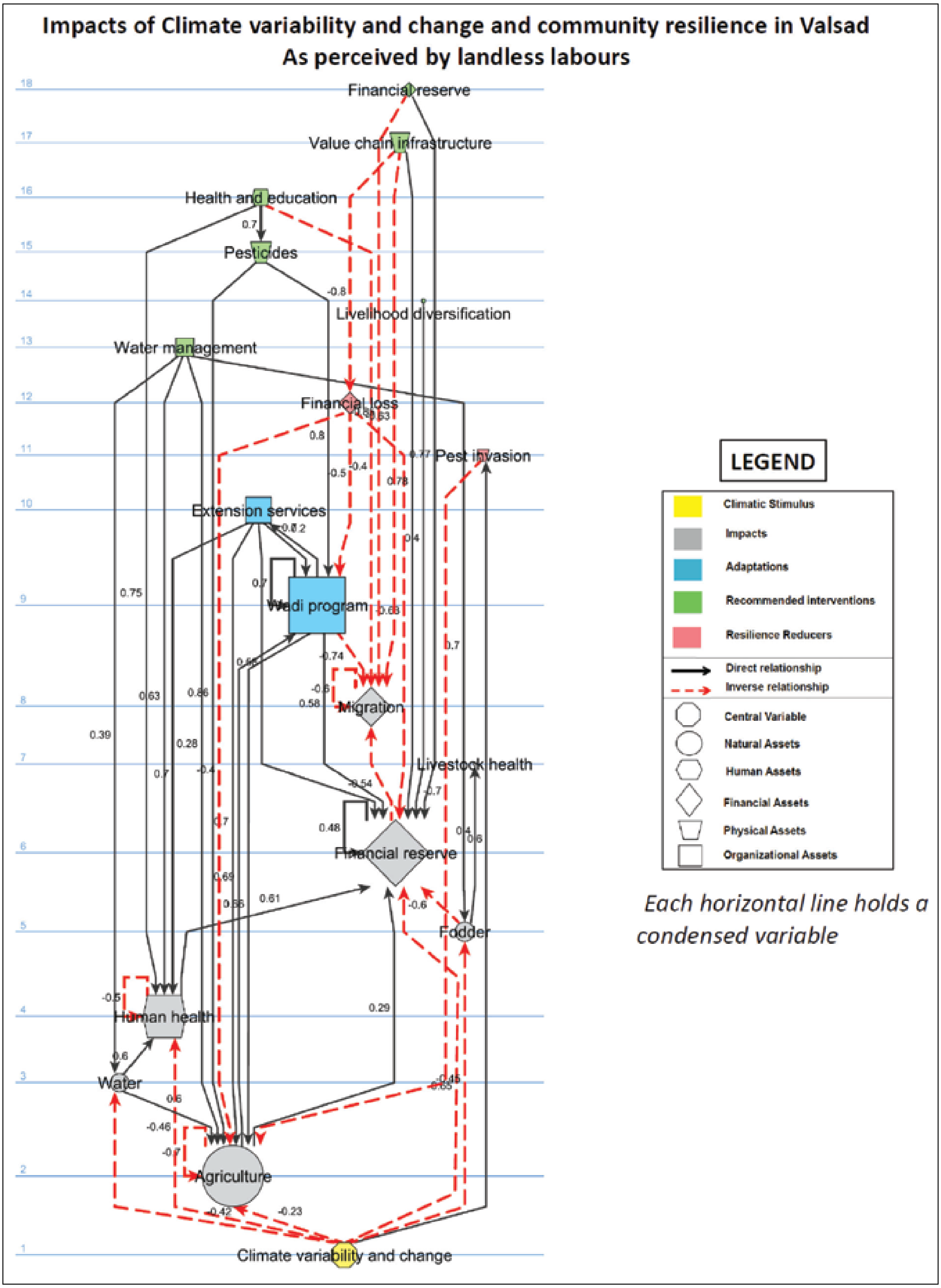

Figure 5.24: Impacts of Climate Variability and Change, and Community Resilience in Valsad as Perceived by the Landless Labours

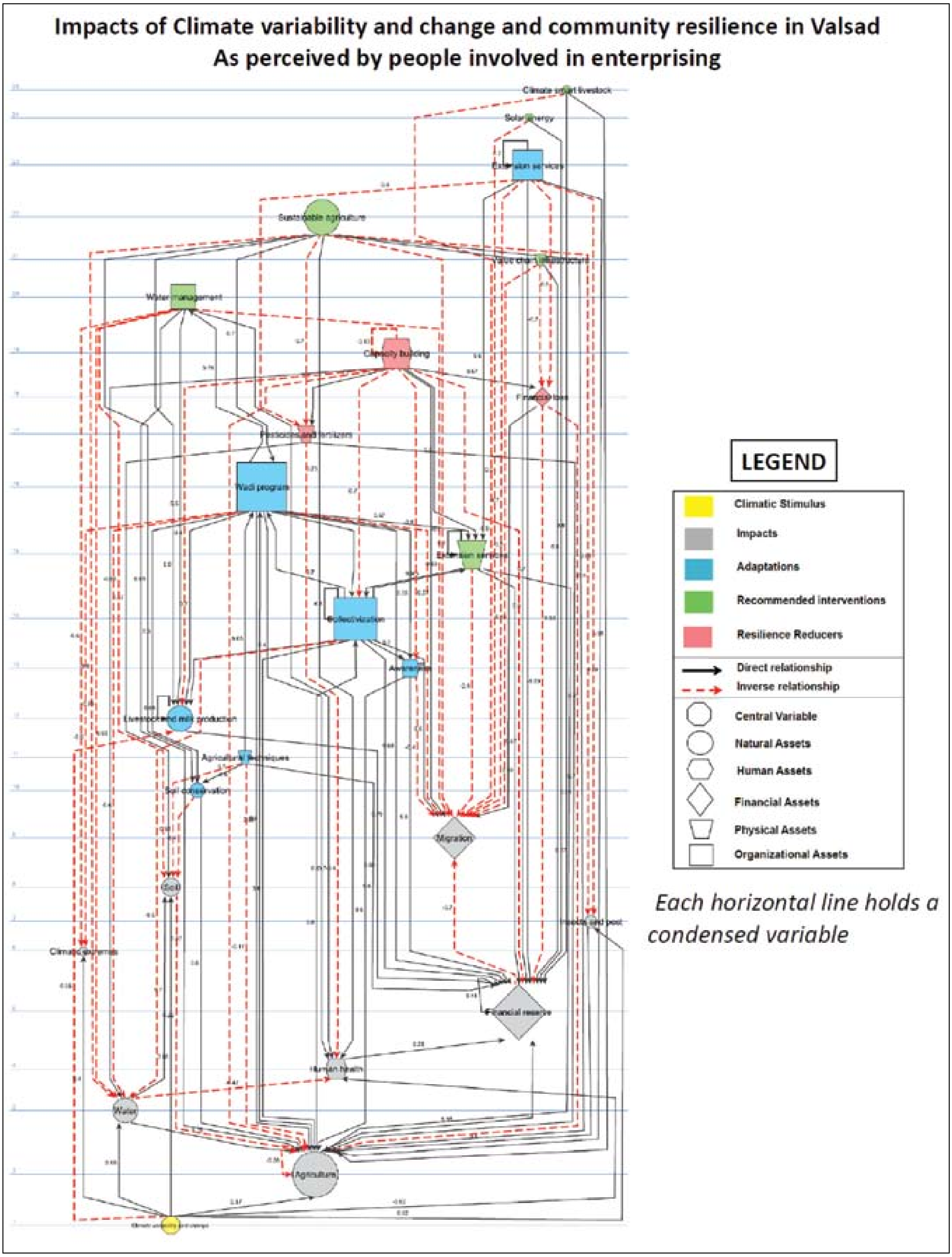

Figure 5.25: Impacts of Climate Variability and Change, and Community Resilience in Valsad as Perceived by the People Involved in Value Chain and Enterprising

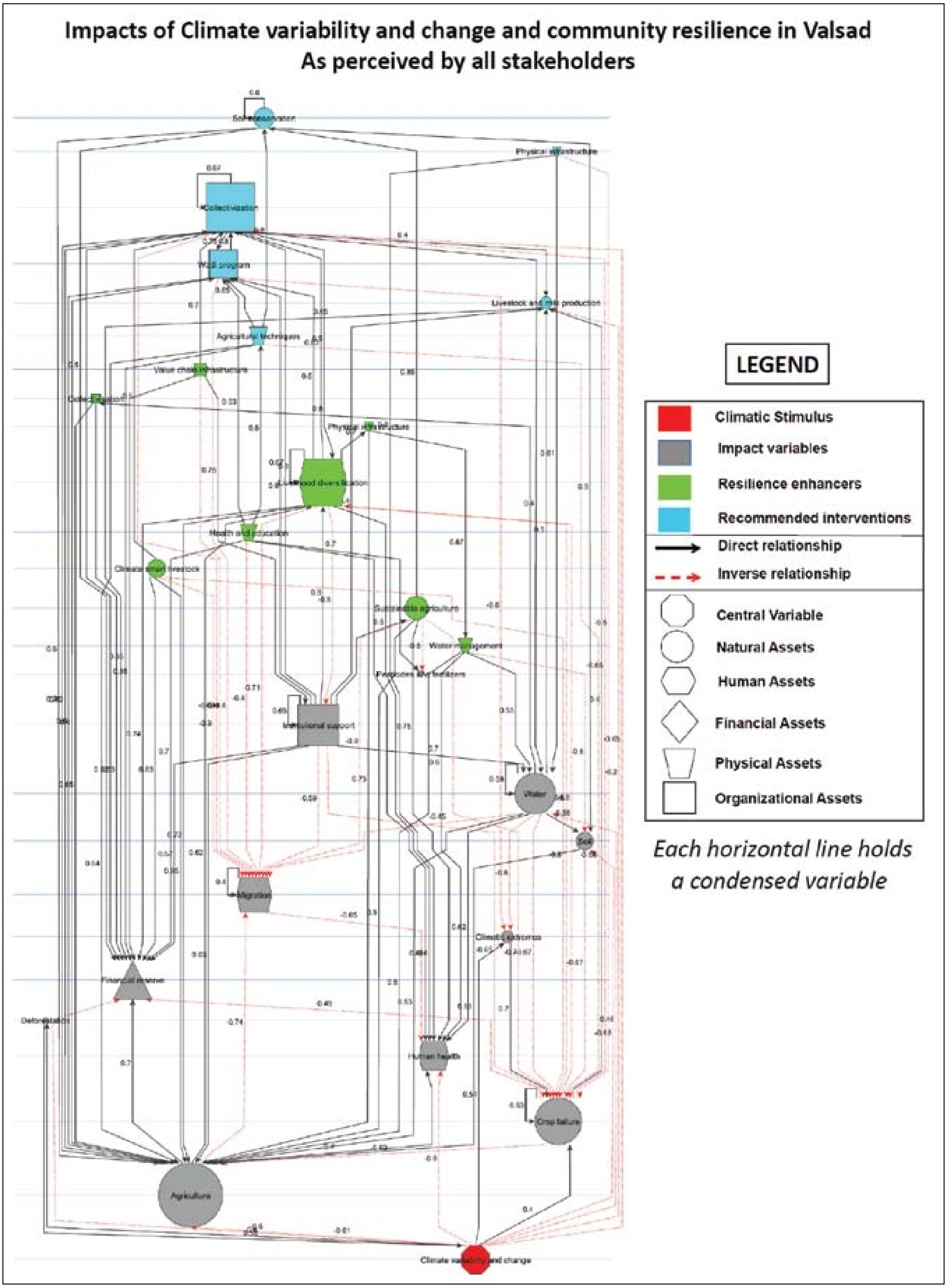

Figure 5.26: Impacts of Climate Variability and Change, and Community Resilience in Valsad as Perceived by all the Stakeholders

5.4.2 Livelihood Vulnerability to Climate Variability and Change in Valsad

Following tables show sensitivity to climate variability and change, concepts enhancing the resilience against climate variability and change as perceived by the stakeholders, concepts recommended by stakeholders to further enhance their resilience to climate variability and change. The stakeholders in Valsad perceived overall sensitivity and adaptive capacity to livelihoods to climate variability and change as 0.601 and 0.6 respectively.

Table 5.15: Sensitivity, Adaptive Capacity, and Future Resilience to Climate Variability and Change as Perceived by the Wadi Owners

Impact concepts	Sensi-tivity	Resilience reducers	Sensi-tivity	Resilience enhancers	Adaptive capacity	Measures recommended by stakeholders	Resilience in future
Agriculture production	0.253	Alcohol addiction	0.4	Physical infrastructure	0.6	Collectivization	0.65
Water resources	0.581	Pesticides and fertilizers	0.456	Agricultural techniques	0.508	Water management	0.506
Land resources	0.433	Thin soil layer	0.308	Water management	0.637	Extension services	0.65
Fodder availability	0.475	Poverty	0.6	Soil conservation	0.5	Physical infrastructure	0.526
Pest invasion	0.6			Wadi programme	0.6	Health and education	0.65
Livestock health	0.3			Extension services	0.483	Organic agriculture	0.527
Deforestation	0.6						
Financial reserves	0.484						
Human health	0.491						

Table 5.16: Sensitivity, Adaptive Capacity, and Future Resilience to Climate Variability and Change as Perceived by the Landless Labours

Impact concepts	Sensi-tivity	Resilience reducers	Sensi-tivity	Resilience enhancers	Adaptive capacity	Measures recommended by stakeholders	Resilience in future
Agriculture production	0.525	Pest invasion	0.7	Wadi programme	0.67	Water management	0.5
Water resources	0.421	Financial loss	0.538	Extension services	0.66	Value chain infrastructure	0.7
Fodder availability	0.45					Pesticides	0.86
Livestock health	0.4					Health and education	0.575

Financial reserves	0.459					Livelihood diversification	0.4
Migration	0.625					Financial reserves	0.808
Human health	0.518						

Table 5.17: Sensitivity, Adaptive Capacity, and Future Resilience to Climate Variability and Change as Perceived by the People Involved in Value Chain and Enterprising

Impact concepts	Sensi-tivity	Resilience reducers	Sensi-tivity	Resilience enhancers	Adaptive capacity	Measures recommended by stakeholders	Resilience in future
Agriculture production	0.244	Pesticides and fertilizers	0.524	Soil conservation	0.5	Water management	0.647
Water resources	0.681	Financial loss	0.655	Agriculture techniques	0.461	Value chain infrastructure	0.816
Climatic extreme	0.4	Lack of capacity building	0.621	Livestock and milk production	0.65	Extension services	0.708
Insect and pests	0.616			Awareness	0.6	Sustainable agriculture	0.724
Land resources	0.675			Collectivization	0.611	Solar energy	0.85
Financial reserves	0.356			Extension services	0.519	Climate smart livestock	0.883
Human health	0.519			Wadi programme	0.606		

Table 5.18: Sensitivity, Adaptive Capacity, and Future Resilience to Climate Variability and Change as Perceived by all Stakeholders

Impact concepts	Sensitivity	Resilience enhancers	Adaptive capacity	Adaptations recommended by stakeholders	Resilience in future
Agriculture production	0.584	Livestock and milk production	0.65	Sustainable agriculture	0.766
Crop failure	0.604	Soil conservation	0.549	Climate smart livestock	0.795
Deforestation	0.6	Agricultural techniques	0.661	Water management	0.612
Climatic extreme	0.668	Physical infrastructure	0.637	Health and education	0.6
Land resources	0.629	Collectivization	0.567	Physical infrastructure	0.695
Water resources	0.579	Wadi program	0.6	Livelihood diversification	0.690

Human health	0.717			Collectivisation	0.587
Migration	0.545			Value chain infrastructure	0.675
Financial reserves	0.588				
Sustainable agriculture	0.5				
Livestock and milk production	0.375				
Livelihood diversification	0.672				
Wadi program	0.6				
Collectivization	0.677				
Collectivisation	0.8				

Table 5.19: Mean Precipitation and Temperature in Valsad for Reference Climate, and Change in for Projected Climates Using Different Models

Years	Models	Precipitation (mm)	Temperature (ºC)
Reference climate (1981-2010)	CRU	2127.08	27.36
Projected climate 2050s	GFDL	1990.98	28.79
	HadGEM	2794.84	29.25
	IPSL	2392.51	29.54
	MIROC	2011.68	28.97
	NorESM	2130.39	28.62
	E-MEAN	2264.08	29.04
Projected climate 2080s	GFDL	2217.30	29.32
	HadGEM	3023.33	29.98
	IPSL	2471.59	30.11
	MIROC	2014.37	29.51
	NorESM	2537.15	28.62
	E-MEAN	2452.74	29.52

5.4.3 Scenarios

To understand the effectiveness of the adaptations measures recommended by the stakeholders, scenarios have been modeled under future climate change regime. To generate future climate change scenario without resilience measures, the central concept is scaled up to their maximum activation level, which is 1. To generate future climate change scenario with adaptations measures, the interventions recommended by the stakeholders, which would help to increase their resilience against climate variability and change, are scaled up to their maximum activation level along with the central concept.

i. Scenarios Generated for Community Resilience with Present Resilience Enhancer Concepts:

In order to understand effectiveness of the adaptation interventions; soil moisture conservation, better agricultural techniques, livestock and milk production, awareness, wadi programme, collectivization, better physical infrastructure, and religious interference, intended for reducing the negative impacts incurred on; agricultural production, land and water resources, fodder availability, livestock and milk production, deforestation, human health, migration, and financial reserve due to increased climate variability and change, climatic extremes, and pest invasion. The simulation results show that given these resilience measures, agricultural production,water resources, human health, fodder availability, financial reserve, land resources, converge on positive side indicating high positive change. At the same time concepts such as deforestation, climatic extremes, pest invasion, and migration converge on negative side indicating negative change. Other concepts recommended by the communities such as water resources management, value chain infrastructure, climate smart livestock, converge on positive side indicating high positive change. While, concepts reducing the resilience of the communities such as, pesticides and insecticides, financial loss, poverty, pest invasion, alcohol addiction, and private traders also converge on negative side indicating negative change. All other concepts such as sustainable agriculture, organic farming, solar energy, collectivization, capacity building, and thin soil layer remain unchanged.

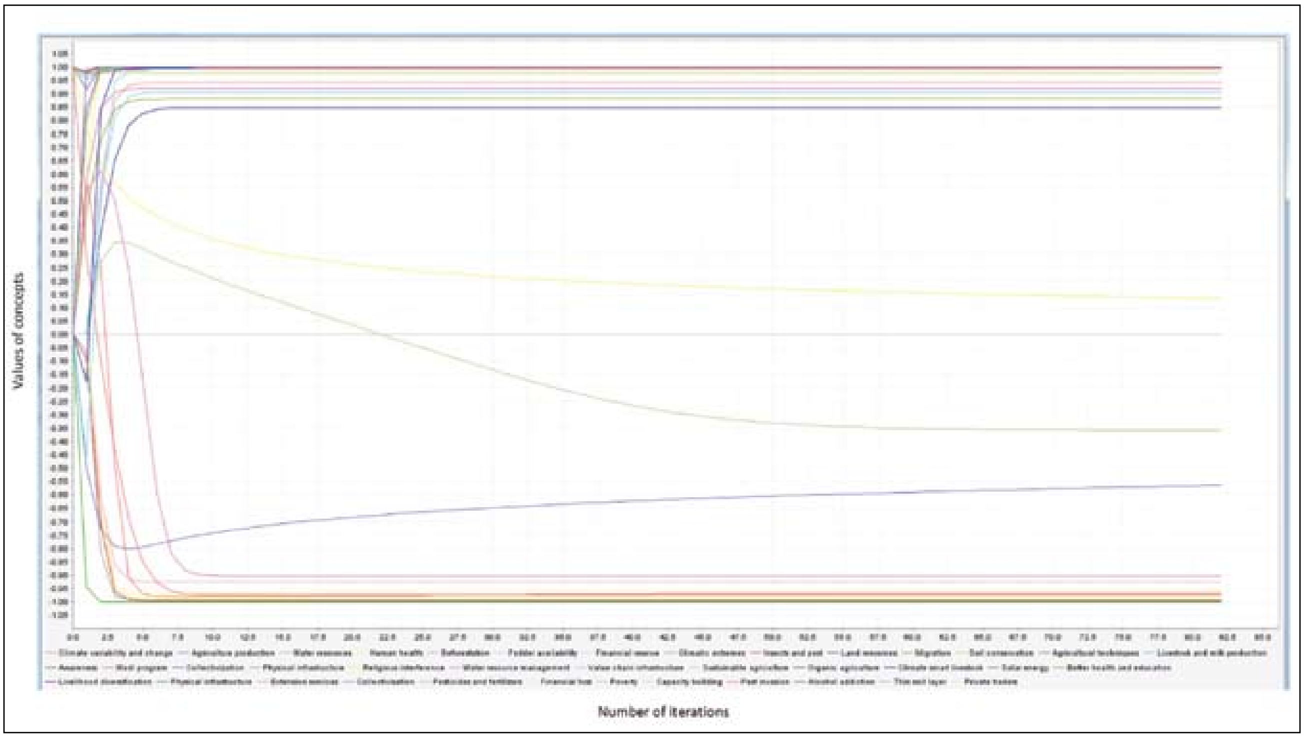

Figure 5.27: Simulations for Climate Variability and Change with Present Resilience Enhancers

ii. Scenarios Generated for Community Resilience with Concepts Recommended by all the Stakeholders:

In order to understand effectiveness of the adaptation interventions; water resources management, value chain infrastructure, sustainable agriculture, organic farming, climate smart livestock, solar energy, better health and education, livelihood diversification, better physical infrastructure, extension services, and collectivization, intended for reducing the negative impacts incurred on; agricultural production, land and water resources, fodder availability, livestock and milk production, deforestation, human health, migration, and financial reserve due to increased climate variability and change, climatic extremes, and pest invasion. The simulation results show that given these resilience measures, agricultural production, water resources, human health, fodder availability, financial reserve, land resources, converge on positive side indicating high positive change. At the same time concepts such as deforestation, climatic extremes, pest invasion, and migration converge on negative side indicating negative change. The concepts signifying present resilience enhancers such as soil moisture conservation, better agricultural techniques, livestock and milk production, awareness, wadi programme, and collectivization converge on positive side indicating high positive change. While, concepts reducing the resilience of the communities such as, pesticides and insecticides, financial loss, poverty, pest invasion, alcohol addiction, and private traders also converge on negative side indicating negative change. However, pesticides and insecticides show very less negative change. All other concepts such as sustainable agriculture, organic farming, solar energy, collectivization, capacity building, and thin soil layer remain unchanged.

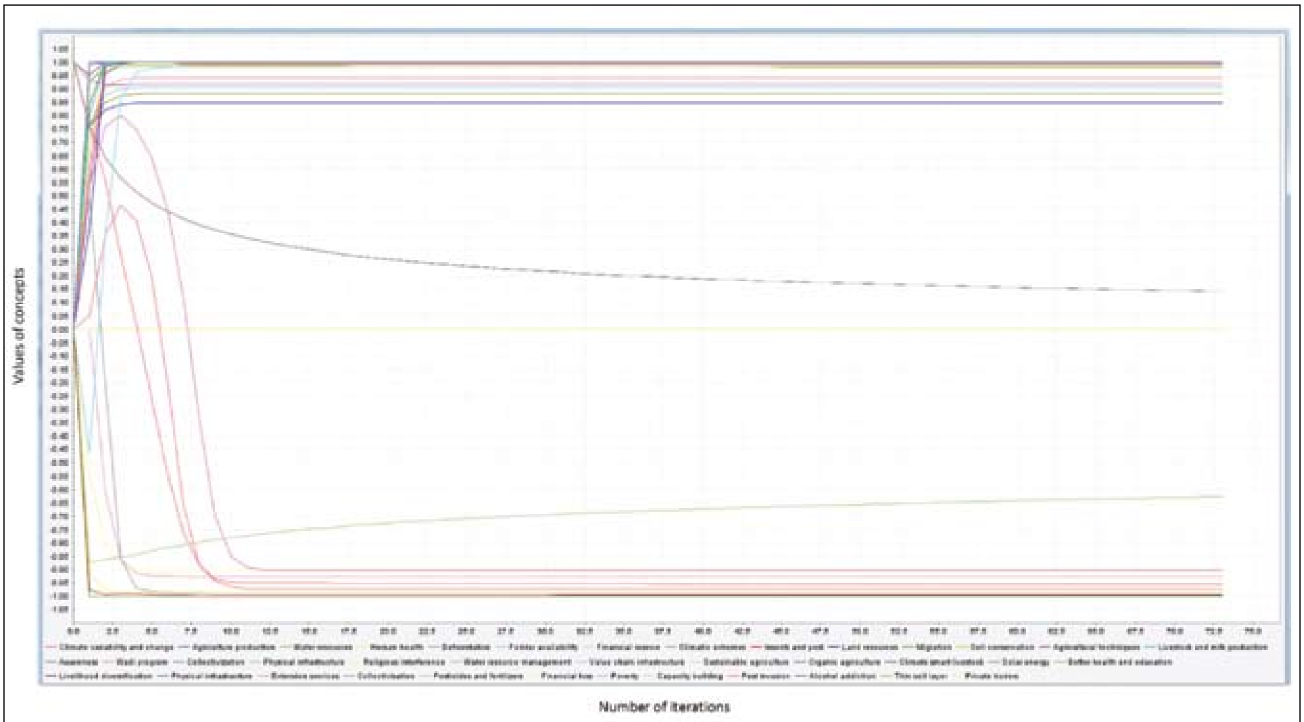

Figure 5.28: Simulations for Climate Variability and Change

CHAPTER-6

Guidance Toward Policies and Governance

6.1 Management of Land Resources

The cultivation systems of a region are determined by a series of parameters such as soil type, temperature, rainfall, etc. Apart from these other factors such as infrastructure (irrigation, transport, storage, etc.), socio-economic and technological advances help to decide the farming system of a particular region. Gujarat is divided into five regions namely south, central, north, Saurashtra, and Kutch. Seven agro-climatic regions have been identified based on soil characteristics, temperature, precipitation and the availability of water resources. These are the south of Gujarat (strong rainy zone), south, middle, north, south of Saurashtra, north Saurashtra, and north-west of Arid (Kutch). Technological changes have favoured intensive water crops, thus changing Gujarat's cultivation pattern since the 1960s. These changes have favoured crops such as cotton, rice, etc. at the expense of areas under vegetables, oilseeds and coarse grains. This change can be attributed to the agro-climatic conditions, technological changes, institutional changes and infrastructure changes associated with agriculture that have taken place in recent years. Gujarat has seen tremendous changes in cropping intensity over the last few decades. These changes could be attributed to the following factors: energy supply, agricultural inputs such as fertilizers, water supply (rain or irrigation) and the type of crop pattern adopted.

The government has made some efforts to reduce these impacts. The praiseworthy initiatives are seeking to increase agricultural productivity and ensure the security of land tenure. The high growth of agriculture in Gujarat has caught the attention of agricultural and political planners. These remarkable results were possible due to meticulously planned and coordinated action plans that secured eight hours of uninterrupted power supply in the agricultural fields throughout the state (under the *Jyoti Gram* scheme), water conservation and management including watershed development, recharge structures, micro irrigation, interconnection of rivers, creation of marketing infrastructure, etc. The soil health card program is also an initiative that seeks to increase soil productivity by improving soil health. Twenty soil testing laboratories covering all districts in the state provide free test facilities to farmers. Based on the soil test analysis report, soil health cards were prepared with the maintenance of computerized soil test data, fertilizer recommendation, soil recovery, crop planning, etc. *Krishi Mahotsav*, where farmers with researchers, scientists, experts, agriculture officials, and ministers interact, provide information, and advice on soil health, organic agriculture, modern technology, agricultural inputs, irrigation, etc., as well as infusing a new spirit of change and mass mobilization.

Forest cover in Gujarat is low compared to the national average. The mode of mission in social forestry and joint forest management (JFM) could help improve forest cover. Several NGOs have also been active with communities in the Gujarat JFM program. The Gujarat Ecology Commission and the Gujarat Forestry

Department have also initiated awareness-raising programs to communicate and share the benefits that can be gained and support for forest ecosystem livelihoods.

Efforts need to be intensified to increase the natural resource base, promote sustainable and organic farming practices. Appropriate land acquisition measures that could provide a win-win situation for all stakeholders who need the time. There is also a need to increase the number of common hazardous waste incineration plants and common effluent treatment facilities since land allocated to the SEZ, SIR, and GIDC areas is large and the increase in the number of industries in Gujarat is likely to generate more waste. The Gujarat Urban Development Company was established to study solid waste management issues. However, the solid waste management system needs to be further modernized. Concerning efforts in the mining and waste sector Gujarat Ecology Society has undertaken the study "Ecological Restoration of Gujarat Mining Sites" at the request of the Gujarat Mineral Development Corporation to intensify the protection and conservation of the environment in mining areas. This is a small initiative that needs to be expanded since Gujarat is a state with the second largest mining lease in the country. There is a need for a dynamic and scientifically advanced system of land use and land registry management to better govern land resources. Advanced scientific tools for mapping land use should be used. The standard system of classification of land use should be adopted by departments dealing with land issues. There must be a land use policy that can reconcile the ecological, economic, and equity dimensions prevailing in the state.

Cropping patterns in Gujarat have shifted to unsustainable agricultural practices. Growing crops unsuitable for rainfall, soil type, and reliance on groundwater have caused serious environmental perturbations calling for immediate sustainable agricultural interventions. There is an urgent need to return to water efficient crops and help prevent further degradation of agricultural land. There needs to be a shift towards sustainable cropping patterns like the system of crop intensification to reduce groundwater depletion while integrated nutrient management needs to be adopted for maintaining sustainability. Water efficient practices including SRI, SWI, micro-irrigation, and water and soil conservation could lead to a significant contribution to the GSDP since Central and Southern Hills of Gujarat produces a variety of cash crops. To ensure long-term land productivity immediate steps need to be taken towards sustainable agricultural practices. Agricultural practices should become sustainable instead of exploitative leading to an environmentally sustainable growth. Some technological and management interventions that could improve soil quality include structural methods for soil conservation like soil and stone bunding and terracing in undulating areas, agronomic practices for soil and water conservation and management such as minimum tillage, integrated nutrient management, etc. Soil conservation measures have, however, been put in place through capacity building programmes like *Krishi Mahotsav* in Gujarat. Another programme initiated by the government is the soil health card programme that informs farmers about the quality of soil and interventions that may be carried out to improve soil quality. These initiatives are unlikely to pay enough dividends unless proper soil conservation measures and appropriate cropping patterns are adopted.

6.2 Management of Water Resources

The regional climatic variation within Gujarat, observed changes in precipitation pattern, temperatures and projected changes in precipitation, temperature, and water flow and storage, and a regional plan is appropriate to address concerns of climate change. A white paper on water in Gujarat (2000) had described the state as one of India's dwindling, water-prone regions. Until 2000, droughts occurred about once every five years on an average that had an adverse impact on the local population and the overall development of the state. For just over a decade, the state has seen a shift in government responses ranging from firefighting tactics to the 1990s to more integrated efforts to reduce drought and reduce water scarcity statewide. Given the positive evolution of the last decade, it may seem that Gujarat has overcome its water problems, but much remains to be done. The state's rapid industrialization and urbanization have aggravated the already complex water management problems facing the state. Constitutionally speaking, water is a state issue, it is the responsibility of state governments to plan, develop and manage their water resources. Responses from the government have a central role to play in addressing water issues.

Fulfilling the water demand in the future, even for a business-as-usual scenario by mid-century will be difficult. The impacts of climate change will further increase demand, if water availability is reduced as indicated. An integrated approach to water management therefore needs to be instituted to take account of the constraints of climate change as well. Central and state governments now play a key role in water resources management. In addition, the participation of the local population is crucial so that they can conserve, develop and manage the water resource at the local level. To this end, the current organizational structure would have to be adequately restructured. The impetus of village level participatory institutions through the Water and Sanitation Management Organization (WASMO) has played an effective role in improving water management at the village level, with clear room for improvement. Participatory institutions at the village level in the case of watershed and irrigation management require strengthening and extension. Schemes such as *Sujalam Sufalam*, river interrelations, plus a state network for domestic and potable water supply have intensified the positive impact of good rainfall and an almost complete SSP on the Narmada. WASMO and *Jyoti Gram* are two institutional responses that have had significant positive impacts on the water sector in Gujarat.

Appropriate macro-level changes in government organizational structures and adoption of the river basin approach for integrated water resource planning and management. At the micro-level, it is suggested to strengthen community organizations - Watershed Committees (WCs) in rain-fed areas, Water User Associations (WUAs) in irrigated areas, Joint Forest Management Committees (JFM) in forest areas and Resident Welfare Associations (RWAs) Urban Areas. These community organizations will be the organizational mechanism through which people can participate in the management of water resources. Watershed management and minor irrigation projects would be best suited for drought-prone areas, tribal and hills, which should be allowed and encouraged by local communities with technical and financial support from government and NGOs. The management of these projects should be with the local communities, through the Watershed Committees/ WUAs. The government must transfer authority to regulate the use of groundwater to the lowest level, the *gram sabha*. The first right to groundwater must be for the community concerned and not for an individual in land ownership. In areas with water shortages, the respective community organizations should have the right to inspect and monitor the use of groundwater by private landowners to ensure that groundwater is not withdrawn beyond permissible limits. The development of groundwater resources should be regulated in such a way that it does not exceed the annual recharge. The detrimental environmental consequences of overexploitation of groundwater should be effectively avoided through legislation and its implementation by local government bodies, local committees, and gram *sabhas*, which will have a vital role to play in this.

For efficient and economical management of water resources, knowledge frontiers need to be pushed in a number of directions, intensifying research efforts in a number of areas, including: (i) hydro-meteorology; (ii) water resources assessment; (iii) hydrology and recharge of groundwater; (iv) water quality, recycling, and reuse; (v) prevention of salinity; (vi) prevention of water and soil salinity; (vii) water harvesting in rural areas in an integral manner;(viii) water collection and recharge groundwater in urban areas; (ix) economic and easy to operate and maintain designs for water resources projects; (x) improved water management practices and improvements in operating technologies; (xi) crop and cropping systems; and (xii) treatment of wastewater at smaller scales and reuse of water after treatment. Since the overall objective of the policy is to involve the population at all stages, the training of those who must manage water resources at all levels should be accorded the highest priority. Training should sensitize all partners to the demands of a popular planning approach to water resource development. Training should also ensure the technical empowerment of all local institutions and communities that need to plan, develop and manage water resources. These include *panchayats, gram sabhas*, NGOs, watershed associations, WUAs, WCs, etc. It should cover training in information systems, sectoral planning, project planning and formulation, project management, operation of projects and their physical structures and systems, and the management of water distribution systems. Training should have a strong component in changing attitudes and behavior.

The main concerns of Gujarat water managers seem to be shifting from increased water to water quality repair and water quality management. There are obvious indications, as the findings of this report suggest, together with other reports on the deterioration of the quality of groundwater and surface water such as rivers, lakes and ponds, that there is an alarming Water. Just as the state has set an example in making lead to set up the Department of Climate Change, a model urban planning framework for saving, developing and conserving our bodies of water is probably the need of the hour. In this context, Gujarat needs to seek paradigmatic change in terms of managing its water holistically to maintain its growth momentum with effort.

CHAPTER-7

Conclusions

Temporal variability of climatic factors shows heterogeneous changes across RCP and models. However, the spatial variability of each of the agro-climatic factors tends to have a similar trend in all the results obtained from different RCP and Models. The reference evapotranspiration deficit shows its highest value in region of Kutch and gradually decreasing toward south Gujarat. In other hand, annual mean temperature, annual mean rainfall, aridity index, net primary production in rain fed region, annual actual evapotranspiration and annual P/PET ratio shows dissimilar trend, showing highest value in south Gujarat which decreases toward Kutch.

South Gujarat, having highest rainfall and temperature in Gujarat in current climatic condition, is also projected to have highest mean annual rainfall and temperature in future. However, the number of rainy days are likely to be reduced in this region. Projecting higher annual actual evapotranspiration in this region is directly related to higher temperature as well higher water availability from rainfall. Higher temperature, as well as the availability of increased amount of water, causes higher evapotranspiration rate, consequently, South Gujarat, as expected, may show highest annual actual evapotranspiration. The rainfall intensity varies significantly higher than temperature across the south Gujarat and Kutch. Therefore, potential evapotranspiration, affected by atmospheric demand specifically temperature; vary relatively less than rainfall from south Gujarat to Kutch. P/PET remains higher in south Gujarat and reduces significantly toward Kutch in parallel to the reduction in rainfall. Net Primary Production under rain-fed condition has a close relation with actual evapotranspiration because it is related to plant photosynthetic activity which is also driven by radiation and water availability. Therefore, considering high actual evapotranspiration in presence of high water availability in south Gujarat, Net Primary Production under rain-fed condition also becomes higher in south Gujarat. Reference evapotranspiration deficit is higher in Kutch because of higher difference between potential evapotranspiration and actual evapotranspiration. The atmospheric demand of evapotranspiration is much higher than the available water for evapotranspiration in the region of Kutch which relatively decreases toward the south. Therefore, reference evapotranspiration remains higher in Kutch and reduces toward south Gujarat.

Cropping patterns in Gujarat have shifted to unsustainable agricultural practices. Growing crops not very suitable for rainfall, soil type, and reliance on groundwater have caused serious environmental perturbations calling for immediate sustainable agricultural interventions. There is an urgent need to return to water-efficient crops and help prevent further degradation of water and agricultural land. Farmers need to be educated to shift towards the cropping patterns based on results of the AEZ modelling. There needs to be a shift towards sustainable cropping patterns like the system of crop intensification to reduce groundwater depletion while integrated nutrient management needs to be adopted for maintaining sustainability. To ensure long-term land productivity immediate steps need to be taken towards sustainable agricultural practices.

Gujarat's microcosmic environment continues to pose multiple challenges for both users and managers of their water resources. For a long time, Gujarat had faced the double challenge of conflicts arising from the demand for consumptive uses of water and drought management. While the water security scenario has improved over the past decade, Gujarat's model of economic development and urban water needs have the potential to change the patterns of water use, as well as the very nature of water. Gujarat has a total of 50.1 billion cubic meters of water including surface water, groundwater and storage capacity of reservoirs (excluding Sardar Sarovar). Surface water resources contribute 38.1 billion cubic meters, while groundwater contributes 12 billion cubic meters. However, the inconsistent distribution of water resources, together with the topographic factors of the state, has led to a partial use of its water potential. The State has raised several important and minor projects that increase the surface storage capacity of its rivers, while allowing the recharge of groundwater in their parched regions. From the Drought Prohibited Area Program (DPAP) to the Integrated Watershed Management Program (IWMP), the approach has shifted from piecemeal solutions to a more integrated approach to watershed management through planning and management of river basins and convergence with other development schemes. However, robust basin management institutions have not yet emerged. The availability of potable water and the health risks associated with drinking water remain key concerns for villages in these salinity areas. Salinity and poor drinking water quality are the main reasons for the prevalence of diseases such as fluorosis and dysentery in these areas. Salinity entry in certain areas has been significantly reduced due to corrective measures taken by the government, NGOs, communities and favorable rainfall intensity over the last decade. The Gulf of Khambhat, the Gulf of Kutch and the western coast of southern Gujarat are prone to storm surges; the resulting salinity intrusion into freshwater bodies requires a dynamic monitoring and alert system.

Gujarat witnessed increased availability of water and relatively high growth in the agricultural sector over the last decade, leading to increased demand for irrigation. The percentage of net surface area of irrigation of groundwater during the last decade has remained very high, from 78.7 to 86.7%. The shift to crops such as cotton, wheat, sugar cane, rice and the increase in net planted areas of crops such as peanuts in sparse areas of water has added to the agricultural outline. Given the multifaceted environment of Gujarat, the impact of climate change will further complicate the problems of water availability and quality in the state. With increasing demands for domestic use, irrigation and industrial water applications, the huge gap between demand and supply has led to the significant role of water as a purifying agent in the overall ecosystem. The generation of wastewater has increased considerably in the last decades, being the main responsible for the elimination of domestic and industrial effluents not treated in the water bodies.

The government and other stakeholders have taken bold steps towards increasing and managing water available in Gujarat over the last decade. The government's vision to strengthen Jal shakti as part of its global development approach called Panchamrut has had a positive impact on protection against drought and water harvesting. Their efforts have produced positive results in part due to favorable weather conditions since the last decade. The state witnessed a trend of increased precipitation in most of its regions during the last decade, although many regions are chronically prone to drought due to irregular precipitation. Factors such as good rainfall, the arrival of Narmada waters and the massive recharge effort undertaken by communities and government through watershed management have come together to play an important role in increasing water availability, access to potable and domestic water in most of the state. A state-level water-based water supply network in Narmada, currently at an advanced stage of development, is expected to provide potable water to 75% of the state's population. Although the quality of drinking water remains a problem in some parts, in particular quantitatively, much has been achieved in terms of the substantial number of villages covered by WASMO.

The pressures related to water and the state of resources in the state are related to the Indian microcosmic environment of Gujarat and human activities in the state. The interaction of these two sets of forces affects water resources in many ways. Rapid industrialization requires a strong watchdog in the form of regulatory agencies, along with well-equipped legislation and institutional mechanisms to control water pollution resulting from the inappropriate discharge of effluents into groundwater aquifers or surface water bodies. The main concerns of Gujarat water managers seem to be shifting from increased water to water quality repair and water quality management.

The fuzzy cognitive mapping (FCM) approach has helped us to capture the dynamics of system functioning. The FCM based livelihood vulnerability index has very well depicted people's understanding of how sensitive they are to climate variability and change, and how they respond to it. The FCM approach has revealed the dynamic vulnerability of communities as compared to linear, indicator-based, vulnerability assessments techniques, which do not showcase interconnected relationships. Livelihood vulnerability analyses have brought in new ways of understanding the insecurities of communities due to the degrading environment and diminishing livelihoods. Our study has revealed livelihood vulnerability of the communities across the regions. Vulnerability to climate variability and change varies across the time as stakeholders perceive, observe and undergo different sensitivity, exposure and adaptive capacity in different seasons.

The chief problems rural areas face due to climate variability and change, across all three seasons, are degrading natural resources such as land and water, declining agricultural productivity, increasing health-related issues, and consequently falling financial reserves. Declining water resources, deteriorating soil quality and increasing pest invasion has led to diminishing agricultural productions. Climate impacts are increasing in humans due to increase in malaria incidence and extreme heat events causing the incidence of severe diseases. Due to degrading natural and human assets the financial resources of the communities are reducing, pushing them further into the riddle of poverty. Interventions by the local governments and non-governmental organizations enable communities to respond to climate change and variability. Community participants believed that the main coping strategies and adaptive capacities are diversification of production systems, better management of water resource, micro-irrigation measures, water budgeting, Participatory Irrigation Management (PIM), soil-water conservation, the introduction of less-water intensive crops, better agricultural inputs, pest control, and livelihood diversification. People's collectives also help them better govern their resources. These coping mechanisms have helped to improve land and water resources, and consequently, agricultural production, increasing people's financial reserves and reducing migration.

The simulations reveal that current traditional adaptation interventions do not sufficiently ensure the resilience of livelihoods against climate variability and change. There is a need for a basket of adaptation interventions, in order to ensure climate resilient livelihoods and to reduce climate-related risks and vulnerabilities. The climate change scenario with scaling up adaptation strategies illustrates a better future in comparison to the baseline and previous scenario, with most of the livelihood assets being improved.

Various attempts are required to strengthen farmland productions and maintain ecological balance to survive against the climate-related impacts and shocks. There has to be a drive to build the resilience of farming and vulnerable communities who are most likely to be affected by climate variability and change. Hence, the government has to take initiatives to help communities to build resilience and adapt to the effects of climate variability and change through scientific, indigenous knowledge and evidence-based decision. Scoping studies need to be conducted to understand communities and ecosystems that are vulnerable to climate change. Communities are in a better position to identify their needs and risks after having accumulated knowledge and experience in the context of climate change impacts. Therefore, it is very important to incorporate their views, observations, and experiences in decision making and policy planning. Investments in climate-smart agriculture, climate-smart livestock management, better water conservation practices, quality agricultural inputs, micro-irrigation practices, development and management of natural resources through watershed and afforestation activities, conservation of biodiversity including crop biodiversity, etc. will not only increase production from farmland but also prove to be transformational adaptation practices.

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