सत्यमेव जयते

Rajasthan State ACTION PLAN on Climate Change

2022

Prepared by
Climate Studies, IIT Bombay

in collaboration with

Department of Environment and Climate Change
Government of Rajasthan

मुख्य मंत्री
राजस्थान

प्राक्कथन

औद्योगिक क्रांति के बाद विश्व में बढ़ते औद्योगीकरण के कारण जलवायु में बहुत अधिक परिवर्तन देखा जा रहा है। इसके परिणाम से बढ़ता हरित गृह प्रभाव (Green House Effect) के रूप में सामने आया है। पृथ्वी का औसत तापमान 15 डिग्री सेल्सियस है, जो कि पूर्व में काफी कम था। पृथ्वी के बढ़ते तापमान से हो रहे जलवायु परिवर्तन से खाद्यान्न उत्पादन में कमी, बाढ़, सूखा प्राकृतिक आपदाओं में वृद्धि, पेयजल की कमी, जीव–जन्तुओं की प्रजातियों के विलुप्त होने के साथ–साथ संपूर्ण मानव प्रजाति पर भी संकट बढ़ रहा है।

जलवायु परिवर्तन एक वैश्विक समस्या है। इस समस्या से निदान के लिए व्यापक रूप से अन्तर्राष्ट्रीय स्तर पर प्रयास किए जा रहे हैं। देश और प्रदेश को जलवायु परिवर्तन की इस समस्या को गंभीरता से लेना आवश्यक है। साथ ही वातावरण को प्रभावित कर रही मानवीय गतिविधियों को नियंत्रित करना बहुत जरूरी है। जीवाश्म ईंधन का दहन, औद्योगिक अपशिष्टों का अनुचित निस्तारण, वाहनों के प्रदूषण से कार्बन का उत्सर्जन आदि जलवायु पर गंभीर और प्रतिकूल प्रभाव छोड़ते हैं।

जलवायु परिवर्तन के दुष्प्रभावों की गंभीरता को ध्यान मे रखते हुए राज्य सरकार ने "Rajasthan State Climate Change Action Plan" तैयार किए जाने की घोषणा की थी।

आशा है इस योजना के क्रियान्वयन से राजस्थान में जलवायु परिवर्तन के दुष्प्रभावों की कारगर ढंग से रोकथाम हो सकेगी।

मैं इस योजना को तैयार करने में प्रतिभागी रहे राज्य सरकार के सभी अधिकारियों और IIT Bombay को हार्दिक बधाई देते हुए इस प्रकाशन की सफलता के लिए अपनी शुभकामनाएं प्रेषित करता हूं।

(अशोक गहलोत)

प्राक्कथन

मानव जनित कारणों एवम प्राकृतिक कारणों से जलवायु परिवर्तन एक वैश्विक समस्या बन गई है। हमे यह भौतिक संसाधनों से परिपूर्ण दुनिया पर्यावरण के दोहन की कीमत पर मिली है। विकास के साथ प्रदूषण भी बढ़ रहा है। शहरीकरण, औद्योगीकरण, खनिज खनन, जनसंख्या वृद्धि रासायनिक कीटनाशको एवं उर्वरकों का असीमित उपयोग, प्राकृतिक संसाधनों का अंधाधुंध दोहन इत्यादि प्रमुखतया जलवायु परिवर्तन का कारक बने है। जलवायु परिवर्तन के दुष्प्रभावो मे अम्ल वर्षा, ओजोन परत का क्षरण एवं ग्रीन हाउस प्रभाव मुख्य है।

हमे प्रकृति के प्रति अपनी जिम्मेदारी समझनी होगी। हमे तुरन्त प्रभाव से वनों की कटाई पर रोक लगाकर वनीकरण करना होगा, जीवाश्म ईंधन का प्रयोग कम कर गैर परम्परागत ऊर्जा स्त्रोतों के उपयोग को बढ़ाना होगा, ग्रीन हाउस गैस के उत्सर्जन को कम कर जैव उर्वरको का अधिकतम उपयोग करना होगा। इस कार्य के लिये प्रदेश में पर्यावरण एवं जलवायु परिवर्तन की स्थिति का एक वैज्ञानिक विश्लेषण के आधार पर तकनीकी उपायों को सम्मलित कर एक योजना तैयार करने की आवश्यकता थी। माननीय मुख्यमंत्री महोदय द्वारा **"State Action Plan for Climate Change"** तैयार किए जाने कि घोषणा करने के लिये मैं ह्रदय से आभार व्यक्त करता हूँ। साथ ही पर्यावरण एवं जलवायु परिवर्तन विभाग के अधिकारियों एवं **IIT Bombay** को इस प्लान को तैयार करने के लिये बधाई देता हूँ। मुझे पूर्ण विश्वास है कि एक्शन प्लान के क्रियान्वयन से राजस्थान प्रदेश की जलवायु में आशातीत सुधार होगा तथा इसके दुष्प्रभावों से बचा जा सकेगा।

(हेमाराम चौधरी)
वन एवं पर्यावरण मंत्री

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Chief Secretary
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Foreword

Climate change is the most ominous global challenge we are facing today which poses a great risk to our Ecology, Economy and Society. Recent observations compared with past trends show that changes being experienced in the environment are over and above the natural variability prevailing in the region. The ill effects of these rapid changes are omnipresent in a way that they follow us everywhere,be it in our home, work or travel whether far or near. Severe winters, summers and erratic rainfalls are a manifestation of climate change and are now becoming a constant feature. The changing weather patterns like irregular or late onset of rainfall affects our agriculture, productivity. The health impact of climate change though may manifest gradually but consequently is of significant importance.Already, water resources in the State are scarce and have a highly uneven distribution both temporally and spatially. Moreover, the State also has the highest probability of drought occurrence in the country. Threats of climate change and poor environmental conditions thus calls for timely and coherent policy response and action that will help reduce vulnerability and build resilience towards climate change impacts.

I am pleased to know that the Departments of Environment & Climate Change Government of Rajasthan in collaborationwith IIT Bombay as its knowledge partner had consultation with stake holders and has prepared a Rajasthan State Climate Change Action Plan. I hope that the priorities identified under this Plan will lead to implementation of strategies that will help to address the challenge posed by the changing scenario of global Environment and Climate. I am sure that such action will help in channellising environmental resources of the State, thereby promoting a sustainableenvironment & develop Rajasthan into a Climate Change Resilient State.

(Usha Sharma)

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Shikhar Agrawal
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सत्यमेव जयते

Principal Secretary
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Date: 24.05.2022

Foreword

Adverse effects of the climate change are more visible than ever. These effects include frequent droughts, erratic rainfall, large scale water scarcity, severe fires and declining biodiversity.

Department of Environment and Climate Change in collaboration with IIT Bombay has prepared this plan after detailed consultation with a large number of stakeholders.

I sincerely hope that this plan would help in appropriate policy formulation and timely action to handle this challenge.

(Shikhar Agrawal)

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FOREWORD

Climate change is already affecting us and is no longer an event in distant future. Strong climate action strategies backed by action on ground will help us build resilient communities and achieve sustainable development goals. An inclusive, decisive, and strategic climate action plan will provide huge opportunities to enhance the public health, living conditions, agricultural yields, productivity, energy efficiency, creation of green jobs, preservation of ecosystems and protection of communities from climate change induced extreme weather events. Acting quickly and decisively to address climate change will bring significant benefits and help us avoid some of the worst consequences of climate change.

As the Director of IIT Bombay, I am pleased that the Department of Environment and Climate Change, Government of Rajasthan, has responded to the ongoing climate crises and prepared the Rajasthan State Action Plan on Climate Change (RSAPCC) in collaboration with Climate Studies, IIT Bombay as the knowledge partner. Implementation of RSAPCC will help in climate change mitigation and adaptation at grass root level, accelerate the climate resilience of Rajasthan and drive it towards sustainable development. Needless to say that climate being a global phenomenon, other states are also required to develop such an action plan.

I would like to congratulate Prof. K. Narayanan and his team for their tireless efforts in conducting an in-depth analysis on the current state and formulating the RSAPCC. I would also like to extend my gratitude to all the stakeholder departments for their knowledge sharing.

I congratulate the Government of Rajasthan for launching the RSAPCC and I wish them luck for a journey towards a greener future. Rajasthan can guide the entire nation by implementing RSAPCC in an effective manner and create a benchmark for climate action in India.

(Subhasis Chaudhuri)

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EXECUTIVE SUMMARY

Climate change, which refers to long-term shifts in weather and temperature patterns, may be natural, but human activities have been the main driver of climate change since the 1800s. Greenhouse gas emissions, released by the burning of fossil fuels, are the leading cause of global warming, and the earth is now warming faster than at any point in history.

Global climate change has observable effects on the environment – melting glaciers, rising sea levels, and a higher frequency of extreme weather events such as droughts, floods and cyclones. It also has profound impacts on human health, socio-economic development, physical environment, food security, water security, agriculture production, tourism, fisheries and energy. For an improved understanding of key climate processes, climate risks and associated consequences as well as for taking decisive action to reduce those consequences, a climate action plan is immensely valuable.

The Rajasthan State Action Plan on Climate Change (RSAPCC) addresses the climate vulnerabilities, risks and impacts that are specific to the State of Rajasthan as well as the opportunities, adaptation and mitigation measures that can be adopted at the State and dis-aggregated levels. Highly sensitive to climate change, Rajasthan is prone to extreme events such as erratic rainfall with frequent dry spells, occasional heavy downpours, extreme temperatures in both summer and winter, sandstorms, droughts, famines and floods. Rajasthan also has unique vulnerabilities caused by varying climate exposure, adaptive capacity and sensitivity.

The RSAPCC is a framework of action for responding to and reducing the current and future impacts of climate change in Rajasthan. It outlines the State's strategies for a range of sectors that are relevant to its economy and local livelihoods – water, agriculture, health, forest and biodiversity, socioeconomic growth, and urban governance. The plan also examines the emission profiles of eight sectors – thermal power generation, industrial manufacturing, brick production, transportation, residential, agriculture, waste management, and tourism – and discusses the mitigation potential of each. The plan builds on the existing policies of the State and centre. Major policies, institutions and programmes have been identified, and the ways in which climate vulnerability and adaptation can be incorporated into these are addressed.

Specifically, our risk analysis at the State, regional and local level shows that groundwater levels in the north-eastern districts of the State have a high magnitude decreasing trend, which implies rapid groundwater depletion. Characterized by arid and semi-arid regions, Rajasthan is highly susceptible to droughts, and our analysis of drought patterns suggests an increase in drought months for several areas across Rajasthan. Water availability shows an increase in the south-eastern part of Rajasthan in the future, but the rest of Rajasthan shows no change or a decrease. Regional water scarcity can be a problem in Rajasthan where the effects of reduced rainfall and overexploitation of ground water are likely to be compounded in future. The 20th century trend in rainfall for Rajasthan is positive for a few regions, while the rest of the regions show no trend. The trend for 21st century shows no specific pattern, which indicates that region-specific water management will be important in the future. We also examined agriculture data and found that districts with high hazard variability also tend to have high agriculture vulnerability. The health sector in Rajasthan has witnessed improvements over time, but there is room for integrating health policies with other allied fields like drinking water, sanitation and nutrition.

Finally, with regard to greenhouse gas emissions, our analysis shows that emissions in Rajasthan are projected to increase by approximately 1.7 times the present value by 2030 under the Business-As-Usual (BAU) scenario. Power is one of the highest CO_2 emitters in India; however, in Rajasthan, sectors like industrial production, agriculture, and tourism are equally important. Rajasthan is estimated to contribute a total of 137 Mt CO_2-eq./y with significantly increasing trends. By 2030, emissions from brick manufacturing are expected to more than double if the present technology mix does not change; in the transport sector, emissions are predicted to increase by 2.7 times; in the residential sector, it is likely to grow by 20%; and in the agricultural sector, it is likely to increase by 18%.

The estimation of CO_2 emissions from Rajasthan's industrial sector shows that the cement industry is responsible for the major share of CO_2 emissions. Although many technology/policy measures are in place (such as PAT, green rating of industries, state energy efficiency index, BEE-SME), various additional CO_2 emission mitigation measures and industry-specific technology alternatives have been proposed for hard-to-abate industries such as cement, chemicals, and iron and steel; for small-scale industries; as well as for MSMEs. For large-scale reduction of CO_2 emissions in the hard-to-abate industries, it is necessary to promote the development and deployment of technologies for carbon capture utilization and/or storage

(CCUS), along with policy/regulatory support in the form of carbon price/tax. Interventions and strategies proposed in this report can help in not only maintaining emissions at the present level but also reducing climate impacts on various sectors in Rajasthan.

To ensure the effective implementation of recommendations proposed in the RSAPCC, this report includes a framework for monitoring and evaluation. In addition to progress tracking, this framework facilitates the success of the action plan by ensuring that the policies are in coherence with the ever-changing nature of an inherently dynamic society. Periodic monitoring and evaluation can help policymakers assess the gaps between existing conditions and desired outcomes. The impact of the State action plan can be assessed in terms of climate change resilience, reduction in emissions, achievement of State targets and the overall impact on national targets.

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List of Abbreviations

AAO	Assistant agriculture officer
AMS	Annual maxima series
AVI	Agriculture vulnerability index
BAU	Business as usual
BEE	Bureau of Energy Efficiency
CAGR	Compound annual growth rate
CBA	Cost-benefit analysis
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CDI	Crop diversification index
CII	Confederation of Indian Industry
CPR	Common property resources
DC	Designated consumers
DDW	District drug warehouses
EV	Electric vehicle
FCBTKs	Fixed chimney Bull’s trench kilns
GCM	General Circulation model
GDP	Gross domestic product
GHG	Greenhouse gas
GSDP	Gross state domestic product
GSVA	Gross state value added
GVA	Gross value added
HDC	Hot desert city
HDI	Human development index
HDV	Heavy diesel vehicle
HI	Hazard index
IMD	Indian Meteorological Department
IMR	Infant mortality rate
IPCC	Intergovernmental Panel on Climate Change
LDV	Light diesel vehicles
LULC	Land use/land cover
MNRE	Ministry of New and Renewable Energy

MSME	Micro, small and medium enterprises
NAPCC	National Action Plan on Climate Change
NCR	National Capital Region
NDC	Nationally determined contributions
NGO	Non-governmental organization
PC	Principal component
PCA	Principal component analysis
P-PET	Precipitation minus potential evapotranspiration
RCM	Regional climate model
RCP	Representative concentration pathway
RMSC	Rajasthan Medical Services Corporation
RSAPCC	Rajasthan State Action Plan on Climate Change
RSEB	Rajasthan State Electricity Board
RSPCB	Rajasthan State Pollution Control Board
RVPN	Rajasthan Rajya Vidyut Prasaran Nigam Ltd
SAPCC	State action plan on climate change
SDA	State Development Authority
SDG	Sustainable development goal
SEEI	State Energy Efficiency Index
SEVI	Socio-economic vulnerability index
SPI	Standard precipitation index
TERI	The Energy and Resource Institute
VBD	Vector borne disease
VSBKs	Vertical shaft brick kilns
WHO	World Health Organization

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Chapter 1

Introduction

Climate change is a growing source of threat to our environment, livelihoods, health and food security and will continue to be so for the next several decades due to the prevalent levels of greenhouse gas emissions. As per the Sixth Assessment Report (2021) of the Intergovernmental Panel on Climate Change (IPCC), it is now beyond doubt that human activities have warmed the atmosphere, ocean and land, leading to widespread and rapid changes in the atmosphere, cryosphere and biosphere. There is ample evidence that climate change-induced extreme weather events, such as changes in precipitation patterns, extreme temperatures, erosion and droughts, are on the rise across the globe. India is also witnessing an increase in the frequency and intensity of extreme weather events such as heatwaves, cyclones, floods and droughts, which have resulted in loss of lives, livelihoods and property. As climate change worsens and extreme weather events become more frequent or severe, mitigating its effects will require strategic planning at the sub-national level.

In 2008, the National Action Plan on Climate Change (NAPCC) was instituted to address the challenges posed by climate change in India. Since then, various states across India have developed their state action plans, including Rajasthan. Building on the previous report (TERI, 2010), the current climate action plan focuses on modelling and estimation at a dis-aggregated level for Rajasthan.

1.1. The Rajasthan Context

Rajasthan is the largest Indian state with 10.4% of India's geographical area (3.4 lakh km^2), but with a population of around 6.85 crores, it accounts for only 5.66% (an increase from 5.49% in 2001) of India's total population as per the 2011 census. The state is sparsely populated, with an overall density of only 200 persons per km^2 in 2011 (an increase from 165 persons per km^2 in 2001) as against a national average of 382 per km^2. However, the population density in the state varies widely from as low as 13 persons per km^2 in Jaisalmer district to as high as 471 persons per km^2 in Jaipur district. The high variation in density is due to the presence of the large, inhospitable Thar Desert.

Located in the north-western part of the country, Rajasthan extends between 23°30' and 30°11' N latitudes and 69°29' and 78°17' E longitudes. It shares its borders with Pakistan, five Indian states (Gujarat, Madhya Pradesh, Uttar Pradesh, Haryana, and Punjab) and one union territory (New Delhi). The state is divided into 33 districts and seven divisions: Jaipur, Jodhpur, Ajmer, Udaipur, Bikaner, Kota and Bharatpur. The state enjoys special significance due to the presence of the Thar Desert and the Aravalli Mountain ranges. The Aravalli Range divides the state into two different climatic zones. The region to the west of Aravallis is arid to semi-arid, while that to the east of Aravallis is semi-arid to sub-humid and characterized by extremes of temperature, long periods of drought, high wind velocity and high potential evapotranspiration (Meena et al., 2019; Rakhecha, 2018). The climate of Rajasthan can be divided into three major seasons: hot summer (March to June), summer monsoon (July to September) and cold winter (October to February).

The state economy is mainly driven by agriculture and industry, with tourism playing an important role (IBEF report). Rajasthan accounted for 11.47% of the total cultivator population in 2011. The net area sown in the state was about 1.75 lakh km^2 in 2012-13, which is 51.07% of the total state area. Agriculture is the backbone of the state's economy, and nearly two-thirds of the population (about 65%) depends on agriculture and allied activities for its livelihood (Swain, Kalamkar, & Ojha, 2012). Some of the major challenges faced by the agriculture sector in Rajasthan are frequent droughts, depleting groundwater levels, scarcity of water resources, inefficient water management practices, deteriorating soil health, low productivity and climate change.

The state receives most of its rainfall during the Indian summer monsoon, which is primarily from June to September. The average annual precipitation is around 572 mm, and winter rainfall is meagre. Rajasthan is one of the most water-deficient states in the country, and groundwater availability is highly variable, depending on hydrogeological conditions. The groundwater quality is poor at deeper levels, and the limited groundwater resources in Rajasthan are increasingly being exploited for irrigation, industrial and domestic uses.

Rajasthan has very high climate sensitivity compared to other states in India (Chorran et al, 2021; Rathore and Verma, 2013). This is essentially ascribed to more severe as well as more frequent spells of drought. Further, the fact that over 75% of the population depends on climate-sensitive sectors such as agriculture, animal husbandry, and forestry creates additional vulnerability. Apart from high climate sensitivity and vulnerability, Rajasthan has the lowest adaptive capacity. A state-wide climate change action plan is vital to ensuring efficient climate change adaptation and mitigation in Rajasthan.

1.2. Approach to Developing the State Action Plan on Climate Change for Rajasthan

The Government of Rajasthan has taken a systematic and proactive approach in formulating the Rajasthan State Action Plan on Climate Change (RSAPCC). The coordination committee, consisting of various departments, is led by the Principal Secretary, Department of Environment and Climate Change, Government of Rajasthan. This study has been conducted in collaboration with the Indian Institute of Technology Bombay (IITB).

The RSAPCC has been developed in view of observed trends and future trajectories that the state may take. The plan covers different sectors, which are as follows:

- Socio-economic vulnerability of the state
- Water and rainfall
- Agriculture
- Heath
- Forest and biodiversity
- Urban governance
- Mitigation

For each of the sectors listed above, state-specific risks, impacts and opportunities are identified, and climate change adaptation and mitigation measures have been recommended. Action plans need to dynamically incorporate the changes in society with time. Accordingly, a monitoring and evaluation framework has been presented.

1.3 Structure of the Report

Chapter 2: Climate, Rainfall and Water

Water resources is a critical sector in the context of climate change within Rajasthan. In this chapter, we first present an analysis of trends in seasonal and extreme precipitation and groundwater levels. Next, using a state-of-the-art hydrological model (VIC model), we simulate the hydrology of the region and analyse key output variables such as soil moisture, runoff, water availability, etc. We, then, map the changes in the severity and frequency of droughts in last 3 decades (1986-2015). To estimate future changes in the hydrology of the region, we use future projections from climate models. We analyse changes in precipitation levels and droughts, and we also run a VIC hydrological model to assess likely changes in water availability in the region. This chapter presents a clear picture of the present hydrology of the state and how it is likely to change in the future.

Chapter 3: Socio-economic Vulnerability

In this chapter, we briefly discuss the socio-economic profile of the state of Rajasthan and assess the socio-economic vulnerability of its districts – specifically identification of factors that contribute to it and ranking of districts based on vulnerability. We also analyse the spatial clustering of districts based on socio-economic vulnerability and propose district-wise recommendations to address the issue.

Chapter 4: Agriculture Vulnerability

In this chapter, we assess the vulnerability of Rajasthan's agriculture sector to climate change and propose measures to reduce it. First, we identify the indicators of agricultural vulnerability, assess district-wise vulnerability status and estimate their correlation with climate hazards. We then rank the districts in terms of agriculture vulnerability and hazard variability. Finally, on the basis of the results, we provide district-wise recommendations to reduce the agriculture vulnerability.

Chapter 5: Urban Governance and Sustainable Habitat

This chapter proposes sustainable urban development pathways that can help Rajasthan's cities and population settlements adapt to climate change better and reduce vulnerabilities. Accordingly, we review national and state-level urban policies, identify gaps to be addressed, and propose climate-related actions and strategies.

Chapter 6: Health

This chapter explores the direct and indirect consequences of climate change on the health and the healthcare system. Adapting to climate change-related health risks is one of the priorities of a resilient health system. In this chapter, we discuss the current public health infrastructure, assess the health risks (direct and indirect) posed by climate change and propose recommendations and action plans to combat the consequences of climate change on human health.

Chapter 7: Forestry and Biodiversity

This chapter focuses on specific vulnerabilities in the forest and biodiversity sectors as a result of climate change. These vulnerabilities have significant adverse social, economic, and environmental impacts, which are briefly outlined and discussed. We also address the adaptation and mitigation potential for forestry and biodiversity in Rajasthan and share our recommendations.

Chapter 8: Emission Profile and Mitigation Opportunity

In this chapter, we examine the emission profiles of eight sectors: thermal power generation, industrial manufacturing, brick production, transportation, residential, agriculture, waste management and tourism. We analyse past emission trends – from 2005 to 2019-20 – and analyse the existing and future policy targets to be achieved by Rajasthan. We discuss alternative scenarios to highlight the mitigation potential of the policy recommendations and project future emission levels up to 2030 on the basis of the recommendations.

Chapter 9: Monitoring and Evaluation

The final chapter, monitoring and evaluation, provides a framework for collecting, managing, analysing and reporting progress on climate action. Periodic monitoring and evaluation ensure that policymakers can assess the gaps between existing conditions and desired outcomes.

Chapter 2

Climate, Rainfall and Water

2.1 Introduction

India's largest state in terms of land area, Rajasthan is spread across 3.4 lakh km^2. Located in the north-western part of the country, it extends between 23°30' and 30°11' N latitudes and 69°29' and 78°17' E longitudes. According to the 2011 census in Indian, the population of the state is around 6.85 crores. Administratively, state has been divided into 33 districts.

The Aravalli ranges divide the state into two different climatic zones: the region to the west of the Aravallis is arid to semi-arid while that to the east of the Aravallis is semi-arid to sub-humid and characterized by large extremes of temperature, long periods of drought, high wind velocity and high potential evapotranspiration (Meena et al., 2019; Rakhecha , 2018).

The climate of Rajasthan can be divided into three major seasons:

- Hot summer (March to June)
- Summer monsoon (July to September)
- Cold winter (October to February)

The state of Rajasthan reports an average annual precipitation of around 572 mm**.** The north-western part of the state is severely arid and receives very low rainfall (200-400 mm annually; Fig. 2.1). In contrast, south-eastern part recieves rainfall of the order of 900-1000 mm. The Indian summer monsoon, which is primarily from June to September, brings most of the rainfall to the state. Winter rainfall in Rajasthan is meagre.

In this chapter, we, first, analyse past trends in seasonal and extreme precipitation as well as groundwater levels. Next, using a state-of-the-art hydrological model (VIC model), we simulate the hydrology of the region and analyse key output variables such as soil moisture, runoff, water availability, etc. We, then, present changes in the severity and frequency droughts in the past period (1901-2005). To estimate changes in the hydrology of the region in the future, we use projections from climate models and analyse changes in precipitation and droughts. We also run a VIC hydrological model for the future period to assess changes in the water availability in the region. This chapter offers a clear picture of the present hydrology of the state and how it is projected to change in the future.

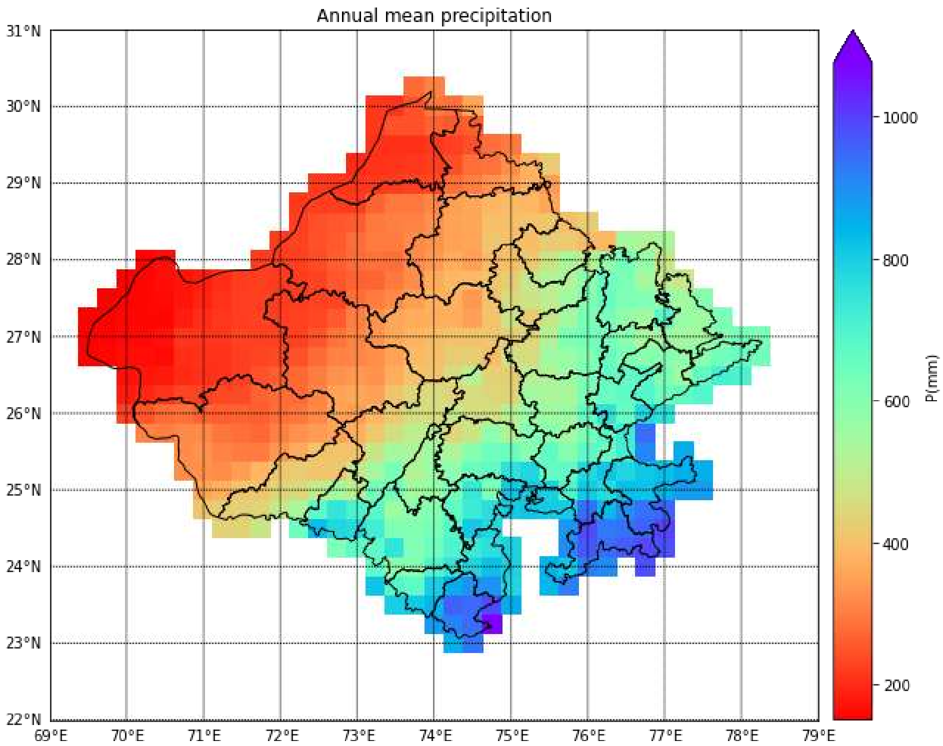


Figure 2.1. Mean annual precipitation in Rajasthan.

2.2. Data and Methodology

2.2.1. Hydro-meteorological Data Sources

Data for hydrological simulations of the observed period has been obtained from the Indian Meteorological Department (IMD). They include average daily precipitation levels, maximum daily temperature, minimum daily temperature, and average daily wind speed. Precipitation data have also been used for seasonal trend analysis.

Data on the groundwater levels in different districts were obtained from the Central Ground Water Board. For hydrological simulations of the future period, the forcing data for different General Circulation models (GCMs) were obtained from www.regclimindia.in. These data have been statistically downscaled using the Kernel regression method (Kannan & Ghosh, 2011, 2013; Salvi & Ghosh, 2013). We have explained this method in section 2.3.

2.2.2. Water Demand Data

We used the water demand data from the Water Global Assessment and Prognosis (WaterGAP) model. It is a global freshwater model, which has been developed at the University of Kassel in 1996. This model calculates the flows and storage of water on all continents (except Antarctica) taking into consideration human influences through water abstractions and dams on natural water systems. Thus, it helps in assessing water scarcity, droughts, floods and, most importantly, in quantifying human impact on freshwater. It consists of the WaterGAP Global Hydrology Model (WGHM) and the water-use models for five different sectors: irrigation, livestock, households, manufacturing and cooling of thermal power plants. An additional model component accounts for fractions of total water use that is abstracted from either groundwater or surface water. As input the model requires time series of various climate data (precipitation, temperature, winds, solar radiation) and physiographic information, which refers to characteristics of surface water bodies, land cover, soil type, topography and irrigated area. All the model computations are done with a temporal resolution of 1 day and a spatial resolution of 0.5 degrees.

2.2.3. Regional Climate Modelling

Although GCMs are valuable predictive tools, they cannot account for the fine-scale heterogeneity of climate variability and change because of their coarse resolution. These resolutions directly hamper the accuracy of rainfall projections since sub-grid features such as topography, cloud physics and land surface processes cannot be incorporated into models that influence rainfall. Further, the grid-level projection of rainfall at coarse resolution impedes impact analyses, as fine-resolution projections are needed for regional decision making. Therefore, coarse-resolution GCM simulations cannot be directly used for hydrologic impact assessment. Downscaling techniques use coarse-resolution data as input and generate high-resolution data by applying various mathematical models. Such downscaling techniques can be grouped two categories (Fowler et al., 2007; Khan et al., 2006; Trzaska & Schnarr, 2014): (1) dynamic and (2) statistical. Dynamic downscaling (Christensen et al., 2007; Feser et al., 2011; Fowler et al., 2007; Giorgi et al., 2001; Rummukainen, 2010; Wang et al., 2004) yields finer-scale physics-based models known as regional climate models (RCMs) by using input from GCM simulations as initial and boundary conditions and incorporating sub-grid features. In statistical downscaling (Frías et al., 2006; Liu et al., 2016; Salvi et al., 2013; Sheffield et al., 2006; Werner & Cannon, 2016), a statistical model is used to model the relationship between coarse-resolution GCM outputs and rainfall in India. A model based on a K-means clustering technique coupled with a supervised data classification technique – classification and regression tree (CART) – is employed for generating rainfall states with the help of large-scale atmospheric variables within a river basin. Reanalysis data are analysed (NCEP/NCAR), and fine-resolution observed rainfall (IMD) is used for bias correction. The relationship is then applied to bias-corrected coarse-resolution GCM outputs to project rainfall in India. Biases in the GCM outputs are corrected using quantile-based mapping techniques.

2.2.4. Hydrological Modelling

Hydrological modelling has been performed using the variable infiltration capacity (VIC) model (Liang et al., 1994). VIC is a mesoscale hydrologic model that calculates moisture and energy balances in a grid-based representation. The grid cells are simulated independently of each other with no exchange of moisture between the grids. The different hydrologic processes in the model are based on physically governing equations. The infiltration in the model is based on the variable infiltration curve (Liang et al., 1994), which decides the division between runoff and infiltration based on soil moisture conditions. The model uses an empirical representation of baseflow based on a non-linear relationship between baseflow and soil moisture. The evapotranspiration in the model is based on the Penman-Monteith equation.

To define surface and sub-surface properties of the grid, VIC relies on soil, vegetation and topographical characteristics. Soil properties such as porosity, bulk density, permeability, soil column depths, etc. are defined for the grids. VIC enables the representing of different vegetation classes in a grid, which are expressed as a fraction of the total area of the grid. Properties of vegetation like leaf area index, canopy height, rooting depths etc. for each vegetation class are represented in the model separately.

We simulated the VIC model on a daily time step in a water balance mode at a spatial resolution of 0.25°. We forced the model with a daily time series of precipitation, maximum temperature, minimum temperature and wind. We used land cover classification data to extract the fractional area of each type of land cover in a grid. Precipitation data, which is available from 1901 to 2015 in a gridded format at a resolution of 0.25°, was obtained from IMD. Temperature and wind datasets were also obtained from IMD for the period from 1979 to 2015 at 0.5° resolution.

The data were interpolated bilinearly onto the IMD rainfall grid. VIC simulations were performed for the period 1979 to 2015.

For estimating the hydrological response in the future, VIC simulations were performed) using the forcing from the three GCMs for the historical period (1986-2015). Subsequently, the VIC model was also run for the period from 2006 to 2099 with the forcing from the three GCMs.

2.2.5. Analysis of Drought

The intensity of summer heatwaves and droughts have increased over the years and are expected to increase further (King & Karoly, 2017; Nangombe et al., 2018; Samaniego et al., 2018; Sun et al., 2014; Trenberth et al., 2014). This makes the analysis of drought important for an arid region such as Rajasthan. Various drought indices have been designed for examining drought extremity. Standard precipitation index (SPI) is the most commonly used indicator worldwide for detecting and characterizing meteorological droughts. Developed by McKee et al. (1993) SPI measures precipitation anomalies at a given location by comparing observed total precipitation amounts for a fixed period (e.g., 1, 3, 12, 48 months) with the long-term historic rainfall record for the same period. The historic record is fitted to a probability distribution (the “gamma” distribution), which is then transformed into a normal distribution such that the mean SPI value for that location and period is zero. For any given region, SPI decreasing below –1.0 indicates increasingly severe rainfall deficits (i.e., meteorological droughts), while SPI increasing above 1 indicates severe rainfall excesses. Because SPI values are in units of standard deviation from the long-term mean, the indicator can be used to compare precipitation anomalies for any geographic location and for any number of time-scales. It must be noted that the name of the indicator is usually modified to include the accumulation period. For example, SPI-3 and SPI-12 refer to accumulation periods of three and twelve months, respectively. The World Meteorological Organization has recommended that the SPI be used by all national meteorological and hydrological services around the world to characterize meteorological droughts The long-term gamma distribution of our product is based on data from 1981 to 2010 (included). The data included in the SPI-48 (4 years SPI) are based on monthly rainfall input data from 1978 until 2010. The SPI values (and corresponding drought intensity) may be classified into three categories:

SPI = < -1 mild drought,

SPI = < -1.5 severe drought,

SPI = < -2 extreme drought

2.2.6. Analysis of Extreme Rainfall

For practical extreme value analysis, block maxima (Gumbel, 1958) series is a preliminary step. In many situations, it is customary and convenient to extract the annual maxima, generating an annual maxima series (AMS). We have utilized the same approach and obtained annual maximum precipitation time series for trend analysis.

2.2.7. Trend Analysis

The Mann-Kendall trend test (sometimes called the MK test) is used to analyse time-series data on consistently increasing or decreasing trends (monotonic trends). It is a non-parametric test, which means it works for all distributions (i.e., data doesn't have to meet the assumption of normality), provided the data do not have serial correlation. A serial correlation in the data can affect the significance level (p-value). We have used the original Mann-Kendall test and set the significance value threshold to 0.05.

2.3. Trends of Observed Data

2.3.1. Seasonal and Extreme Precipitation

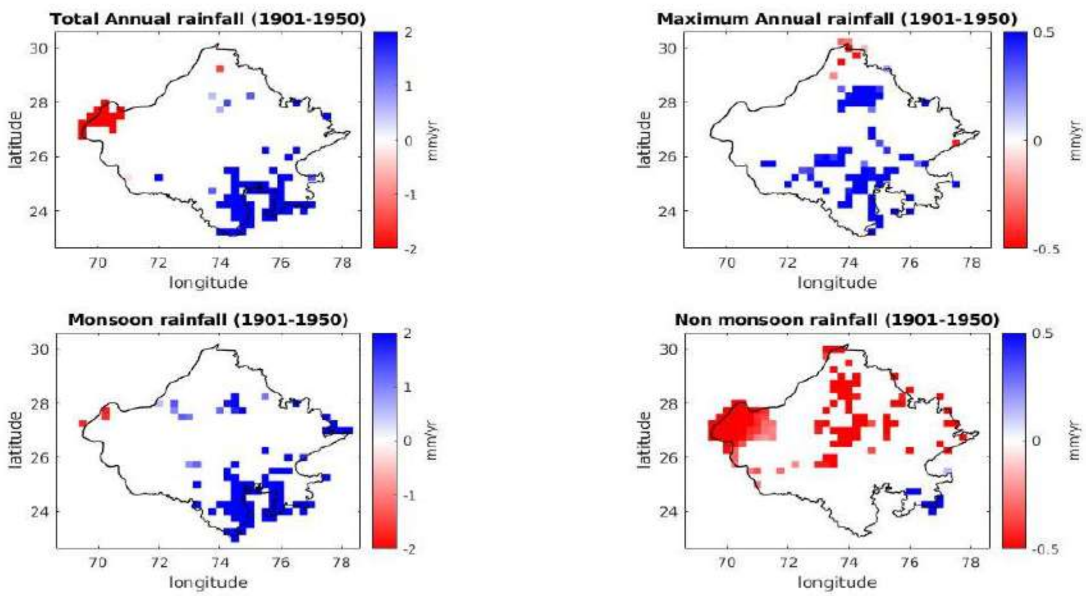


Figure 2.2. Trend in total annual rainfall, annual maximum rainfall, monsoon rainfall and non-monsoon rainfall for period 1901–1950.

The western part of the state shows an increasing trend (2>mm/y) while the south-eastern part shows a positive trend of a similar magnitude (Fig 2.2). A few grids in central Rajasthan show an increase in annual maximum rainfall. The south-eastern part shows a positive trend in monsoon rainfall, which explains the positive trend in total annual rainfall in the same region. Non-monsoon rainfall shows a negative trend in the western part of the state, which explains a similar trend in total annual rainfall in the western part.

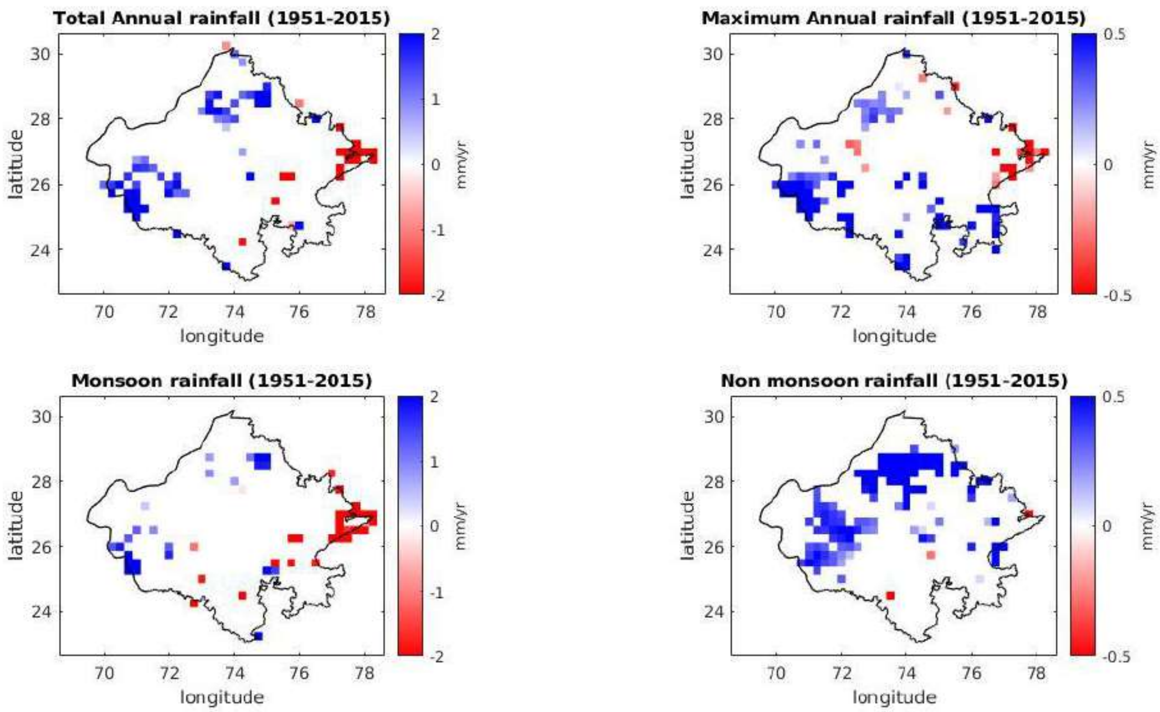


Figure 2.3. Trend in total annual rainfall, annual maximum rainfall, monsoon rainfall and non-monsoon rainfall for period 1951-2015.

The period of 1951-2015 shows positive trends in some grids for total annual rainfall, but no trends are visible in monsoon precipitation (Fig. 2.3). Annual maximum rainfall shows a small positive trend in south-western grids. Non-monsoon rainfall shows a small positive trend in the western and northern part of the state.

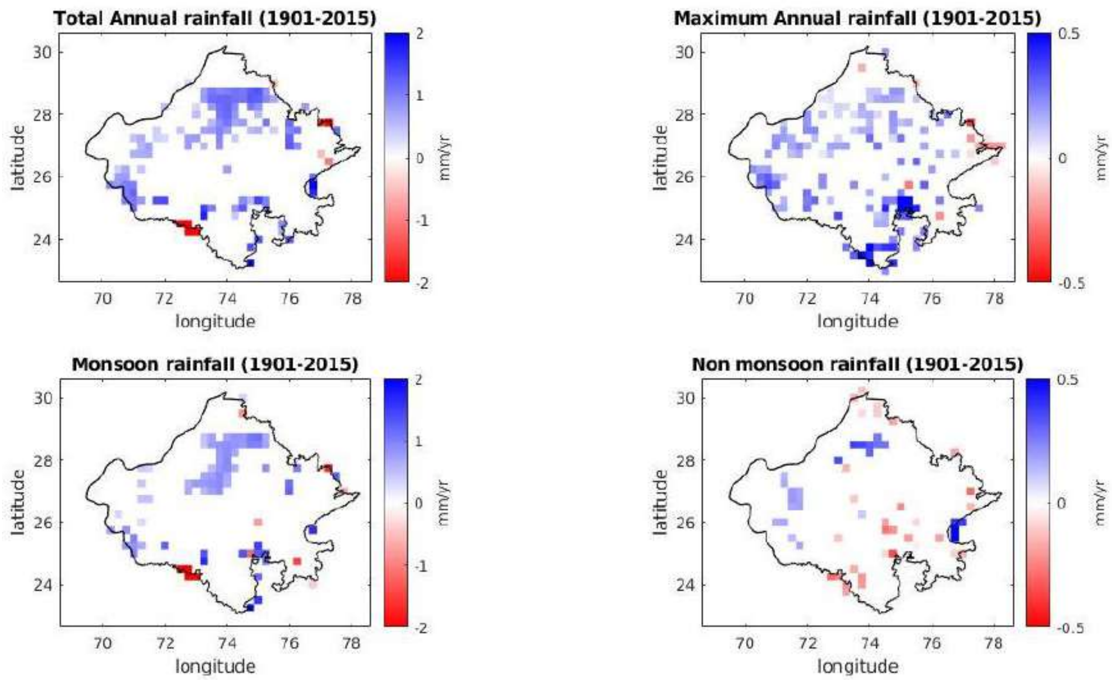


Figure 2.4. Trend in total annual rainfall, annual maximum rainfall, monsoon rainfall and non-monsoon rainfall for period 1901-2015.

The total annual rainfall and monsoon rainfall show positive trends in the northern districts of Rajasthan (Fig. 2.4). The annual maximum rainfall shows a positive trend in several grids spread all over Rajasthan. Most grids do not show any trends for non-monsoon rainfall. The trends were calculated using modified Mann Kendall's method discussed in detail in Methods section.

2.3.2. Ground Water Levels

The principal source of recharge to ground water in Rajasthan is rainfall. In canal-irrigated areas, a part of canal water through seepage from the conveyance system and a part of water utilized for irrigation also returns to ground water and contributes to storage. Systematic and regular monitoring of ground water levels highlights the changes taking place in the groundwater regime.

We here present a trend analysis of ground water level as calculated from observed well water level depth. Mapping trends in ground water level is useful for dealing with problems of water logging and artificial recharge, where the relative position of water level with reference to the ground surface is of critical importance. They help in developing contingency plans, especially in regions that are heavily dependent on ground water and have decreasing levels.

We observe that districts in north-eastern part of the state show a high magnitude decreasing trend, which implies rapid depletion of ground water from the region (Fig. 2.5). The central region shows a slightly decreasing trend, while the other parts show a slightly increasing trend. A check on ground water use is necessary in hotspots of ground water depletion, which are highlighted in dark red colour in Fig. 2.5.

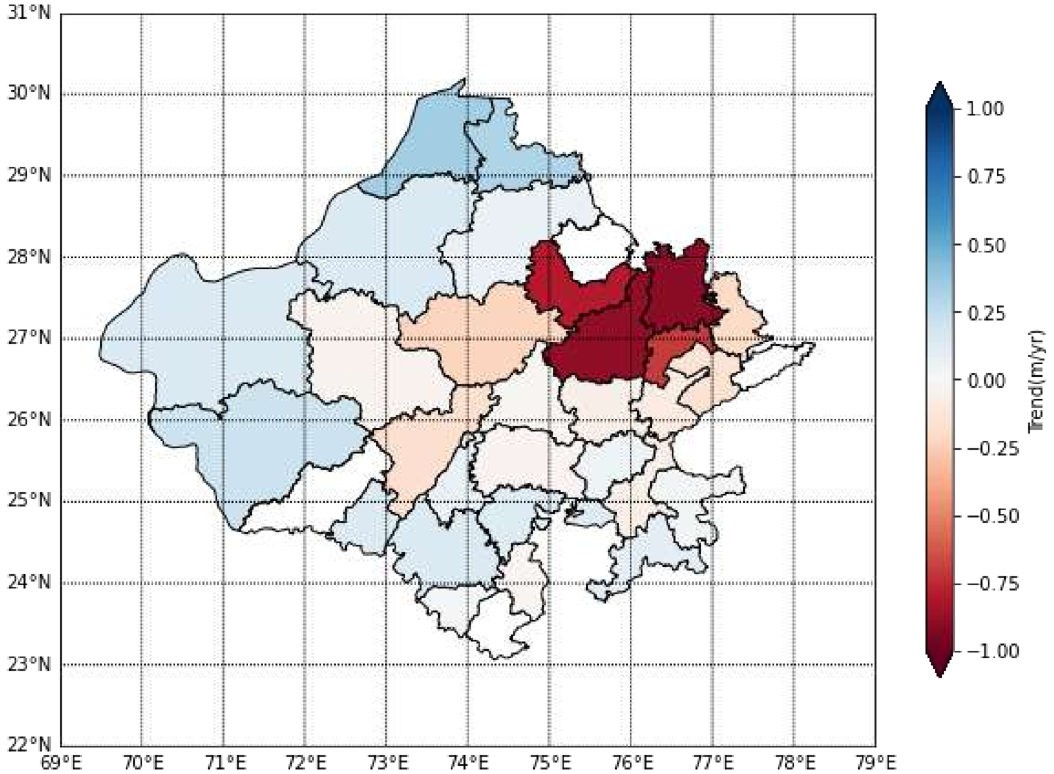


Figure 2.5. Trends in ground water levels for period 1996-2014.

Aquifer mapping needs detailed investigation – a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses are necessary to characterize the quantity, quality and sustainability of ground water in aquifers. Understanding the geologic framework of aquifers, their hydrologic characteristics, the water levels in the aquifers and the occurrence of contaminants in Rajasthan is a time-consuming task, and a detailed investigation of aquifers by a team comprising multidisciplinary experts from the fields of hydrology, geology and chemistry is highly recommended.

2.3.3. Simulated Hydrological Variables

Figure 2.6 shows the analysed mean annual evaporation for the state. The south-eastern part of the state shows a high rate of evaporation, and the north-western part has the lowest rate. Evaporation is higher in the eastern part of the state because of more precipitation and more soil moisture.

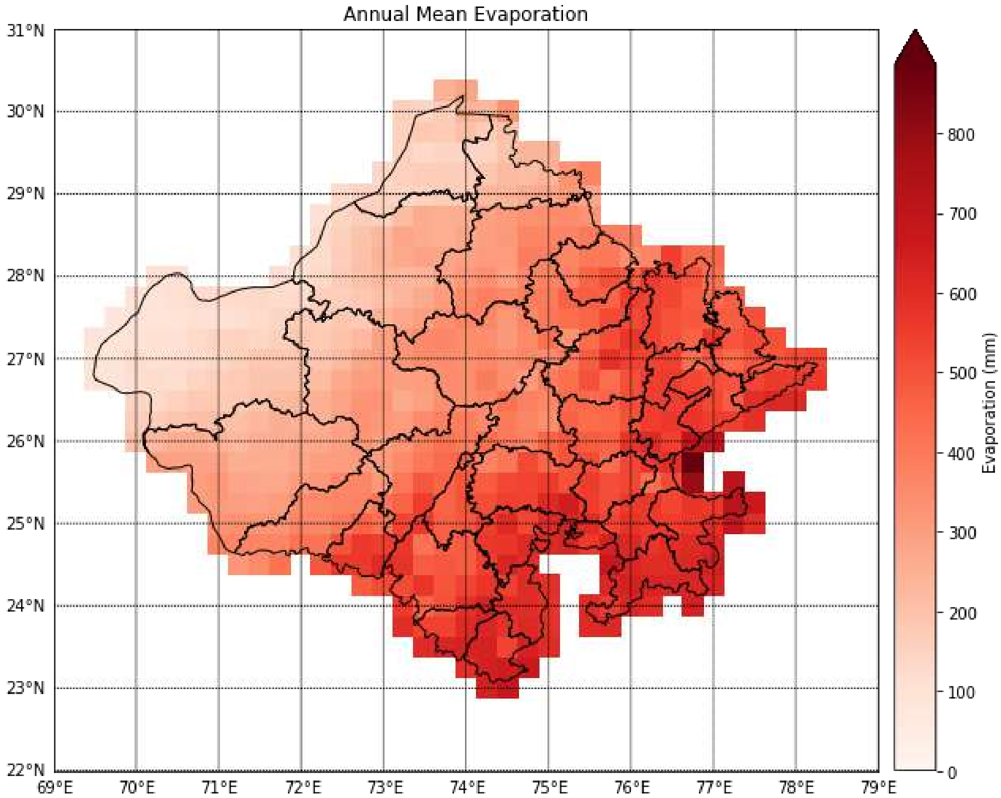


Figure 2.6. Mean annual evaporation.

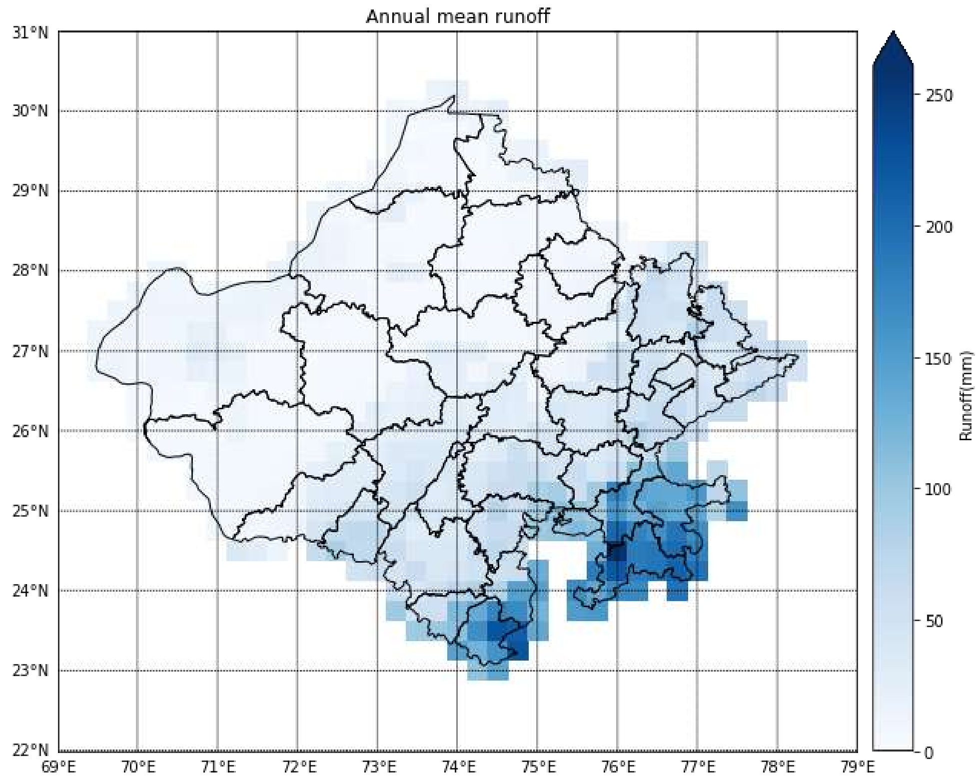


Figure 2.7. Mean annual runoff.

The runoff in the south-eastern part of the state is highest, ranging from 200-250 mm (Fig. 2.7). The western part shows very less runoff (less than 50 mm). There is a clear east-west separation between the soil moisture for the state (Figure). We speculate that, in addition to rainfall pattern, the soil texture also plays a role in this.

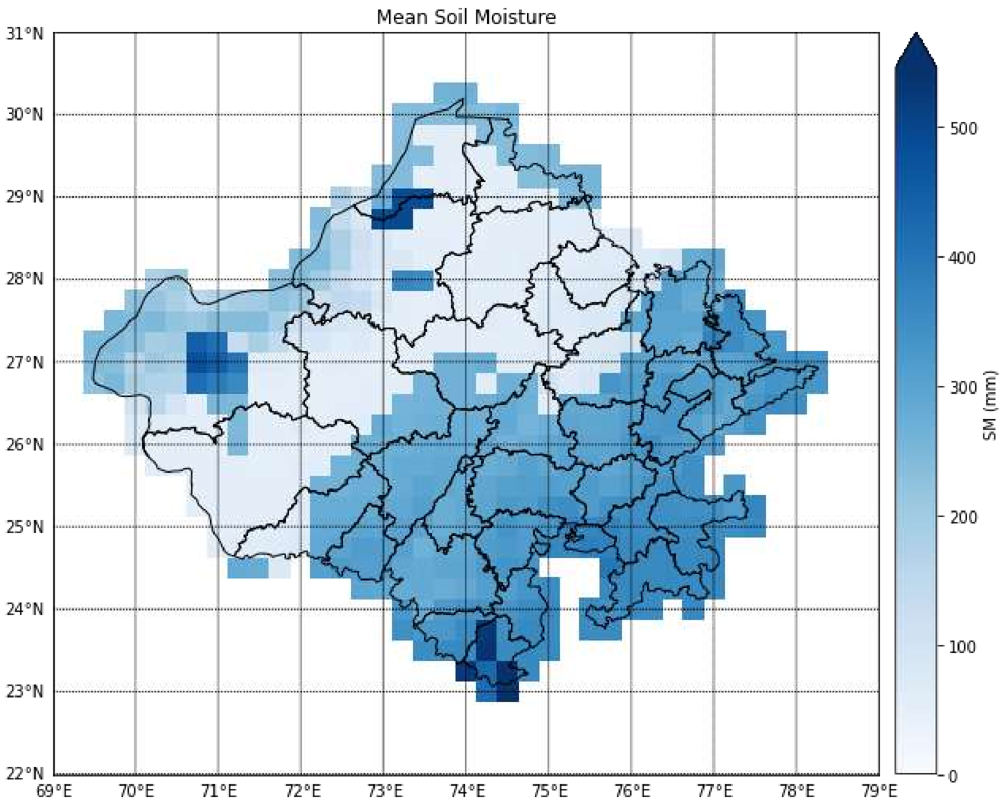


Figure 2.8. Mean soil moisture.

This analysis shows that the south-eastern part of Rajasthan has ample water resources due good precipitation received annually. Further, higher levels soil moisture suggests good potential for agriculture in this part of Rajasthan.

2.3.4. Water Demand and Availability

2.3.4.1. Water use

Water demand in the state can be divided into following categories:

1. Domestic
2. Livestock
3. Institutional
4. Fire-fighting
5. Irrigation
6. Power station cooling

We plotted the annual water use of the state in Fig. 2.9. The demand was calculated as a summation of irrigation, livestock, institutional, industrial and domestic water demand.

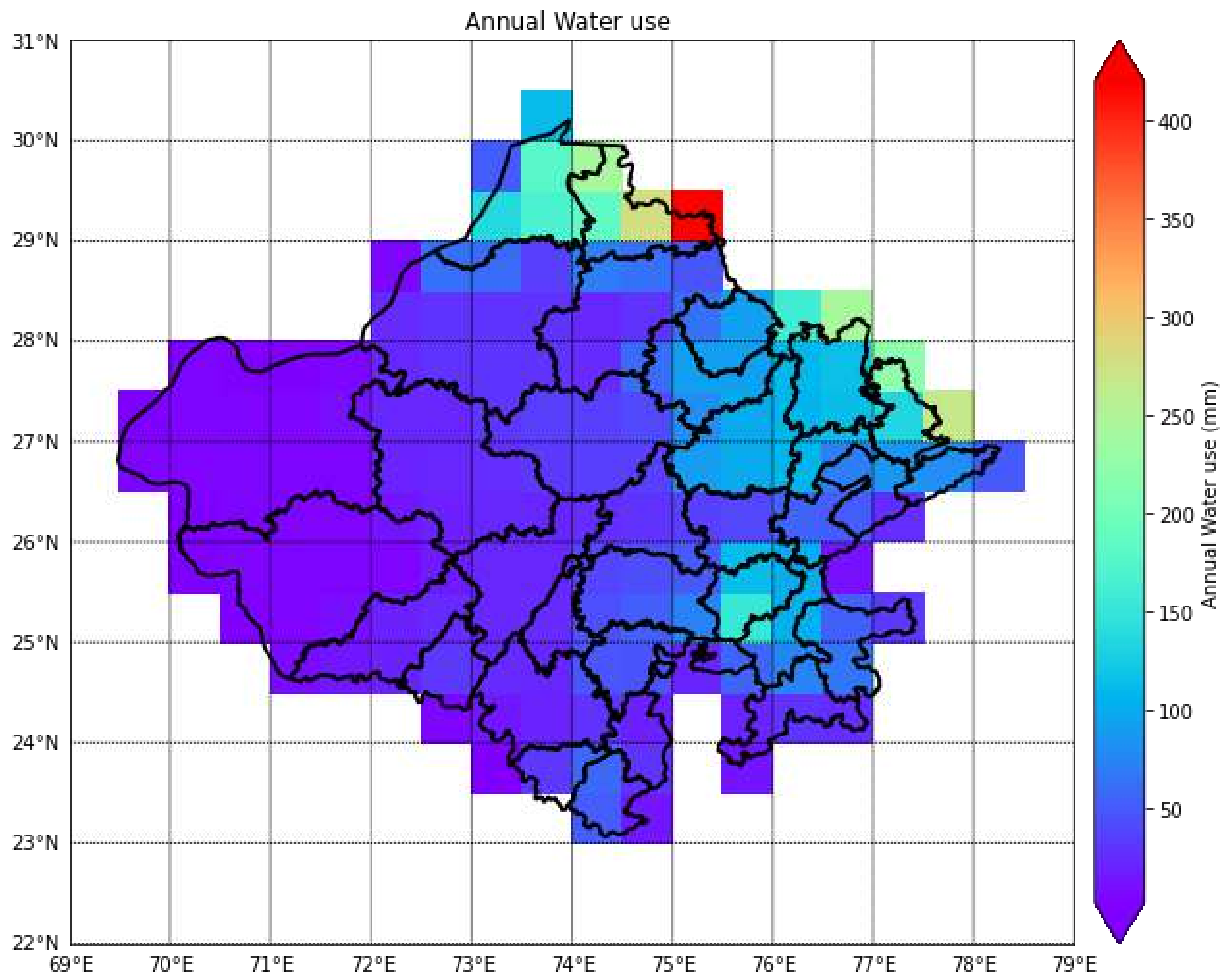


Figure 2.9. Annual water use for Rajasthan.

2.3.4.2. Water availability (from VIC simulations)

Precipitation minus potential evapotranspiration (P-PET) is an important factor for assessing moisture condition and hence water availability in a region. Precipitation and evapotranspiration are often unequal. Sometimes evapotranspiration exceeds precipitation in an area through a year or vice versa. The magnitude and distribution of both precipitation and evapotranspiration differ temporally as well as spatially. This is because of the spread of vegetation, latitudinal location or even the geomorphology of a region. Fig. 2.10 shows very low values of P-PET in the western arid region of the state while the south-eastern part shows negative values of a lesser magnitude.

The state transitions from a region with extremely low water availability in the west to one with mildly low water availability in the east. The western region shows P-PET values as low as -2500 mm annually, whereas the south-eastern region shows high values. This suggests that the western part of region is extremely arid, and water resources are limited.

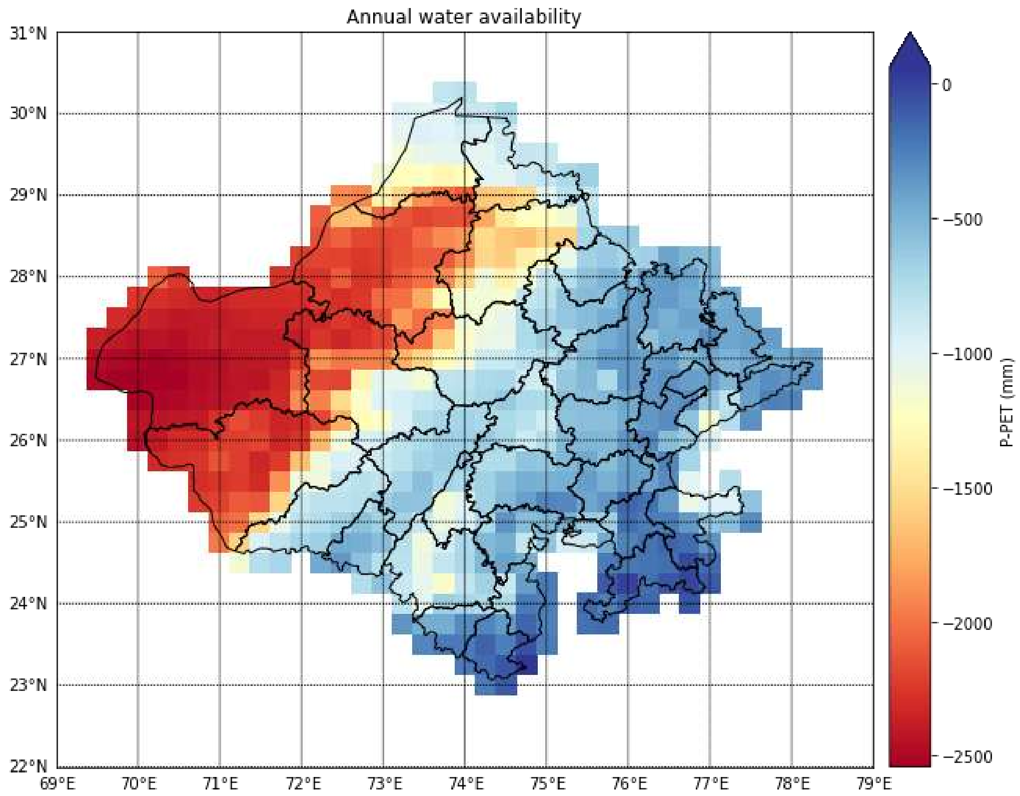


Figure 2.10. Annual water availability (P-PET) as calculated from VIC model simulations for period from 1985 to 2005.

2.3.5. Drought

Drought is the result of prolonged dry weather and/or insufficiency of rain, which causes exhaustion of soil moisture, depletion of underground water supply and reduction of stream flow. Drought is frequently defined in accordance with the literature. There are four types of droughts, namely, (i) meteorological drought, (ii) surface water drought, (iii) ground water drought and (iv) soil-water drought.

We calculated the percentage of drought months in the above four categories, and we plotted the change from the period 1901-1951 to 1951-2015 (Fig. 2.11). Data show an increase in number of months that fall in the mild drought category. There has also been an increase in the number of severe and extreme droughts, but it is not as high as the mild droughts.

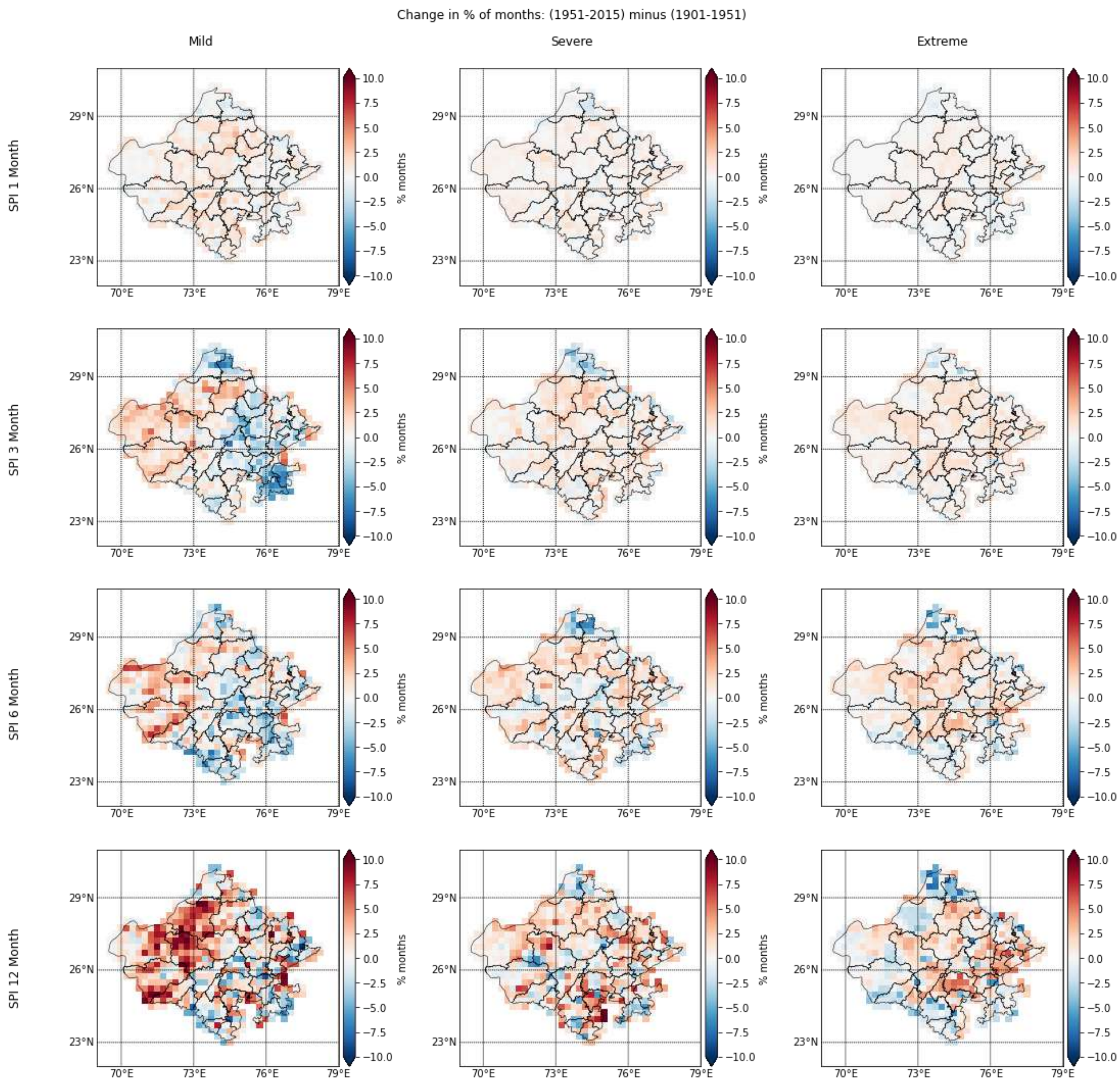


Figure 2.11. Change in percentage number of months for the period 1951-2015 with respect to the period 1901-1950. The rows show SPI 1 month, SPI 3 month, SPI 6 month and SPI 12 month, while the columns show severity of droughts: mild, severe and extreme.

2.4. Future Projections

2.4.1. Change in Precipitation

Analysing change in precipitation is important for determining future water availability. Here, we have analysed change in total annual precipitation, annual maximum precipitation, monsoon precipitation and non-monsoon precipitation. We have used three GCMs and two representative concentration pathways (RCP) viz. RCP 4.5 and RCP 8.5. We have plotted the mean change from the three GCMs between three future periods with respect to the historical period.

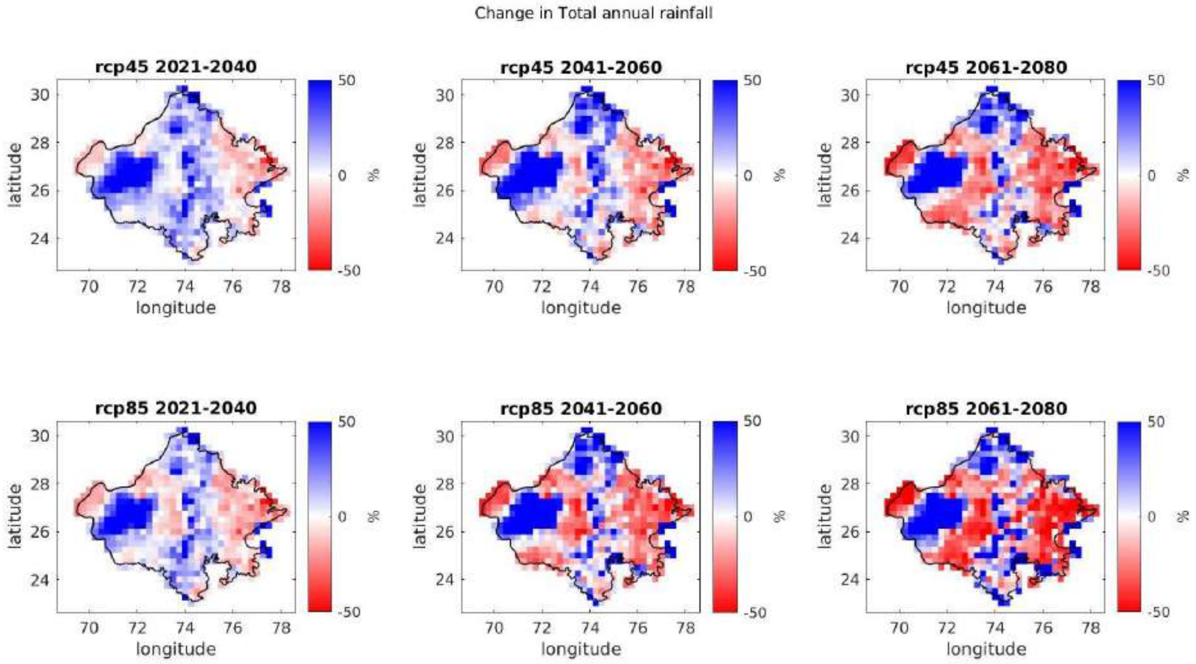


Figure 2.12. Multi-model mean of percentage change in total annual precipitation in RCP 4.5 and RCP8.5 for the three periods (2021-2040, 2041-2060 and 2061-2080) with respect to the historical period (1986-2005).

Trends predict an increase in total precipitation in the western and northern parts of Rajasthan. This increase in precipitation remains unchanged from the early part of the century to the later part of the century. However, the rest of Rajasthan shows decreasing precipitation levels with time (Fig. 2.12). By the end of century, in both RCP 4.5 and RCP 8.5 scenarios, similar patterns of changes can be seen in Rajasthan, with the magnitudes of decrease being slightly higher in RCP 8.5 scenarios.

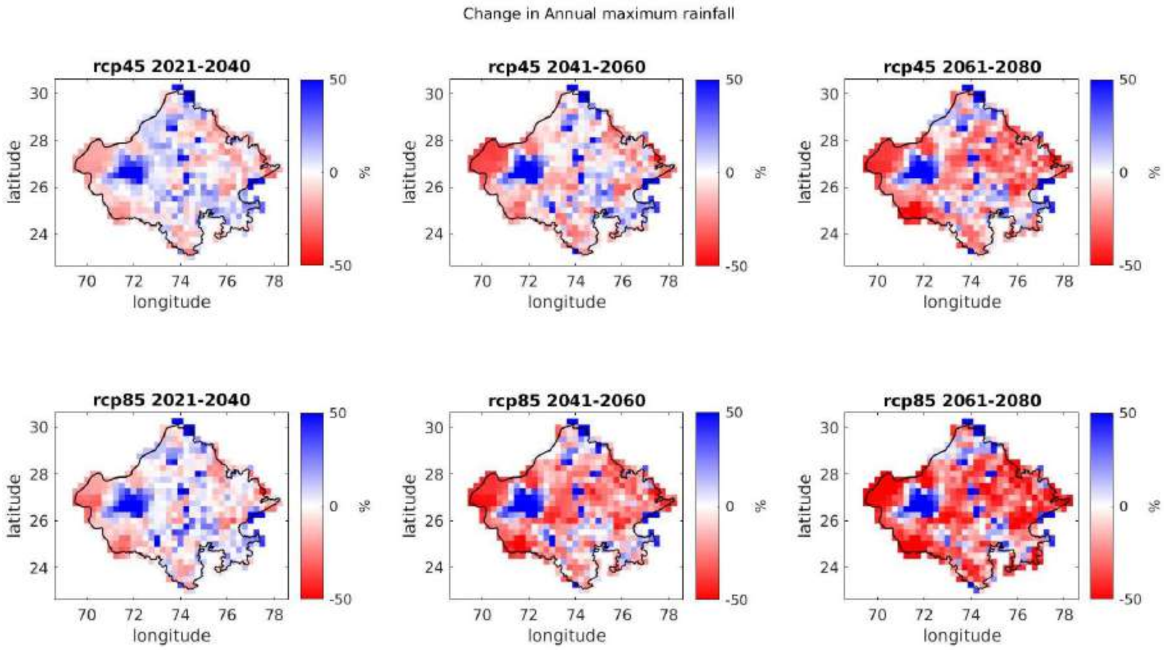


Figure 2.13. Multi-model mean of percentage change in maximum annual precipitation in RCP 4.5 and RCP 8.5 for the three periods (2021-2040, 2041-2060 and 2061-2080) with respect to the historical period (1986-2005).

In the early part of century, both RCP scenarios show an increase in annual maximum precipitation in a small patch in western Rajasthan. As we move towards the middle and end of the century the increase remains the same in the small patch, while other parts of Rajasthan show a decrease with higher increases in the later part of century (Fig. 2.13).

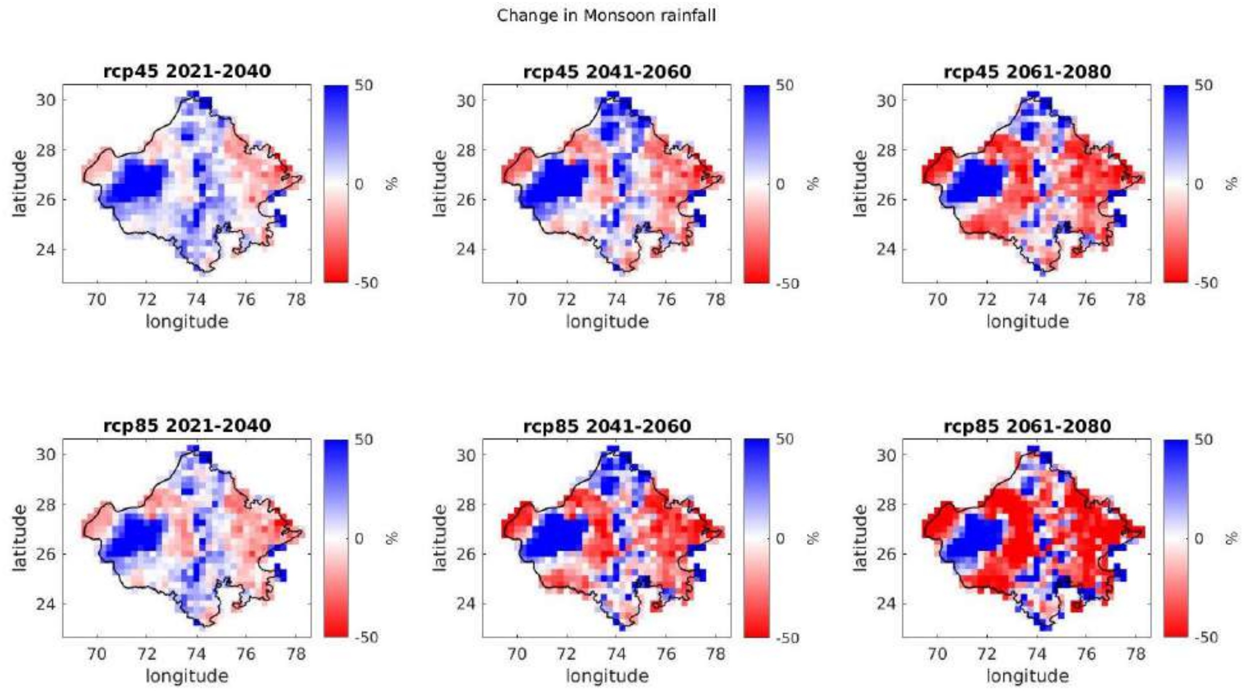


Figure 2.14. Multi-model mean of percentage change in monsoon precipitation in RCP 4.5 and RCP8.5 for the three periods (2021-2040, 2041-2060 and 2061-2080) with respect to the historical period (1986-2005).

The changes in monsoon precipitation are quite similar to the total monsoon precipitation because of the high contribution of monsoon rainfall to total precipitation in Rajasthan (Fig. 2.14). Non-monsoon precipitation shows an increase in precipitation under both the scenarios as we move towards the end of the century (Fig. 2.15).

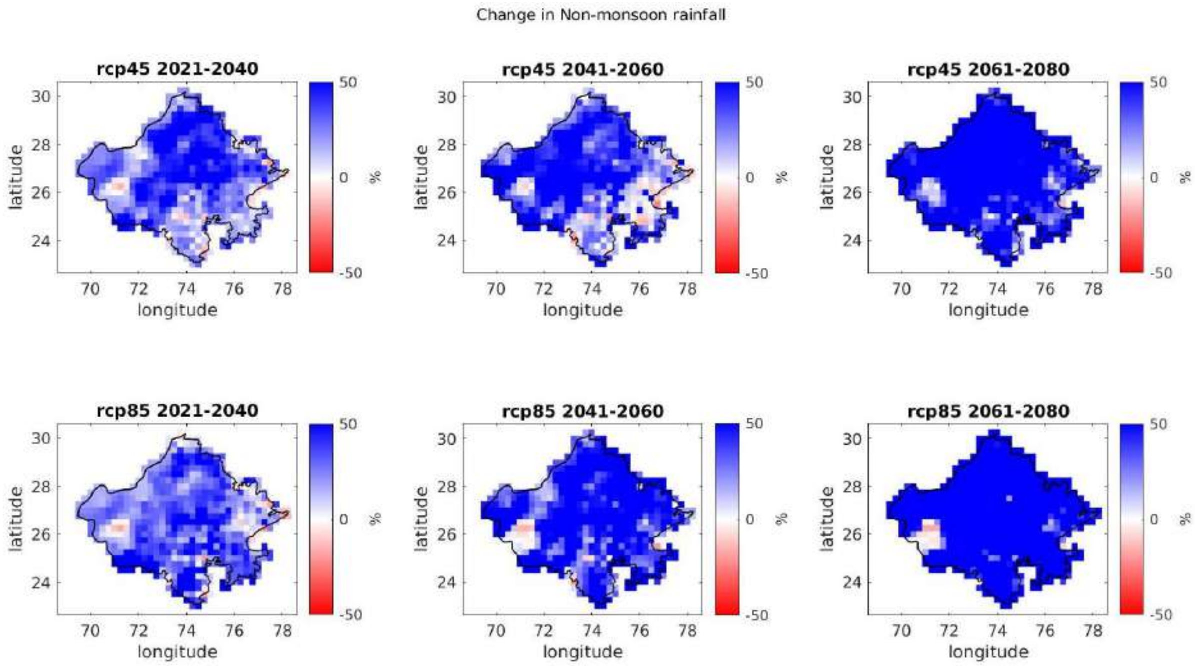


Figure 2.15. Multi-model mean of percentage change in non-monsoon precipitation in RCP 4.5 and RCP 8.5 for the three periods (2021-2040, 2041-2060 and 2061-2080) with respect to the historical period (1986-2005).

2.4.2. Changes in Drought

As discussed earlier, an increase has been observed in the number of drought months during the previous century, and a similar trend is expected for the future.

For mild droughts during 2021-2040 in both RCP scenarios, some grids show an increase while others show a decrease for SPI-1 and SPI-3. However, for SPI-6 and SPI-12, more number of grids show a decrease, and the magnitude is higher than SPI-1 and SPI-3 (Fig. 2.16; Fig. 2.17). The number of severe or extreme droughts change in similar pattern, but the magnitude is less in severe droughts and even lesser in extreme droughts.

For the period 2041-2060 in both scenarios, the change is less (<+-2%) from the historical period for all severities of droughts except for mild droughts in SPI-6 and SPI-12, which show higher magnitudes (Fig. 2.18; Fig. 2.19). For the period 2061-2080, droughts of almost all severities and durations show an increase in number (Fig. 2.20; Fig.2.21). The increase in the number of months is highest for mild droughts, and the magnitude decreases with an increase in severity. Surprisingly, RCP 4.5 shows a higher increase in the number of drought months when compared with RCP 8.5 (Fig. 2.20; Fig. 2.21).

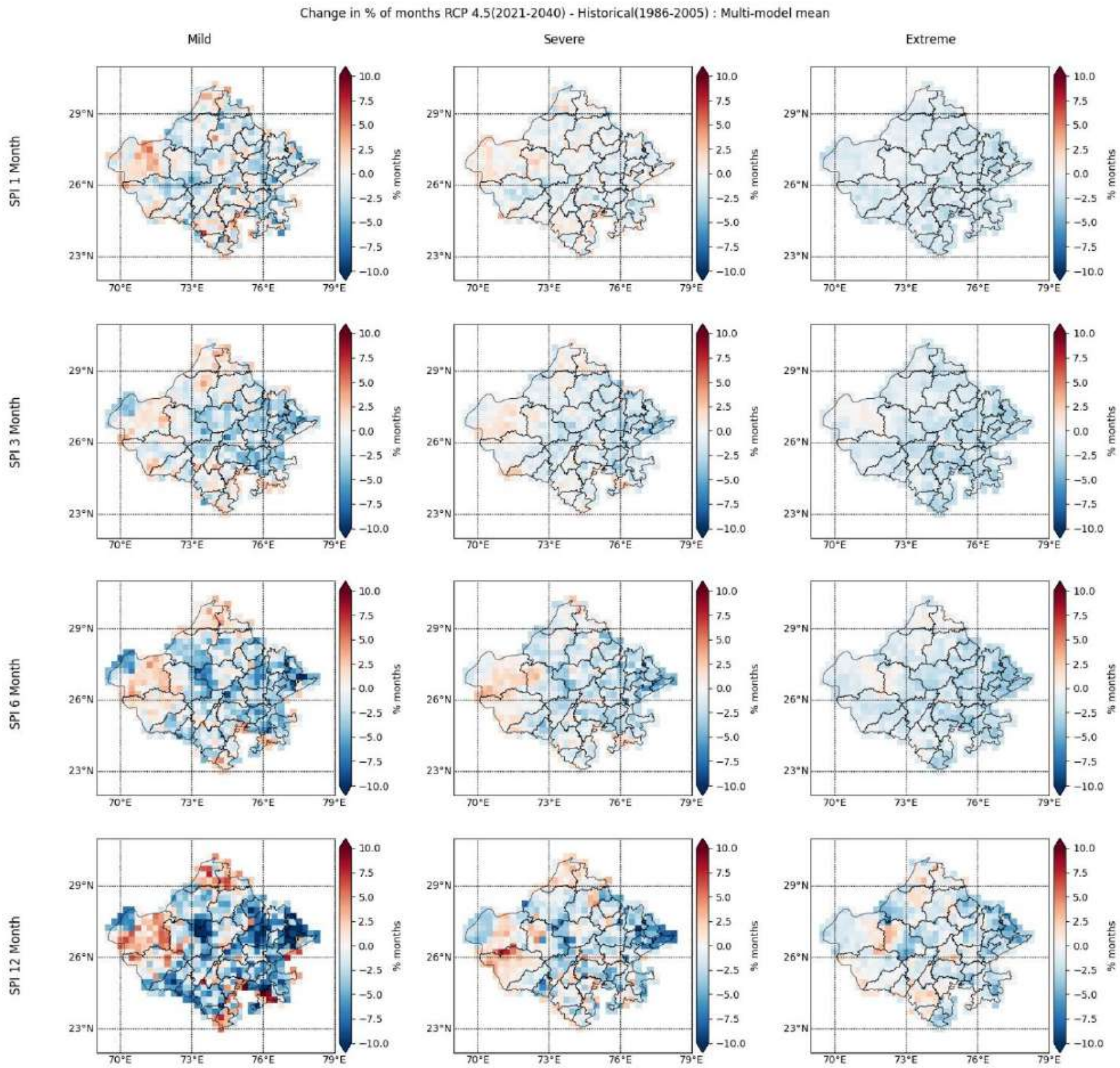


Figure 2.16. Multi-model mean of change in percentage number of months for RCP 4.5 for the period 2021-2040 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6 and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

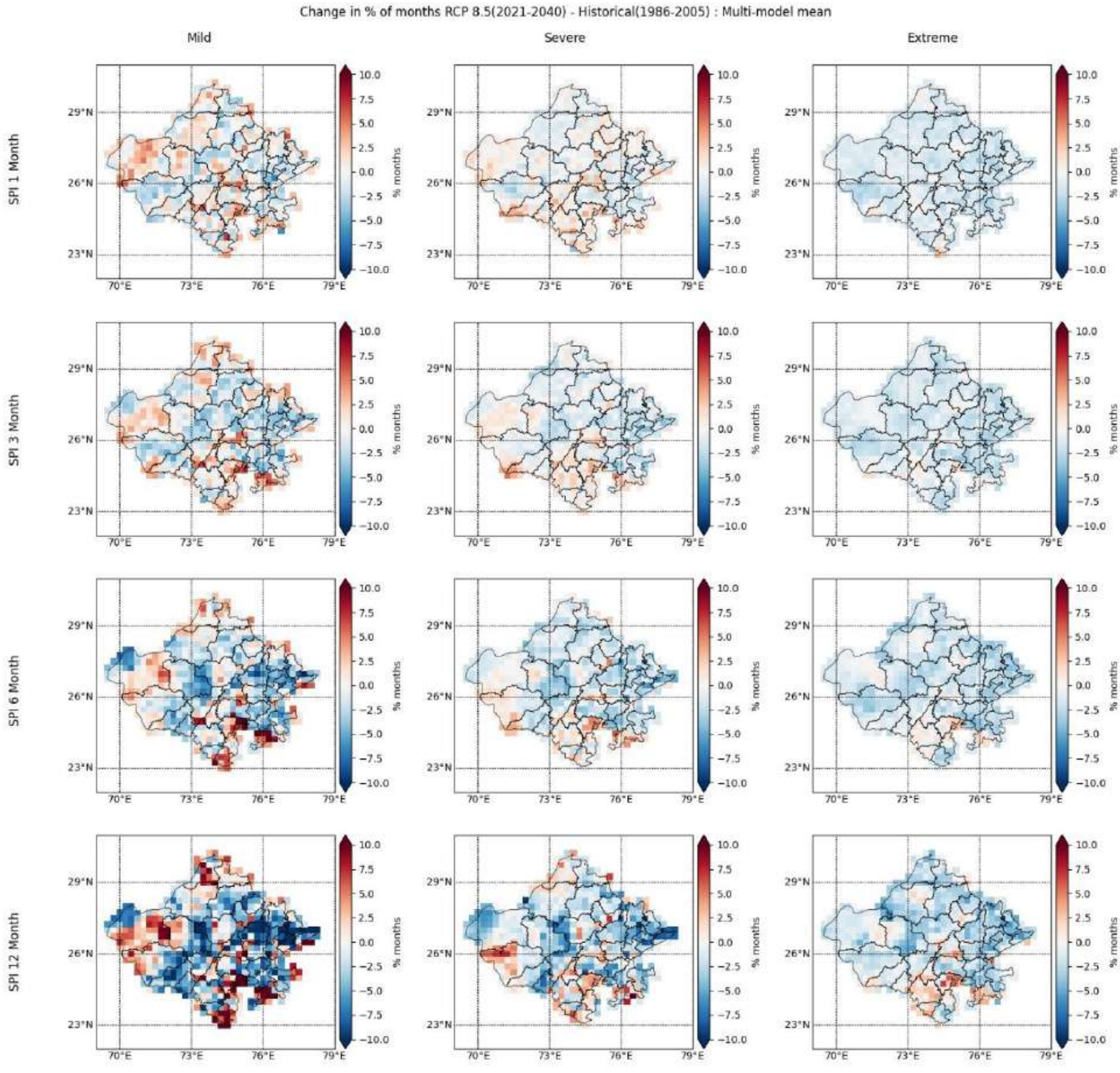


Figure 2.17. Multi-model mean of change in percentage number of months for RCP8.5 for the period 2021-2040 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6 and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

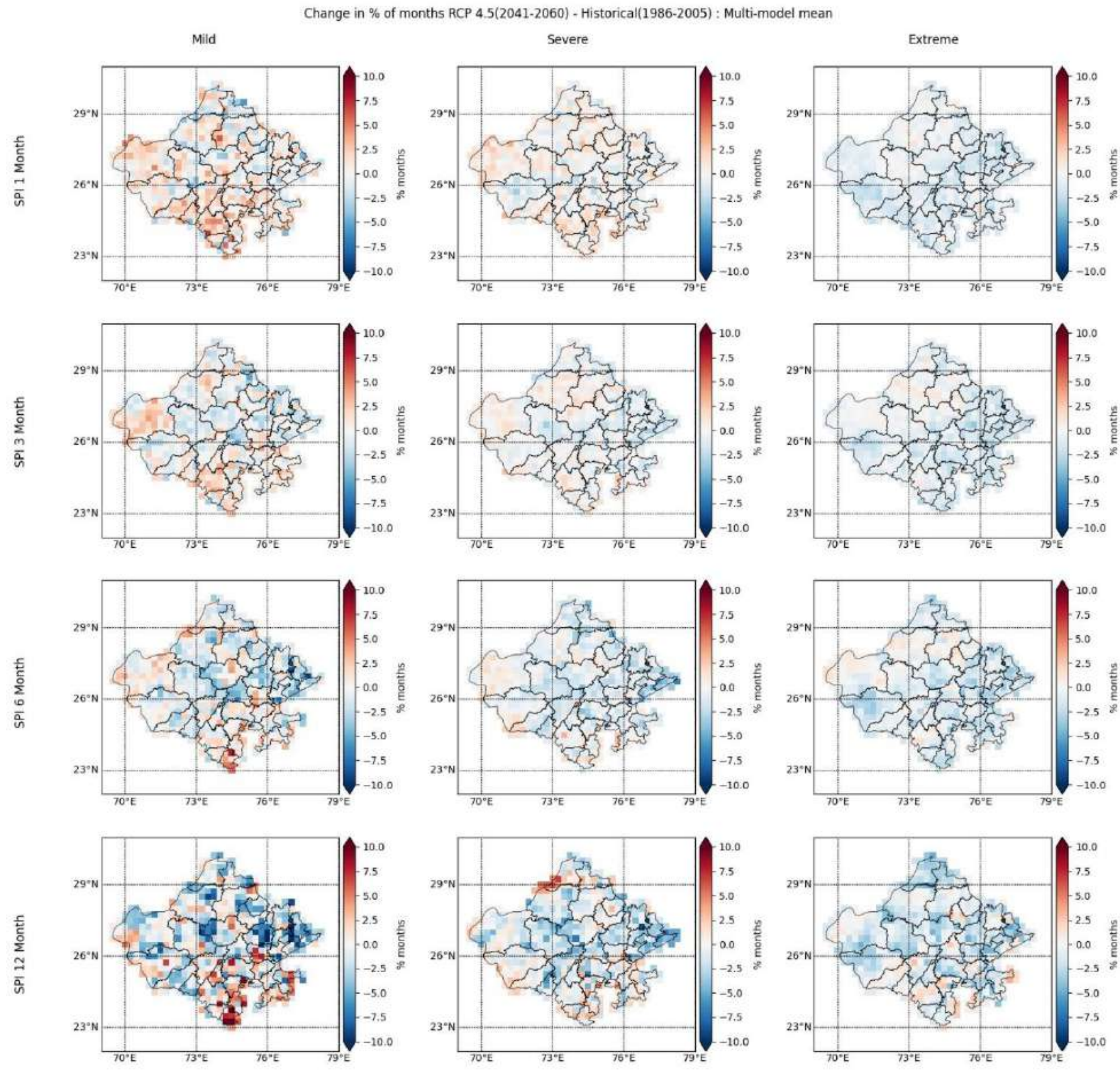


Figure 2.18. Multi-model mean of change in percentage number of months for RCP4.5 for the period 2041-2060 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6 and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

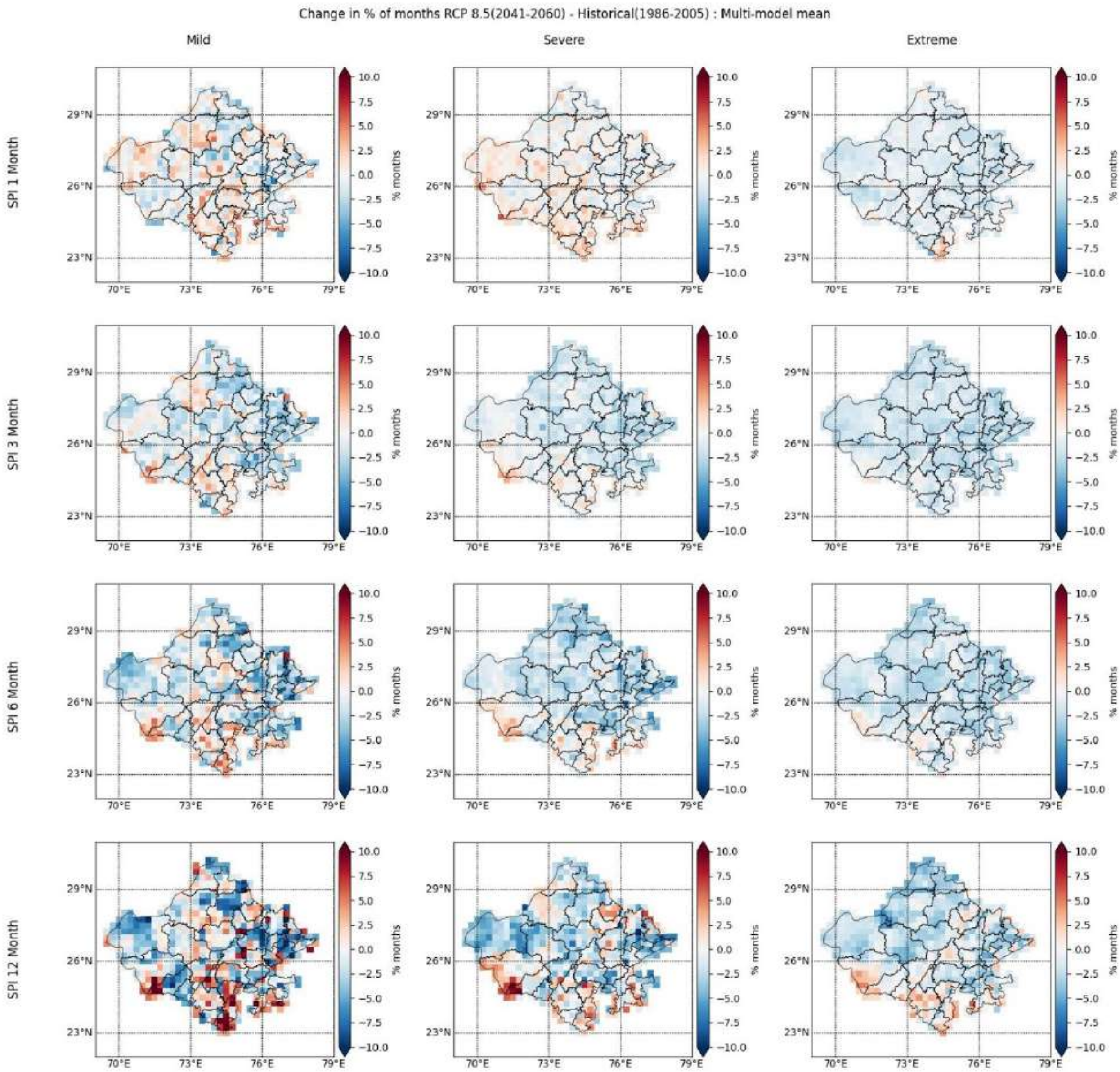


Figure 2.19. Multi-model mean of change in percentage number of months for RCP 8.5 for the period 2041-2060 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6, and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

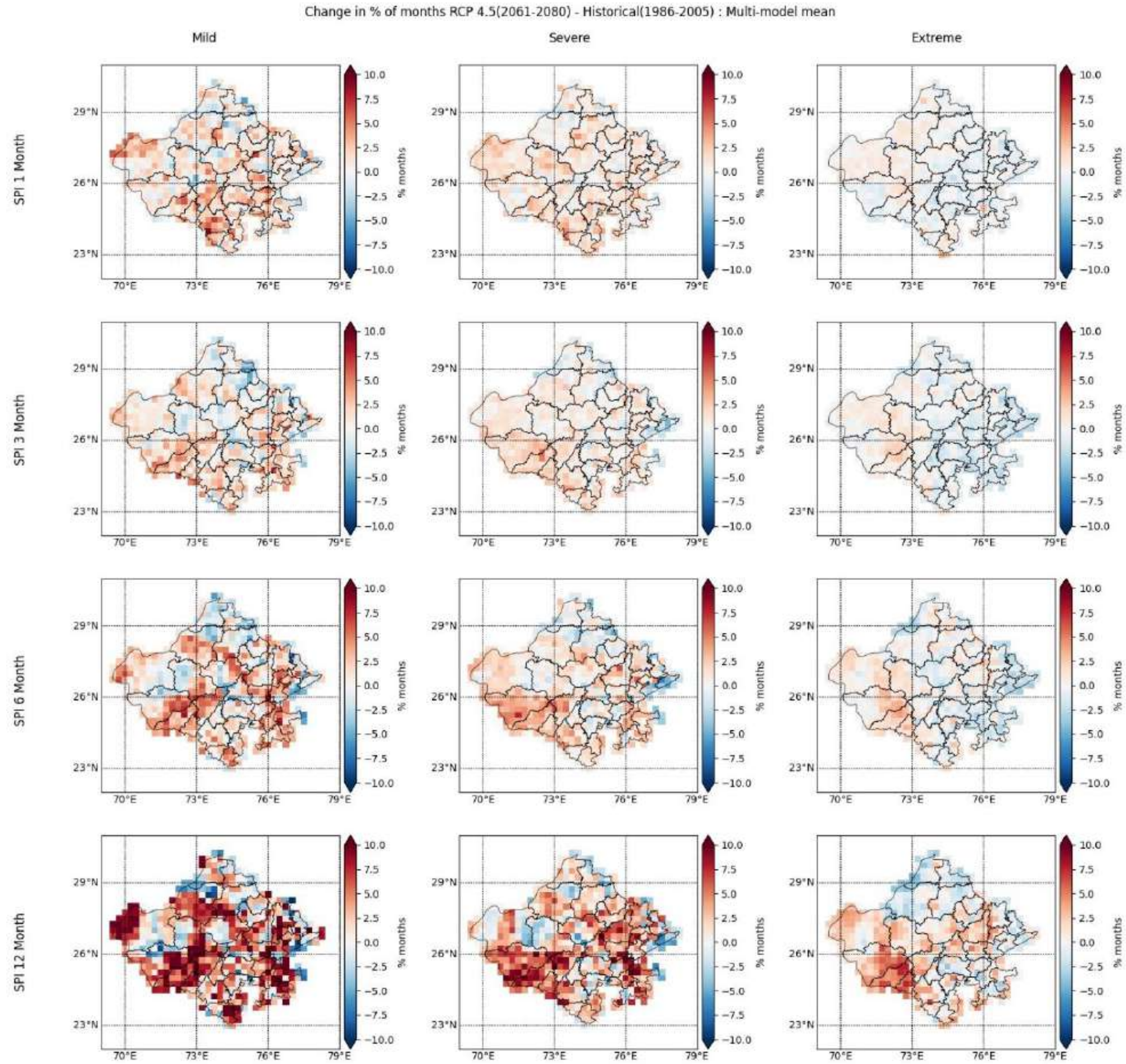


Figure 2.20. Multi-model mean of change in percentage number of months for RCP 4.5 for the period 2061-2080 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6 and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

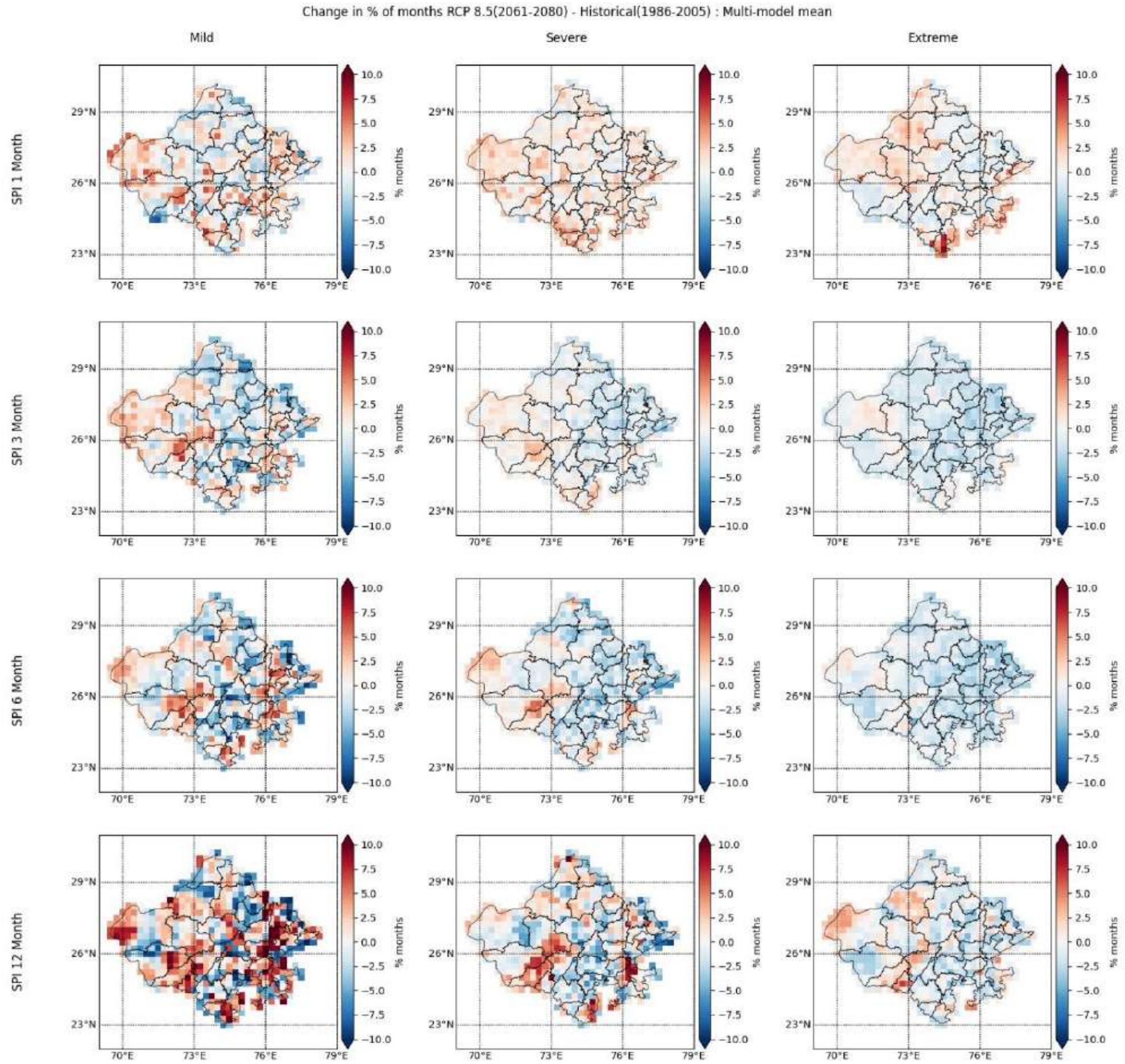


Figure 2.21. Multi-model mean of change in percentage number of months for RCP 8.5 for the period 2061-2080 with respect to the historical period (1986-2005). The rows show data for SPI-1, SPI-3, SPI-6 and SPI-12, while the columns show severity of droughts: mild, severe and extreme.

The drought analysis shows an increase in drought months for several grids across Rajasthan. The increase in number of months is higher for mild droughts followed by severe and then by extreme droughts. When we consider droughts of different durations, long-term droughts show the greatest increase in percentage number of months, which suggests that certain regions of Rajasthan might face an increased number of long-duration droughts.

2.4.3. Changes in Water Availability P-PET

To analyse future water availability, we compared future P-PET with historical data. First, we derived P-PET for the historical period from VIC simulations using forcing from observed data and GCM outputs. Then, we performed VIC simulations for the future period and analysed the change between future and historical simulations.

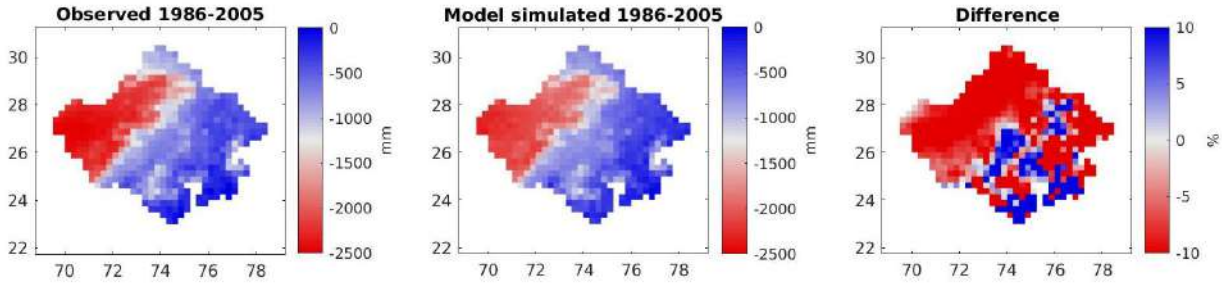


Figure 2.22. Comparison of water availability during 1986-2005 between observed data and multi-model mean of historical simulation from the three GCMs.

We find that the P-PET from the observed forcing simulations and the GCM-forced simulations are in good agreement and deviations range between ±10% (Figure 2.). For the future period, both scenarios and the three periods show an increase in water availability in the south-eastern part of the state (Figure 2. 2.23).

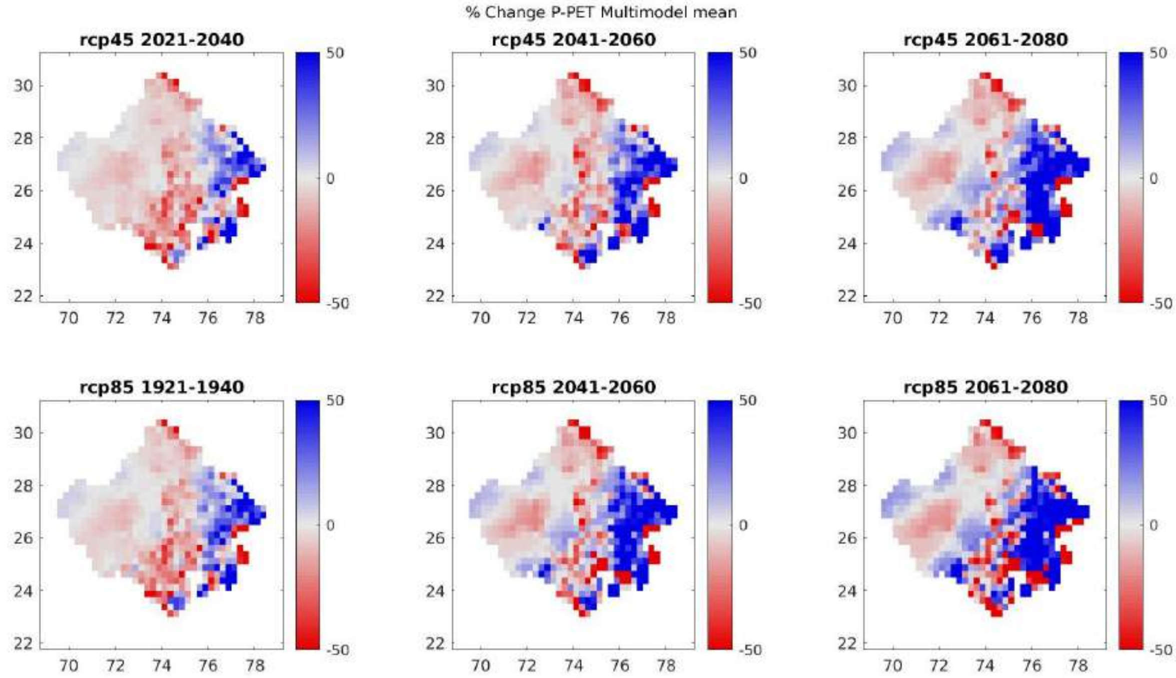


Figure 2.23. Multi-model mean of percentage change in water availability (P-PET) in RCP 4.5 and RCP 8.5 for the three periods (2021-2040, 2041-2060 and 2061-2080) with respect to the historical period (1986-2005).

2.5. Summary

We analysed trends in precipitation patterns from the observed data. The total annual rainfall and monsoon rainfall show some positive trends in the northern districts of Rajasthan from 1901-2015. The annual maximum rainfall also shows a positive trend in several grids spread all over Rajasthan. We then analysed changes in ground water levels from the observed ground water level data. We found that districts in the north-eastern part of the state show a high magnitude decreasing trend, which implies rapid ground water depletion from the region. An arid region such as Rajasthan is highly susceptible to droughts. We analysed the changes in droughts of different severity and found that, for the observed period, there has been an increase in the number of months that fall in the mild, severe and extreme drought categories, but the increase in severe and extreme droughts is not as high as that for the mild droughts.

We also extended our analysis to the future. We found that there is an increase in total precipitation in the western and northern parts of Rajasthan. This increase in precipitation remains same as we move from the early part of century to the latter part century, but the rest of Rajasthan shows a decreasing trend in precipitation with time. Our drought analysis shows an increase in some grids of mild droughts during 2021-2040 under both RCP scenarios, while other grids show a decrease for SPI-1 and SPI-3, and a decrease with a higher magnitude for SPI-6 and SPI-12. The change pattern in the number of severe or extreme droughts is similar, but the magnitude is less in severe droughts and even lesser in extreme droughts. We also evaluated changes in water availability in the future. We found that both RCP 4.5 and RCP 8.5 scenarios show an increase in water availability in the south-eastern part of the state.

2.6. Recommendations

We recommend rainwater harvesting and making rooftop rainwater harvesting compulsory in new and existing buildings whose area exceeds a certain threshold to reduce stress on ground water resource. We also recommend rainwater harvesting via ponds on farming fields which would recharge the Ground Water resource and also meet farmers' irrigation requirements. Generating location maps and a spatial database of rainwater harvesting structures and artificial storage structures across the state is also recommended. Peer-reviewed scientific investigations and detailed field investigations are required to assess the feasibility and cost effectiveness of innovative rainwater harvesting techniques. Such scientific literature is missing for Rajasthan.

We also recommend recharge of underground aquifers through artificial recharge methods (such as percolation tank, recharge well, etc) and the creation of green areas in urban regions through the use of paving materials that facilitate ground water infiltration. Centralization of groundwater extraction is also recommended to ensure judicious and regulated distribution of groundwater resources. Water tax and metering of water usage should be implemented on irrigation water use for farmers with large land parcels in order to reduce water wastage. We do not recommend rooftop installation of solar photo voltaic (SPV) for ground water extraction or pumping from storage. This is because costless methods of groundwater pumping without any regulation can lead to overexploitation of groundwater resources. This would not amount to a judicious use of limited groundwater resources in Rajasthan.

Using more efficient methods of irrigation, such as drip irrigation, and avoiding flood irrigation are very effective practices and should be implemented in all districts of the state. In addition, reducing the area under water-intensive crops can also help in water management and should be extended to all districts of Rajasthan. Before implementing new techniques, their feasibility in the region should be assessed.

Detailed field investigations should be undertaken for determining innovative methods for hydropower generation and estimating the hydroelectric potential of different sites in Rajasthan. Moreover, Rajasthan’s huge potential for generating solar power and devising solar technologies should be harnessed on a large scale. The state should also explore other renewable sources of energy such as wind energy.

Chapter 3

Socio-economic Vulnerability

3.1. Introduction

Climate change can disrupt the socio-economic fabric of a region, which may already be reeling from diverse issues such as unemployment, discrimination, poverty, corruption and illiteracy. The impacts of climate change are not constant and vary between groups of people. Some social groups are more sensitive to climate change than others due to their inability to cope, adapt and recover (Cutter & Finch, 2008). For example, people living in densely packed slum areas are more vulnerable to climate change-induced hazards such as floods and cyclones than those who live in wealthy neighbourhoods with proper drainage systems and other infrastructure. Therefore, characteristics such as high poverty, high unemployment rates and ageing populations suggest greater sensitivity and weaker ability to adapt to climate change.

Vulnerability is defined as the *propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt* (IPCC, 2014). United Nations (2004) broadly classified vulnerability to natural hazards induced by climate change into physical, social, economic and environmental. Social vulnerability is defined as the susceptibility of social groups to hazard impacts or their ability to recover from them (Boruff et al., 2005). Social vulnerability is influenced by a variety of factors that make the people of a community more vulnerable than others, and it focuses not only on the characteristics of an individual but also their relationship with society. Economic vulnerability is defined as the exposure to income and wealth (Briguglio, 1995). The factors that influence socio-economic vulnerability include age, gender, class, race, family structure, income, savings, education, employment, nationality, built environment, infrastructure, population growth, medical facilities and other basic services.

For better decision making, it is essential to know which group of people are more vulnerable to climate change than others. Assessing socio-economic vulnerability to climate change requires the identification of indicators that can measure the state of socio-economic conditions of a system. A socio-economic vulnerability index (SEVI) is developed by aggregating select indicators. This study aims to assess the socio-economic vulnerability of the districts of Rajasthan and propose measures to reduce it. We will also analyse if there is any spatial clustering of districts based on socio-economic vulnerability. Furthermore, we rank the districts of Rajasthan according to socio-economic vulnerability. For this study, we use principal component analysis (PCA), a widely used method in vulnerability assessment studies to reduce dimensions, obtain indicator weights and compute the index.

The structure of this chapter is as follows. Section 2 briefly discusses the socio-economic profile of the state of Rajasthan. Section 3 briefly describes the selected indicators and the methodology adopted. Section 4 discusses the study results, and finally, section 5 presents our conclusions.

3.2. Socio-economic Profile of Rajasthan

The largest state in the country, Rajasthan occupies 10.4% of India's geographical area but is home to only 5.66% (an increase from 5.49% in 2001) of India's total population as per the 2011 census. Hence, the state is sparsely populated; it had an overall density of only 200 persons per km^2 in 2011 (an increase from 165 persons per km^2 in 2001) compared to the national average of 382 km^2. However, the population density in the state varies widely from as low as 13 persons per km^2 in Jaisalmer district to as high as 471 persons per km^2 in Jaipur district. The high variation in density is due to the presence of the large, inhospitable Thar Desert.

The state is predominantly rural, with nearly 75.13% of the population living in rural areas as per the 2011 census. But due to urbanization, the urban population has increased from 23.39% in 2001 to 24.87% in 2011. Traditionally, the state has been regarded as "backward" and was included in the BIMARU list, along with the states of Bihar, Madhya Pradesh and Uttar Pradesh, for its poor economic conditions. However, recent initiatives and steps taken by the government with the support of the private sector have started to break this old adage. As per the 2011-12 poverty estimates released by the government of India, Rajasthan has only 16% of the population living below the poverty line, which makes it a non-BIMARU state. The BIMARU states have some of the highest fertility rates in India, which leads to high population growth in these states than in other states. The state of Rajasthan, with a fertility rate of 3.3 in 2009, compared to the nation's average of 2.6, reported a population growth rate of 21.31% in 2001-2011 (a decrease from 28.33% in 1991-2001) which is still high compared to the nation's average of 17.7%. Despite the slowdown in population growth in this decade, it is still above India's average. However, with its reforms, the state has broken the barriers to growth and dramatically reduced its poverty to become a non-BIMARU state.

The state ranked 29th among Indian states in the human development index (HDI) with a score of 0.628 in 2019, which is below the national average of 0.645. The HDI takes into consideration health, education and per capita income. Most of the districts of Rajasthan have low HDI. The literacy rate in Rajasthan was just 66.11% in 2011 (60.41% in 2001), which is below the nation's average at 72.99%. Female literacy is as low as 52.12% (43.85% in 2001), which is also below the nation's average of 64.64%. The sex ratio in Rajasthan was 928 in 2011 and 921 in 2001, which indicate an increase from 910 in 1991. Rajasthan has an infant mortality rate and maternal mortality rate of 43 and 244, which are very high in comparison to the nation's average of 37 and 167, respectively. Rajasthan has seen an improvement in its HDI value from 0.403 in 1990 to 0.629 in 2018, but still has a lot to progress.

The state of Rajasthan has a diversified economy with agriculture, mining and tourism as the supporting engines. Currently, Rajasthan is the third most attractive investment destination in India and one of the fastest-growing economies. It is the 7th largest state economy in India with ₹10.20 lakh crore (US$140 billion) in gross domestic product and a per capita GDP of ₹118,000 (US$1,700). In terms of social infrastructure, the state of Rajasthan has a low poverty ratio of 8.3% against a national average of 21.92%, which is highly encouraging. Significant changes in the field of industrialisation have occurred in the past few years. The agriculture sector, the primary sector, has witnessed a slight decline in its share in the gross state value added (GSVA) to around 25% in FY2018. The industry (secondary) sector has also witnessed a marginal decline in its share in the state's GSVA to around 28% in FY2018. In comparison, the share of the services (tertiary) sector has increased to around 47% in FY2018. There is a need to understand how the variables such as unemployment, main and marginal workers, agricultural workers, household industrial workers, female labourers, literacy rates, etc. interact with the socio-economic vulnerability of the districts.

3.3. Data and Methodology

The state of Rajasthan has 33 districts, and district-level data for 26 socio-economic indicators were collected from the 2011 census. Table 3.1 gives a brief explanation of the selected indicators along with the hypothesized relationship between the indicators and vulnerability. We converted the absolute indicators to relative indicators as part of pre-processing of data for better analysis. The absolute value of indicators such as 'number of cultivators' does not represent the scenario of a district, as the districts are of varying geographical areas. As larger districts tend to have a larger number of cultivators, the analysis tends to be biased towards the districts with large numbers. Therefore, if we divide such indicators by the total population of that particular district and multiply by 100, the resultant indicator gives the percentage (of cultivators for the total population in the district), which is comparable among districts.

Table 3.1. Socio-economic indicators selected for this study and their hypothesized relationship with vulnerability

S. No.	Indicators	Units	Hypothesized relationship between the indicator and socio-economic vulnerability
1	Population density	Persons per sq. km	High population density is normally associated with poor sanitation, a shortage of public facilities and services, and environmental degradation. Hence, vulnerability increases with an increase in population density
2	Females	Percentage	The female population tends to be less when there is social unpopularity of a female child. Hence, an increase in the percentage of the female population shows a decrease in socio-economic vulnerability.
3	Mean household size	Persons per household	High household size can come with adverse implications such as low income and status, poor health, low levels of education, etc. Hence socio-economic vulnerability increases with an increase in mean household size.
4	Houseless population	Percentage	An increase in the houseless population represents an increase in poverty and hence an increase in vulnerability.
5	Population in age group 0-6	Percentage	The higher the population in the 0-6 age group, the higher the dependant population and thus the higher the vulnerability.
6	Scheduled castes population	Percentage	The higher the scheduled caste population, the higher the marginalised people, and thus the higher the vulnerability.

7	Scheduled tribes population	Percentage	The higher the scheduled tribes' population, the higher the marginalised people, and the higher the vulnerability.
8	Literacy rate	Percentage	The higher the literacy rate, the lower the vulnerability.
9	Female literacy rate	Percentage	The higher the female literacy rate, the lower the vulnerability.
10	Main cultivators	Percentage	An increase in the cultivator population can relate to a decrease in the average size of land holding, and an increase in the feasibility of farming. Thus, an increase in cultivators shows a decrease in vulnerability.
11	Main cultivators – Female	Percentage	An increase in the female cultivator population can lead to a decrease in vulnerability.
12	Main agricultural labourers	Percentage	An increase in agricultural labourers shows an increase in unemployment, under-employment and in unorganised and illiterate workers. Thus, an increase in agricultural labourers shows an increase in vulnerability.
13	Main agricultural labourers – Female	Percentage	An increase in the female agricultural population can lead to an increase in vulnerability.
14	Main household industries population	Percentage	An increase in the main household industries' population can lead to a decrease in vulnerability.
15	Main household industries population – Female	Percentage	An increase in the female main house household industries' population can lead to a decrease in vulnerability.
16	Marginal workers	Percentage	The higher the marginal workers, the higher the number of people who have not worked for a major part of the year; thus, the higher the vulnerability.
17	Marginal workers – Female	Percentage	The higher the female marginal workers, the higher the vulnerability.

18	Marginal cultivators	Percentage	Higher number of marginal cultivators shows that farming is becoming infeasible, increasing agricultural wages, rampant selling of agricultural land and shift of employment from the agricultural to non-agricultural sector. Thus, it indicates an increase in vulnerability.
19	Marginal cultivators – Female	Percentage	An increase in the number of female marginal cultivators shows an increase in vulnerability.
20	Marginal agriculture labourers	Percentage	Higher number of marginal agriculture labourers shows a decrease in cultivator population, thus, an increase in vulnerability.
21	Marginal agriculture labourers – Female	Percentage	Higher number of female marginal agriculture labourers shows a decrease in the cultivator population, thus, an increase in vulnerability.
22	Marginal household industries population	Percentage	Higher number of marginal household industries population shows an increase in vulnerability.
23	Marginal household industries Population – Female	Percentage	Higher number of female marginal household industries population shows an increase in vulnerability.
24	Households with dilapidated census houses	Percentage	The higher the number of households with dilapidated census houses, the higher the poverty, thus, the higher the vulnerability
25	Increase in population since 1901	Percentage	The higher the increase in population since 1901, the higher the vulnerability.
26	Non-working population	Percentage	The higher the non-working population, the higher the dependency and lower the employed population, thus, the higher the vulnerability.

We use the principal component analysis (PCA) technique to reduce the number of dimensions, assign weights to the indicators and compute the vulnerability index. The indicators are standardised using Z-score before the PCA technique. In this study, we select the first principal component (PC) as it accounts for the maximum variance of the data. The socio-economic vulnerability index (SEVI) is computed using the first PC for each district. Later, we use the Moran's I statistic to quantify the spatial autocorrelation of the SEVI scores. A correlation matrix is constructed to calculate the correlation between the indicators and SEVI. We used the Pearson correlation statistic, whose value ranges from -1 to +1. A value of -1 represents a negative linear correlation between two variables, and +1 represents a positive linear correlation. Based on the results, measures to reduce socio-economic vulnerability in the state of Rajasthan are proposed.

3.4. Results and Discussion

After data collection and data pre-processing, PCA is applied to 26 socio-economic indicators. The first principal component (PC), which explains 96.4% of the variance of the data, is selected for the study. Population density explains the maximum variance of the first PC. A very small coefficient for a variable represents the variance in data with respect to that variable. For example, the percentage of the houseless population is almost the same in all districts; hence, the smaller coefficient. The socio-economic vulnerability index (SEVI) for each district is computed using first PC, which is a linear combination of the original indicators. The SEVI scores are represented spatially (Fig. 3.1), and there is clear spatial clustering of districts. To measure the spatial autocorrelation of SEVI, we compute the Moran's I index. For a Moran's index of 0.27 and a p-value less than 0.01, the observed autocorrelation of SEVI is quite significant. Given the z-score of 3.2, there is a less than 1% likelihood that this clustered pattern could be the result of random chance. Thus, socio-economic vulnerability is spatially varying in the state of Rajasthan. The highest and high vulnerable districts are clustered across the state from east to west, with low vulnerable districts located towards the southern and northern part of the state. Finally, the districts are ranked based on the index value – the higher the vulnerability score, the higher the vulnerability, refer to Table 3.2.

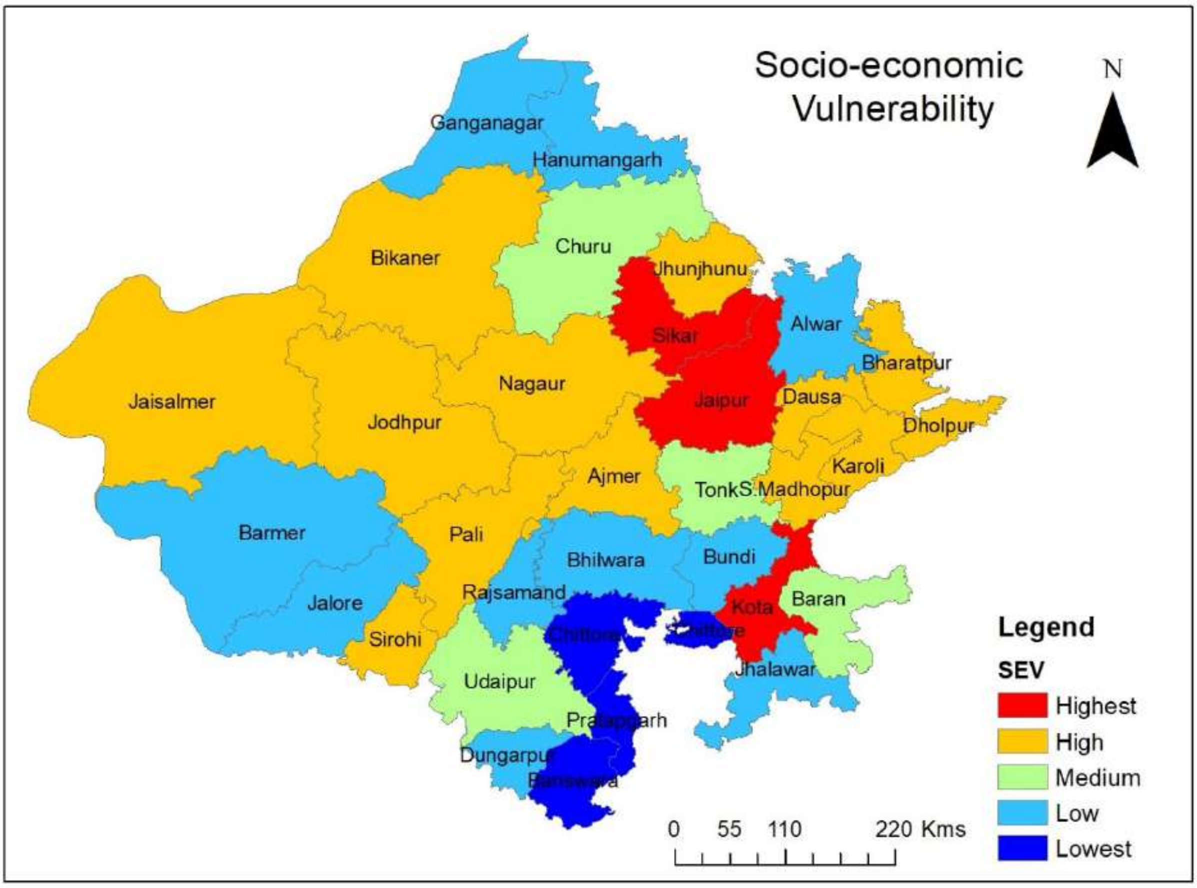


Figure 3.1. District-wise socioeconomic vulnerability in the state of Rajasthan.

Table 3.2. Ranking the districts of Rajasthan based on socio-economic vulnerability

Districts	**SeV Normalized Index**	**Rank**
Jaipur	100	1
Sikar	97.841	2
Kota	93.53038	3
Jodhpur	82.4519	4
Sirohi	81.86546	5
Ajmer	80.31458	6
Pali	77.32405	7
Bikaner	75.24751	8
Jhunjhunu	74.45361	9
Dausa	74.36357	10
Bharatpur	73.53596	11
Nagaur	67.64292	12
Karoli	67.60041	13
Jaisalmer	67.54618	14
S.Madhopur	66.68061	15
Dholpur	66.22924	16
Churu	61.29672	17
Udaipur	59.95601	18
Baran	56.22808	19
Tonk	53.59225	20
Barmer	50.80039	21
Dungarpur	50.70396	22
Ganganagar	49.89441	23
Alwar	49.05524	24
Hanumangarh	45.96777	25

Bundi	44.36931	26
Rajsamand	42.90037	27
Bhilwara	42.64969	28
Jhalawar	37.5065	29
Jalore	35.20104	30
Banswara	24.46082	31
Chittaurgarh	19.04706	32
Pratapgarh	0	33

To measure the correlation between each socio-economic indicator and SEVI, we constructed a correlation matrix (Fig. 3.2). The correlation coefficients showing the strength of the relationship between each indicator and SEVI are given in Table 3.3. From 26 indicators, 16 are positively correlated to vulnerability. One can notice clearly that an increase in marginal workers increases the socio-economic vulnerability of the districts. With an increase in agricultural and household industrial workers, vulnerability decreases.

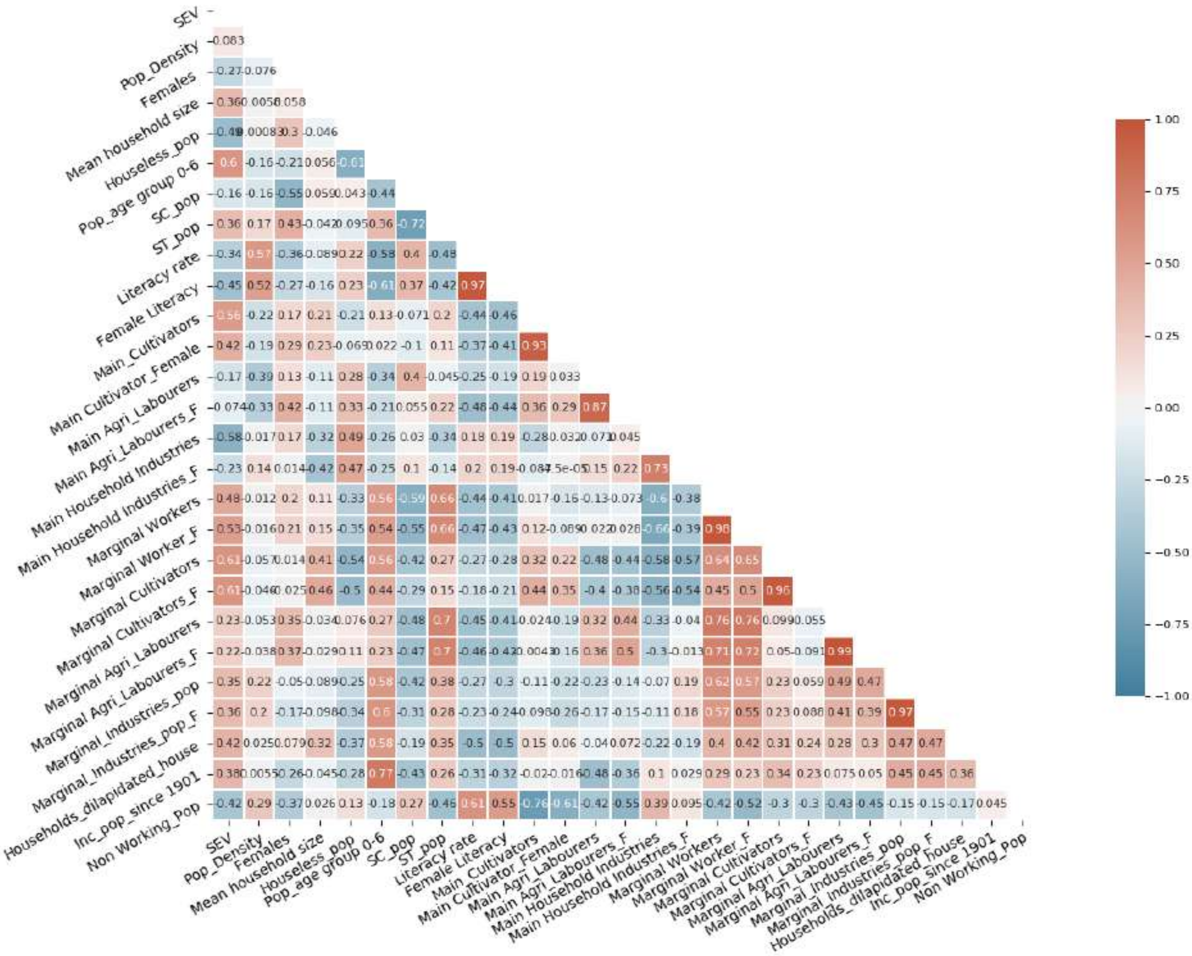


Figure 3.2. The correlation matrix of socioeconomic indicators and socioeconomic vulnerability index.

Table 3.3. Correlation coefficients showing the strength of the relationship between the indicators and SEVI

S.No.	Indicators	Correlation with SEVI
1	Population density	0.083
2	Females (%)	-0.27
3	Mean household size	0.36
4	Houseless population (%)	-0.4
5	Population in age group 0-6 (%)	0.6
6	Scheduled castes’ population (%)	-0.16
7	Scheduled tribes’ population (%)	0.36
8	Literacy rate (%)	-0.34
9	Female literacy rate (%)	-0.45
10	Main cultivators (%)	0.56
11	Main cultivator – Female (%)	0.42
12	Main agricultural labourers (%)	-0.17
13	Main agricultural labourers – Female (%)	-0.074
14	Main household industries (%)	-0.58
15	Main household industries – Female (%)	-0.23
16	Marginal workers (%)	0.48
17	Marginal worker – Female (%)	0.53
18	Marginal cultivators (%)	0.61
19	Marginal cultivators – Female (%)	0.61
20	Marginal agriculture labourers (%)	0.23
21	Marginal agriculture labourers – Female (%)	0.22
22	Marginal household industries population (%)	0.35
23	Marginal household industries population – Female (%)	0.36
24	Households with dilapidated census houses (%)	0.42
25	Increase in population since 1901 (%)	0.38
26	Non-working population (%)	-0.42

3.5. Measures and Recommendations to Reduce Socio-economic Vulnerability

Socio-economic vulnerability is a major component of vulnerability to climate change. It exacerbates climate risks, and measures should be taken to reduce it in the state of Rajasthan. Primarily, Rajasthan needs to focus on improving the quality of education and increasing the literacy rate. A majority of its population earns its livelihood from agriculture directly or indirectly, and the state government has to take significant measures towards the development of the agriculture sector. The state has the potential to generate new employment opportunities. The state can provide employment opportunities to rural people by diversifying the rural economy through the promotion of agro-processing, horticulture and other ancillary activities. To promote social and economic development of the state and reduce socio-economic vulnerability, we recommend the following:

1. Rajasthan is one of India's worst-performing states in terms of literacy, with only a 69.7% literacy rate. The gender divide is also high, and only 57.6% of the females are literate in the state, while 80.8% of the males are literate (75^{th} NSS). Education is a critical agent for addressing the issues of climate change. Education can directly influence people’s skills and knowledge, contribute to poverty reduction, increase employment opportunities and improve access to information and resources. Education enables people to make informed decisions, and it encourages them to change their attitudes and behaviours towards climate change. Educated people understand the impacts of climate change and learn how to adapt to it. Thus, taking measures to improve the literacy rate in the state would improve climate preparedness and reduce the vulnerability of the population by increasing their adaptive capacity.
    - A. Female education and climate change are inextricably linked. When women are educated, they will better understand the threats of climate change and prepare for disasters. For example, to cope with the malnutrition that often follows a drought or flood, educated mothers tend to spend more money on children. Furthermore, educated women have money to guard themselves during a disaster. Thus, increasing the female literacy rate in the state and reducing the gender gap in school enrolment will reduce climate vulnerability by minimising disaster risk, reducing disaster-related mortality and increasing climate preparedness.

B. Girls dropping out of school is quite significant in Rajasthan. More than half the girls drop out before entering secondary school. Strict enforcement of female school enrolment and completion can improve the female literacy rate of the state.
C. Despite the government's best efforts, a good number of parents spend a certain amount of money from their pockets. Parents may choose to pay for their son's education rather than their daughter's education. The state needs to take more effective steps to reduce such out-of-pocket expenditure.
D. Educating the families about the importance of female education is essential. The government should call for volunteers who have a passion for humanitarian work at every village level so that they can educate the locals about the importance of education and strive to bring more girls to school. The village volunteers can work in collaboration with rural NGOs and the government (Panchayati Raj Department of Rajasthan can be involved) to support and educate the village people.
E. An increase in education levels will create more employment opportunities. Lower education level is one of the primary reasons for low-income and low-quality jobs.

2. The poor tend to be more exposed to climate change-induced extreme weather events than their wealthier counterparts. Increasing employment opportunities and providing alternative opportunities to marginal cultivators and labourers will reduce their susceptibility to climate change and increase their ability to cope with the adverse impacts of climate change.
   A. Skill development for job creation is an adaptation strategy to climate change as it helps the unemployed and marginal workers to find jobs in other sectors where there is employment growth. Therefore, the state, with the help of *gram panchayats*, should provide skill development and improve the sectoral diversification of employment.
   B. With an increase in household industries, there is a decrease in the socio-economic vulnerability of the district. In particular, the growth in household industries can help alleviate poverty and develop an area.
   C. Incentives should be given to poor farmers, marginal agricultural labourers and cultivators to set up agriculture-based industries/enterprises.

3. The housing department should make urban spaces more liveable by improving housing conditions and reducing the number of homeless people. District-wise recommendations to reduce the socio-economic vulnerability of the state are given inTable 3.4.

Table 3.4. District-wise recommendations

Clusters	Districts	Recommendations
Highest Vulnerability	Jaipur	Reduce houseless population, reduce the number of non-working population by increasing the proportion of the population in cultivation.
	Sikar	Reduce the number of non-working people by increasing the proportion of the population in cultivation & household industries, encourage females in household industries & cultivation, reduce marginal cultivators.
	Kota	Reduce houseless population, reduce the proportion of non-working population by increasing the proportion of the population in cultivation.
High Vulnerability	Jodhpur	Reduce houseless population, reduce the proportion of non-working population by increasing the proportion of the population in cultivation.
	Sirohi	Reduce the proportion of non-working population by increasing the proportion of the population in cultivation or household industries, reduce houseless population, improve literacy rate, improve female literacy rate, improve female engagement in household industries, reduce the proportion of households living in dilapidated housing conditions.
	Ajmer	Reduce houseless population, reduce the proportion of non-working population by increasing the proportion of the population in cultivation.
	Pali	Reduce houseless population, reduce the proportion of households living in dilapidated housing conditions, reduce the proportion of non-working population by increasing the proportion of the population in cultivation, reduce the

	number of marginal workers/labourers/cultivators, improve literacy rate.
Bikaner	Reduce the proportion of non-working population.
Jhunjhunu	Reduce the number of marginal cultivators, encourage household industries, improve female engagement in household industries, reduce the proportion of non-working population.
Dausa	Reduce the proportion of households living in dilapidated housing conditions, reduce the number of marginal workers/labourers/cultivators, reduce the proportion of non-working population.
Bharatpur	Reduce the proportion of households living in dilapidated housing conditions, reduce the number of marginal workers/labourers/cultivators, reduce the proportion of non-working population.
Nagaur	Reduce houseless population, reduce the proportion of households living in dilapidated housing conditions, reduce the number of marginal cultivators, improve female engagement in household industries, improve literacy rate, reduce the proportion of non-working population.
Karoli	Encourage household industries, improve female engagement in household industries, reduce the proportion of non-working population, reduce the proportion of households living in dilapidated housing conditions, reduce the number of marginal cultivators, improve gender ratio.
Jaisalmer	Improve literacy rate, improve female literacy rate, reduce the number of marginal cultivators/workers, reduce the proportion of non-working population by increasing the proportion of the population in cultivation & household industries, improve gender ratio.
S.Madhopur	Reduce the proportion of non-working population by increasing the proportion of the population in cultivation &

		household industries, reduce the number of marginal cultivators/workers.
	Dholpur	Reduce the proportion of non-working population by increasing the proportion of the population in cultivation & household industries, reduce the proportion of households living in dilapidated housing conditions, reduce the number of marginal cultivators/ workers, improve gender ratio.
Medium Vulnerability	Churu	Reduce the number of marginal cultivators/ workers, reduce the proportion of households living in dilapidated housing conditions, encourage household industries, improve female engagement in household industries.
	Udaipur	Reduce the number of marginal cultivators/workers, improve literacy rate, improve female literacy rate, increase the proportion of the population in cultivation.
	Baran	Reduce houseless population, reduce the number of marginal cultivators/ workers, increase the proportion of the population in cultivation.
	Tonk	Improve literacy rate, improve female literacy rate, reduce houseless population.
Low Vulnerability	Barmer	Improve literacy rate, improve female literacy rate, reduce the number of marginal cultivators/workers, encourage household industries, improve female engagement in household industries, reduce the proportion of households living in dilapidated housing conditions.
	Dungarpur	Improve female literacy rate, reduce the number of marginal cultivators/workers, reduce the proportion of households living in dilapidated housing conditions, increase the proportion of the female population in cultivation & household industries.
	Ganganagar	Increase the proportion of the population (and female participation) in cultivation & household industries.

	Alwar	Reduce houseless population, reduce the number of marginal cultivators/ workers, increase the proportion of the population in household industries.
	Hanumangarh	Increase the proportion of the population in household industries.
	Bundi	Reduce houseless population, improve literacy rate, improve female literacy rate, reduce the number of marginal cultivators/workers, increase the proportion of the population in household industries.
	Rajsamand	Reduce houseless population, reduce the number of marginal cultivators/ workers, increase the proportion of the population in cultivation.
	Bhilwara	Reduce houseless population, improve literacy rate, reduce the number of marginal cultivators/workers.
	Jhalawar	Reduce houseless population, reduce the number of marginal cultivators/workers, increase the proportion of the population (and female engagement) in household industries, improve literacy rate.
	Jalore	Reduce the proportion of households living in dilapidated housing conditions, improve literacy rate, improve female literacy rate, increase the proportion of the population (and female engagement) in cultivation & household industries, reduce the number of marginal cultivators/workers.
Lowest Vulnerability	Banswara	Reduce the number of marginal workers, encourage household industries, improve literacy rate, improve female literacy rate, reduce the proportion of households living in dilapidated housing conditions.
	Chittaurgarh	Reduce houseless population, improve literacy rate, improve female literacy rate.
	Pratapgarh	Reduce the number of marginal workers/cultivators, encourage household industries, improve literacy rate, improve female literacy rate.

Chapter 4

Agriculture Vulnerability

4.1. Introduction

Climate change exerts pressure on the environment, livelihoods, human health and food security and will continue to do so for the next several decades due to previously released greenhouse gas emissions. Millions of people suffer from food insecurity, and the risks to food security are further exacerbated by climate change (Olsson et al., 2014). The agricultural sector is one of the worst affected by climate change. There is good evidence that climate change-induced extreme weather events such as changes in precipitation patterns, extreme temperatures, erosion and droughts increase the risk of climate change in the agriculture sector. But agriculture continues to be the main source of livelihood for people living in low and middle-income countries. Agriculture and allied sectors account for a large proportion of the labour force work, varying from 40% in some countries to as much as 90% in the case of least developed countries (FAO, 2002).

Agriculture is the backbone of the Indian economy, and about 60% of the population depends either directly or indirectly on agriculture and its allied sectors. For instance, the share of agriculture in India's gross domestic product (GDP) increased from 17.8% in 2019-20 to 19.9% in 2020-21. Agriculture faces several complex challenges in India due to factors such as the reduction in the share of agricultural land, depletion of water and irrigation sources, migration of farm labour to other sectors, and increased labour costs (Kantamaneni et al., 2020). The agriculture sector's share in GDP, which was 39% in 1983, declined to 24% in 2000-01 and further fell to 19.9% in 2020-21. Though the share of agriculture in India's GDP has declined after the 1980s, it continues to play a vital role in India's overall economic and social well-being.

Indian agriculture is highly dependent on climatic conditions, and it can be understood from the fact that only 40% of the total cropped area is irrigated as against 60% of the cropped area, which is rainfed. Most of India's rainfall is received from the southwest monsoon, and it is crucial for the availability of irrigation for agriculture. Thus, farmers who depend on rainfall are particularly more vulnerable to climate change. An increase in the frequency and intensity of extreme weather events lead to disruption in crop growth, increasing agricultural losses. Climate change can affect crop productivity both directly and indirectly – directly by changes in temperature or precipitation and indirectly through changes in soil moisture or frequency of crop diseases (Bhadwal et al., 2003). Thus, agriculture-driven growth and food security are at risk from climate change.

Over the decades, several studies have assessed the effects of climate change on the agriculture sector in India (Mall, 2006; Tao et al., 2011; Kareemulla et al., 2017; Kantamaneni et al., 2020). Agriculture vulnerability to climate change has not been clearly defined; therefore, authors have been basing their understanding of agriculture vulnerability on the definition of vulnerability by the IPCC (Tao et al., 2011). According to IPCC, v*ulnerability is defined as 'the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt'* (IPCC, 2014). Vulnerability to climate change is a function of sensitivity and adaptive capacity (IPCC, 2014). Agriculture vulnerability can be defined as the degree to which an agricultural system is susceptible to harm or unable to cope with the adverse impacts of climate change.

This study aims to assess Rajasthan's agriculture vulnerability to climate change and propose measures to reduce it. To achieve that, we: (a) identify indicators that significantly influence agriculture vulnerability in Rajasthan, (b) assess district-wise agriculture vulnerability and its correlation with climate hazards, and (c) propose measures to reduce agriculture vulnerability in Rajasthan. Since a hazard is no longer a component of vulnerability per the Fifth Assessment Report (IPCC, 2014), we compute separate indices for hazard and vulnerability. For this study, we adopt principal component analysis (PCA), a widely used method in vulnerability assessment studies to reduce dimensions, obtain indicator weights and compute an index. We rank the districts of Rajasthan according to agriculture vulnerability and hazard. Furthermore, based on the results, we propose measures to reduce the agriculture vulnerability in the state of Rajasthan.

The structure of this chapter is as follows. Section 2 discusses the profile of the state of Rajasthan with a focus on the agriculture sector. Section 3 gives a brief description of the selected indicators, sources of data, and spatial profile of those indicators. Section 4 elaborates the methodology and discusses the constituent steps. Section 5 discusses the results of the study, and the summary is given in section 6. Finally, section 7 proposes measures to reduce agriculture vulnerability

4.2. Rajasthan's Agriculture Profile

The state of Rajasthan is the largest Indian state by area and occupies 10.4% (i.e., about 3.42 lakh sq. km) of the total geographical area of India. The state accounted for only 5.66% of the total country's population but for 11.47% of the total cultivator population in 2011. Cultivators constitute 23.3% of the total state population, and cultivators in the rural area constitute 98.3% of the total rural population. The net area sown in the state was about 1.75 lakh square kilometres in 2012-13, which is 51.07% of the total state area. Thus, the state's population is heavily dependent on agriculture for their livelihood.

Agriculture is the backbone of the state's economy, and nearly two-thirds of the population (which is about 65%) is dependent on agriculture and allied activities for their livelihood (Swain et al., 2012). The contribution of agriculture & allied sectors to the state's total gross state domestic product (GSDP) was 25.56% in 2019-20. High fluctuations in agriculture productivity have resulted in wide fluctuations in the GSDP of the state over the years (Swain et al., 2012). Since a vast majority of the population (56.5 million) is dependent on agricultural activities for their livelihood, the state can achieve its goals of reducing poverty, food security, and inclusive development if agriculture is given a higher priority.

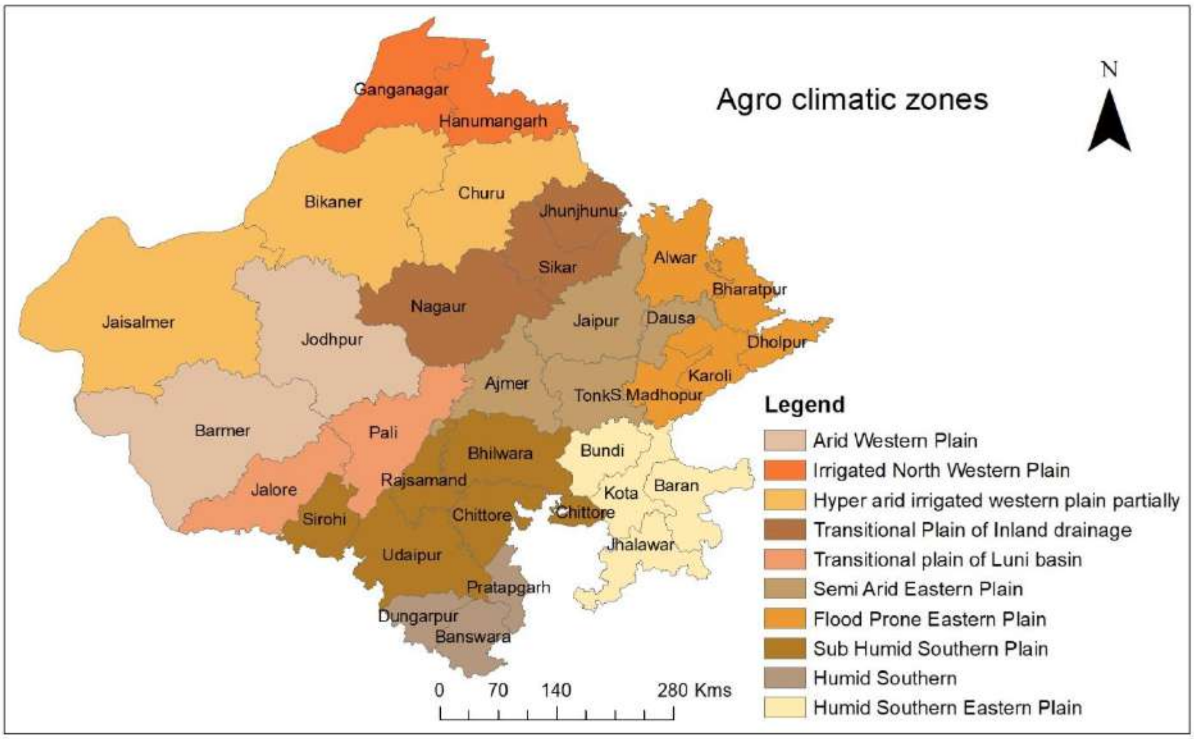


Figure 4.1. Agro-climatic zones in the state of Rajasthan.

The state has diverse soil and weather conditions and has ten agro-climatic zones, refer to Fig. 4.1. The north-western part of the state, which is about 60% of the total state's area, is desert or semi-desert. The south-eastern part of the state is fertile for crop production. Agriculture in Rajasthan is largely dependent on rainfall, but the rainfall is inadequate. The monsoon period is also short, with late-onset and early withdrawal. The average rainfall of east Rajasthan is 675mm, while the rainfall in west Rajasthan is only 313 mm. More than 60% of the state's geographical area lies in arid and semi-arid zones. Nearly 75% of the net cropped area is rain-fed; therefore, expanding irrigation facilities is an important and challenging task. Irrigation is challenging as the state of Rajasthan is also deficient in groundwater.

Some of the major challenges the agriculture sector faces are frequent droughts, depleting groundwater, scarcity of water resources, inefficient water management practices, deteriorating soil health, low productivity and climate change. Frequent droughts in the state lead to a decline in productivity and reduced performance. Climate change further aggravates the existing problems of the state.

4.3. Data

The state of Rajasthan has 33 districts, and district-level data for 25 variables (or indicators) has been collected for this study. Out of the 25 indicators, 20, which represent various agricultural factors, are used to construct the agriculture vulnerability index (AVI), and the remaining five indicators, representing climate hazard variability, are used for the construction of a hazard index (HI). Data is obtained from the Department of Agriculture (Government of Rajasthan) or government reports. Table 4.1 gives a brief explanation of the selected indicators along with their hypothesised relationship with agriculture vulnerability.

Table 4.1. Agriculture and hazard indicators used in this study

S. No.	Indicators	Units	Description of indicator	Hypothesised relationship between the indicator and agriculture vulnerability	Data Source	Data Year	References
			Agriculture				
1	Area of non-problematic soil (A_{soil})	Percentage	Problematic soils are uneconomical or unfeasible for cultivation. The area of non-problematic soil is obtained by subtracting the area of problematic soil from the total district area, expressed as a percentage.	The higher the area of non-problematic soil, the lower vulnerability	[1]	2017-18	(Bhadwal et al., 2003; O'Brien et al., 2004)
2	Fertiliser consumption in kharif (A_{fert_kharif})	Kg/ha.	Fertiliser consumption measures the quantity of fertiliser used per unit of arable land.	Usage of chemical fertilisers increases agricultural production. Thus, increase in fertiliser consumption in kharif reduces vulnerability	[1]	2017-18	(Ravindranath et al., 2011)
3	Fertiliser consumption in rabi (A_{fert_rabi})	Kg/ha.	Fertiliser consumption measures the quantity of fertiliser used per unit of arable land.	Usage of chemical fertilisers increases agricultural production. Thus, increase	[1]	2017-18	(Ravindranath et al., 2011)

				in fertiliser consumption in rabi reduces vulnerability			
4	Productivity under kharif crop (A_{prod_kharif})	Kg/ha.	Crop productivity is a measure of crop yield within a given area of the field.	An increase in agricultural productivity leads to agricultural growth. Thus, the higher the productivity in kharif, the lower the vulnerability level.	[1]	2017-18	(Varadan & Kumar, 2015) (considered yield)
5	Productivity under rabi crop (A_{prod_rabi})	Kg/ha.	Crop productivity is a measure of crop yield within a given area of the field.	The higher the productivity in rabi, the lower the vulnerability level.	[1]	2017-18	(Varadan & Kumar, 2015) (considered yield)
6	Irrigated area under kharif (A_{irri_kharif})	Percentage	Irrigated area is irrigated for growing crops through sources such as canals, tanks, wells, etc.	Irrigation has the potential to provide higher yields than rain-fed agriculture—the higher the irrigated area in kharif, the lower the vulnerability level.	[1]	2017-18	(Gbetibouo & Ringler, 2009; Ravindranath et al., 2011; Sridevi et al., 2014)
7	The irrigated area under the rabi crop	Percentage	Irrigated area is irrigated for growing crops through sources such as canals, tanks, wells, etc.	Irrigation has the potential to provide higher yields than rain-fed agriculture—	[1]	2017-18	(Gbetibouo & Ringler, 2009; Ravindranath

	(A_{irri_rabi})			the higher the irrigated area in rabi, the lower the vulnerability level.			et al., 2011; Sridevi et al., 2014)
8	Net area sown ($A_{netArea}$)	Percentage	Net area sown represents the total area sown with crops, but the area sown more than once in the same year is only counted once.	The higher the net sown area, the higher the importance to agriculture, the lower the vulnerability level.	[1]	2016-17	(Rao et al., 2013; Ravindranath et al., 2011; Sridevi et al., 2014)
9	Gross cropped area ($A_{grossArea}$)	Percentage	Gross cropped area or the total area sown represents the area sown once and more than once in a year. The area will be counted as many times as there are sowings in a year.	The higher the cropped area, the lower the vulnerability.	[1]	2016-17	
10	Area sown more than once ($A_{MoreThan1}$)	Percentage	Represents the area where crops are cultivated more than once a year.	The higher the area sown more than once, the lower the vulnerability level.	[1]	2016-17	
11	Cropping intensity (A_{crop_Int})	Percentage	Cropping intensity is the ratio of gross cropped area to net area sown, expressed as a percentage.	Higher cropping intensity implies higher productivity per unit of arable land, thus,	[1]	2016-17	(Palanisami et al., 2008; Sridevi et al.,

			Higher cropping intensity means a higher proportion of land is being cropped more than once a year	lower the vulnerability level.			2014; Varadan & Kumar, 2015)
12	Irrigation intensity (A_{irr_Int})	Percentage	Irrigation intensity is the ratio of net irrigated area to net sown area expressed as a percentage. Irrigation helps grow crops even during the dry season.	Higher the irrigation intensity, lower the vulnerability level.	[1]	2016-17	(Palanisami et al., 2008)
13	No. of wells (A_{wells})	Per km^2	Represents the number of wells present in a square kilometre of area. Wells are one of the main sources of irrigation water.	A higher number of wells represents higher irrigation facilities and thus lower vulnerability	[1]	2016-17	-
14	No. of tube wells ($A_{tubewells}$)	Per km^2	Represents the number of tube wells present in a square kilometre of area. Tube wells are one of the main sources of irrigation water.	A higher number of tube wells represents higher irrigation facilities and thus lower vulnerability	[1]	2016-17	-
15	Electrified wells and tube wells (A_{ele_wells})	Per km^2	Represents the number of electrified wells and tube wells present in a square kilometre of area. Electrification changes irrigation and agriculture.	Electrification of irrigation facilities increases the availability of irrigation water and thus increases productivity. Thus, the	[1]	2016-17	-

				higher the number of electrified wells and tube wells, the lower the vulnerability.			
16	Crop Diversification Index (A_{cdi})	Varies from 0 to 1	Crop Diversification Index is the sum of squares of proportions of all crops. The proportion of a crop is the ratio of 'area of the crop' to 'total cropped area'.	The value of one indicates complete specialisation, and zero indicates perfect diversification. A lower index value represents higher diversification and thus lower vulnerability	[2]	2017-18	(Gbetibouo & Ringler, 2009; Varadan & Kumar, 2015)
17	Crop Diversification Index in kharif (A_{cdi_kharif})	Varies from 0 to 1	„	„	[2]	2017-18	(Gbetibouo & Ringler, 2009; Varadan & Kumar, 2015)
18	Crop Diversification Index in rabi (A_{ecdi_rabi})	Varies from 0 to 1	„	„	[2]	2017-18	(Gbetibouo & Ringler, 2009; Varadan & Kumar, 2015)

19	Percentage increase in the area of major crops (A_{area_growth})	Percentage	Represents the change in the area of major crops in 2017-18 with regard to the base year 2013-14	Higher growth in the area of major crops leads to an increase in cropped area, thus lowering vulnerability.	[2]	2017-18	(Varadan & Kumar, 2015)
20	Percentage increase in the yield of major crops (A_{yield_growth})	Percentage	Represents the change in the yield of major crops in 2017-18 with regard to the base year 2013-14	An increase in the yield of major crops leads to an increase in productivity and profitability. Therefore, higher growth in yield lowers vulnerability.	[2]	2017-18	(Varadan & Kumar, 2015)
				Hazard			
1	Annual normal rainfall (E_{annual_rain})	mm	Annual normal rainfall is the amount of precipitation expected in a given year. Rainfall is very critical for agriculture as a majority of agriculture is rain-fed.	Higher the rainfall, the better the crop growth, thus lower the vulnerability	[1]	2017-18	(Rao et al., 2013)

2	Deviation from (annual) normal (E_{annual_dev})	Percentage	Deviation from annual rainfall represents the difference in the rainfall in a particular year in comparison to the normal expected rainfall, expressed as a percentage	An increase in rainfall (positive deviation) is favourable for agriculture; thus, the vulnerability is low	[1]	2017-18	(Palanisami et al., 2008)
3	Normal Monsson rainfall (E_{mons_rain})	mm	Normal monsoon rainfall is the amount of precipitation expected during the monsoon period in a given year. Rainfall is very critical for agriculture as a majority of agriculture is rain-fed.	Higher the rainfall, the better the crop growth, thus lower the vulnerability	[3]	2018	(Varadan & Kumar, 2015)
4	Deviation from normal (monsoon period) (E_{mons_dev})	Percentage	Represents the difference in the monsoon rainfall in a particular year in comparison to the normal expected monsoon rainfall, expressed as a percentage	An increase in rainfall is favourable for agriculture and, thus the vulnerability is low.	[3]	2018	(Varadan & Kumar, 2015)
5	Drought frequency (once in __ years) ($E_{drought}$)	No. of Years	Represents the number of years it takes for a drought to return, I.e., frequency of drought occurrence.	More droughts represent risky agriculture. Higher the number of years it takes for a drought to return, lower the vulnerability.	[4]	-	(Rao et al., 2013)

[1] Rajasthan Agricultural Statistics at a glance 2017-18 (Rathore & Bairwa, 2019)

[2] Department of Agriculture, Government of Rajasthan

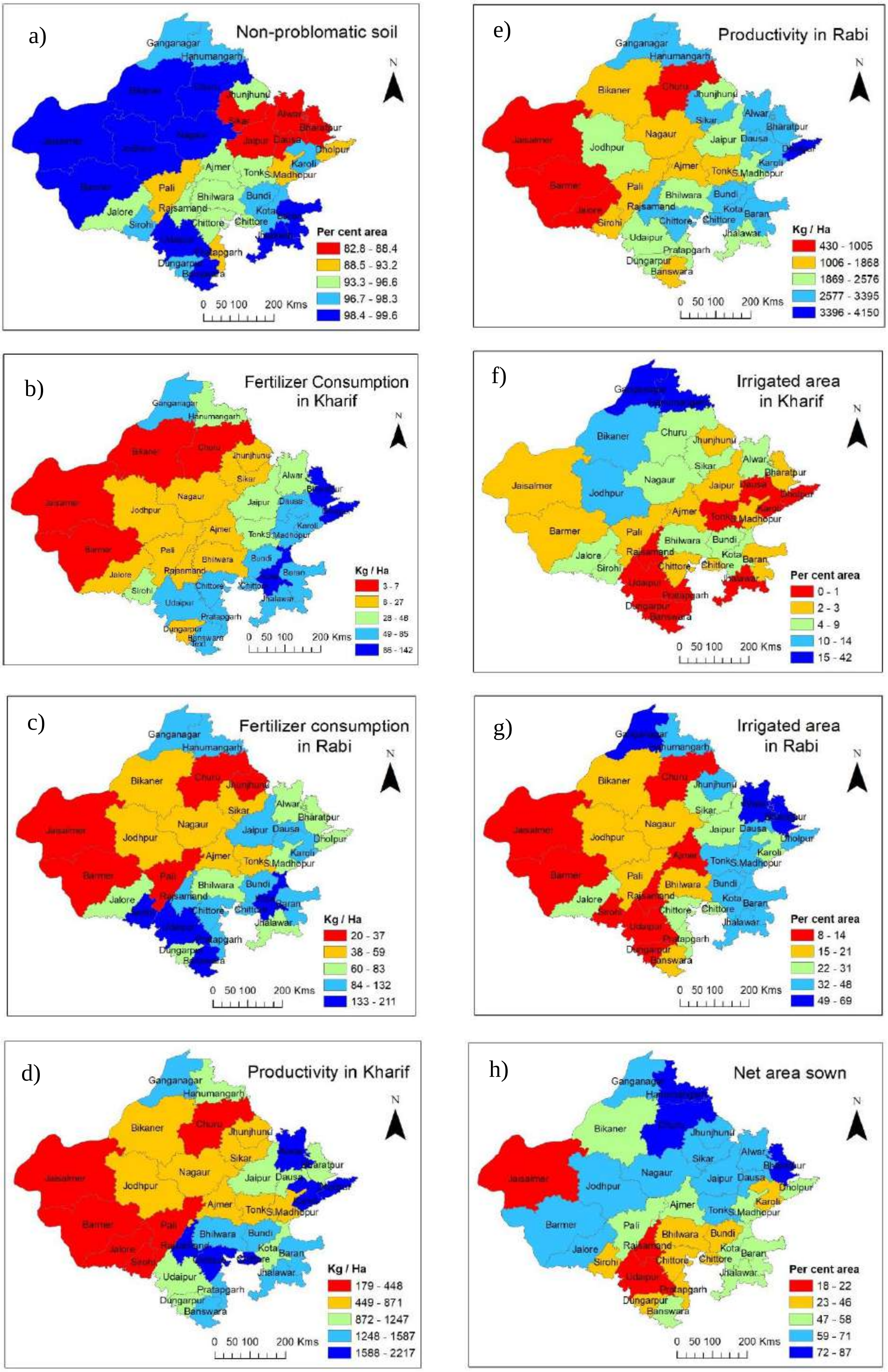
[3] Monsoon report 2018, Water resources department, Government of Rajasthan

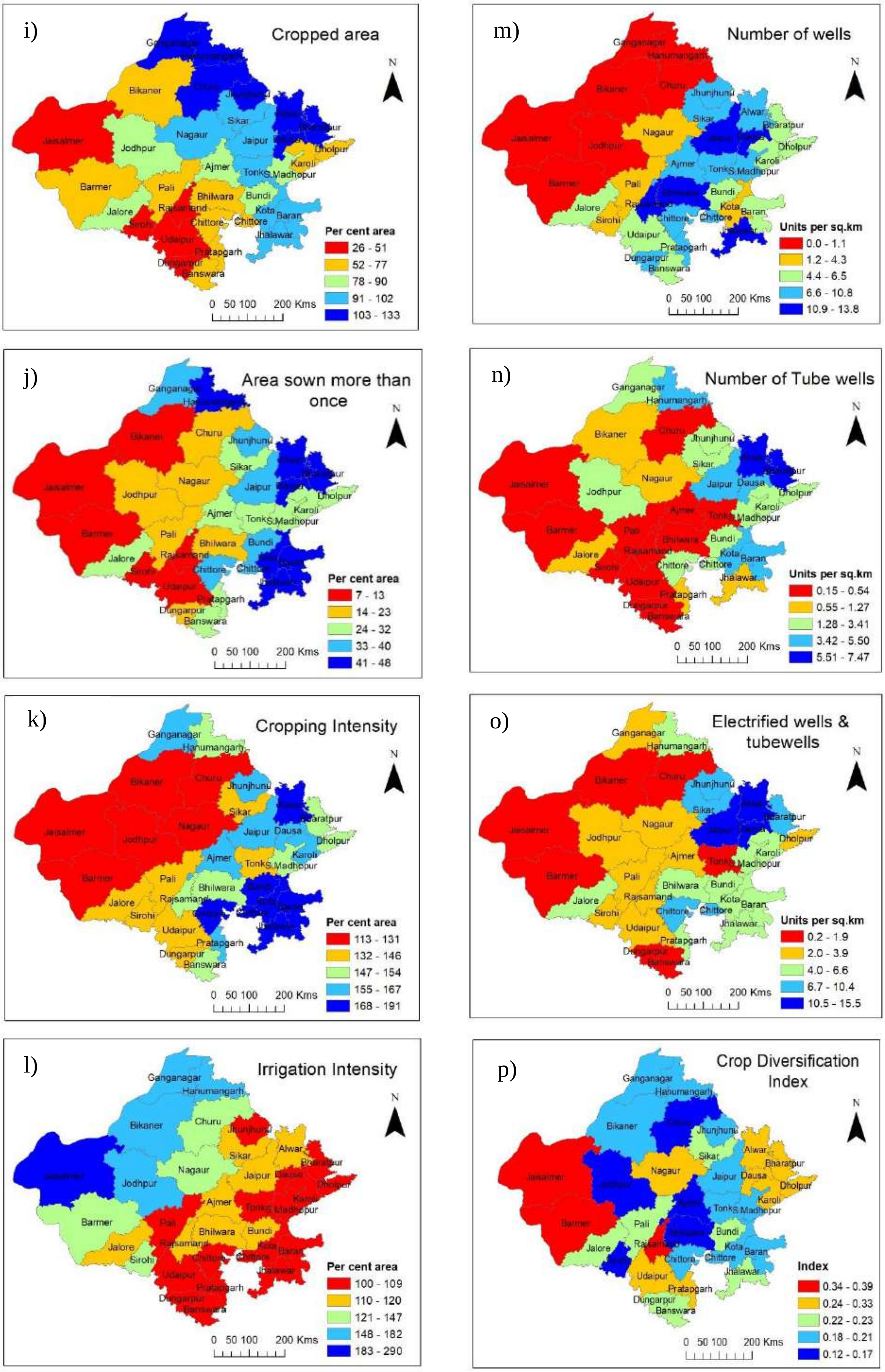
[4] Disaster Management, Relief & Civil Defence Department, Government of Rajasthan

While most of the indicators are extracted directly, a few of them are modified for the study. The absolute value of indicators such as 'number of wells' does not represent the scenario of a district, as the districts are of varying geographical areas. As larger districts tend to have a higher number of wells, the analysis gets biased towards the districts with large numbers. Therefore, we divide such indicators by the area of that particular district, and the resultant indicator gives the density (number of wells present per unit area), which is comparable among districts. The modified indicators and the formulas used are shown in Table 4.2.

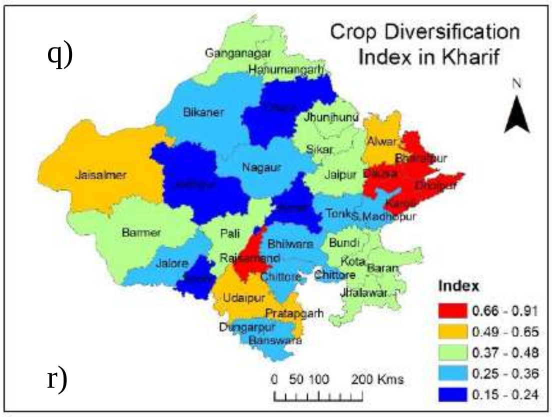
Table 4.2. Modified indicators and the formula used

Indicator	**Units**	**Formula**
Area of non-problematic soil (productive soil)	Percentage	$100 - \frac{\text{Area of problematic soil (saline + alkali)}}{District\ Area} * 100$
The irrigated area under kharif	Percentage	$\frac{Irrigated\ area\ under\ kharif}{District\ Area} * 100$
The irrigated area under rabi	Percentage	$\frac{Irrigated\ area\ under\ rabi}{District\ Area} * 100$
No. of wells	Per km^2	$\frac{Total\ number\ of\ wells}{District\ Area}$
No. of tube wells	Per km^2	$\frac{Total\ number\ of\ Tube\ wells}{District\ Area}$
Electrified wells and tube wells	Per km^2	$\frac{Total\ number\ of\ electrified\ wells\ and\ tubewells}{District\ Area}$

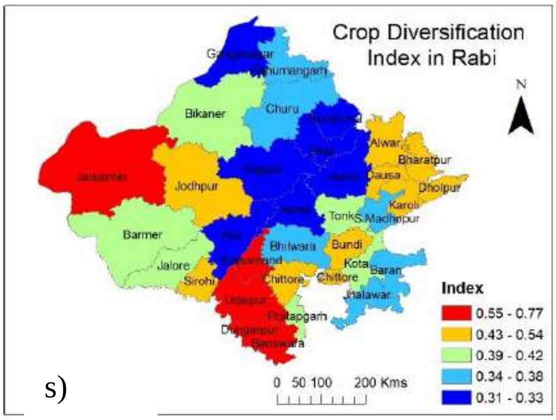

a)
Non-problomatic soil
Per cent area
82.8 - 88.4
88.5 - 93.2
93.3 - 96.6
96.7 - 98.3
98.4 - 99.6
0 50 100 200 Kms
b)
Fertilizer Consumption in Kharif
Kg / Ha
3 - 7
8 - 27
28 - 48
49 - 85
86 - 142
0 50 100 200 Kms
c)
Fertilizer consumption in Rabi
Kg / Ha
20 - 37
38 - 59
60 - 83
84 - 132
133 - 211
0 50 100 200 Kms
d)
Productivity in Kharif
Kg / Ha
179 - 448
449 - 871
872 - 1247
1248 - 1587
1588 - 2217
0 50 100 200 Kms
e)
Productivity in Rabi
Kg / Ha
430 - 1005
1006 - 1868
1869 - 2576
2577 - 3395
3396 - 4150
0 50 100 200 Kms
f)
Irrigated area in Kharif
Per cent area
0 - 1
2 - 3
4 - 9
10 - 14
15 - 42
0 50 100 200 Kms
g)
Irrigated area in Rabi
Per cent area
8 - 14
15 - 21
22 - 31
32 - 48
49 - 69
0 50 100 200 Kms
h)
Net area sown
Per cent area
18 - 22
23 - 46
47 - 58
59 - 71
72 - 87
0 50 100 200 Kms


i)
Cropped area
N
Per cent area
26 - 51
52 - 77
78 - 90
91 - 102
103 - 133
0 50 100 200 Kms
m)
Number of wells
N
Units per sq.km
0.0 - 1.1
1.2 - 4.3
4.4 - 6.5
6.6 - 10.8
10.9 - 13.8
0 50 100 200 Kms
j)
Area sown more than once
N
Per cent area
7 - 13
14 - 23
24 - 32
33 - 40
41 - 48
0 50 100 200 Kms
n)
Number of Tube wells
N
Units per sq.km
0.15 - 0.54
0.55 - 1.27
1.28 - 3.41
3.42 - 5.50
5.51 - 7.47
0 50 100 200 Kms
k)
Cropping Intensity
N
Per cent area
113 - 131
132 - 146
147 - 154
155 - 167
168 - 191
0 50 100 200 Kms
o)
Electrified wells & tubewells
N
Units per sq.km
0.2 - 1.9
2.0 - 3.9
4.0 - 6.6
6.7 - 10.4
10.5 - 15.5
0 50 100 200 Kms
l)
Irrigation Intensity
N
Per cent area
100 - 109
110 - 120
121 - 147
148 - 182
183 - 290
0 50 100 200 Kms
p)
Crop Diversification Index
N
Index
0.34 - 0.39
0.24 - 0.33
0.22 - 0.23
0.18 - 0.21
0.12 - 0.17
0 50 100 200 Kms

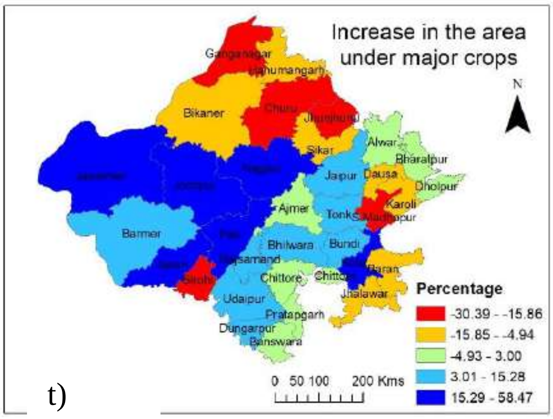
q)


Crop Diversification Index in Kharif
Index
0.66 - 0.91
0.49 - 0.65
0.37 - 0.48
0.25 - 0.36
0.15 - 0.24
0 50 100 200 Kms

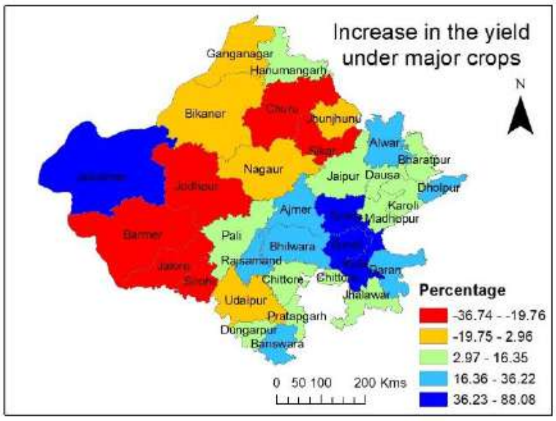
r)


Crop Diversification Index in Rabi
Index
0.55 - 0.77
0.43 - 0.54
0.39 - 0.42
0.34 - 0.38
0.31 - 0.33
0 50 100 200 Kms

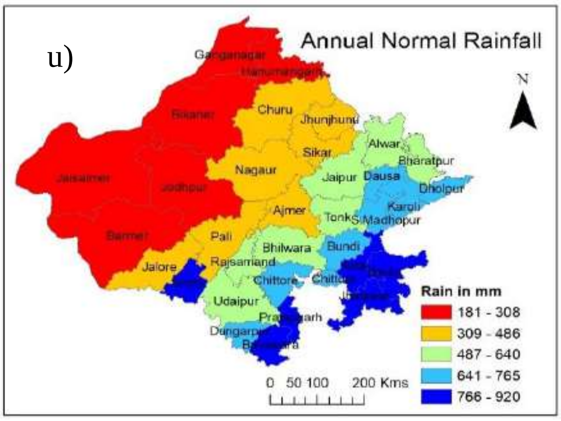
s)


Increase in the area under major crops
Percentage
-30.39 - -15.86
-15.85 - -4.94
-4.93 - 3.00
3.01 - 15.28
15.29 - 58.47
0 50 100 200 Kms

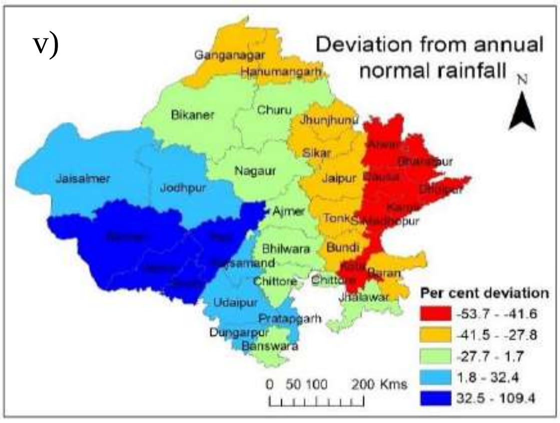
t)


Increase in the yield under major crops
Percentage
-36.74 - -19.76
-19.75 - 2.96
2.97 - 16.35
16.36 - 36.22
36.23 - 88.08
0 50 100 200 Kms

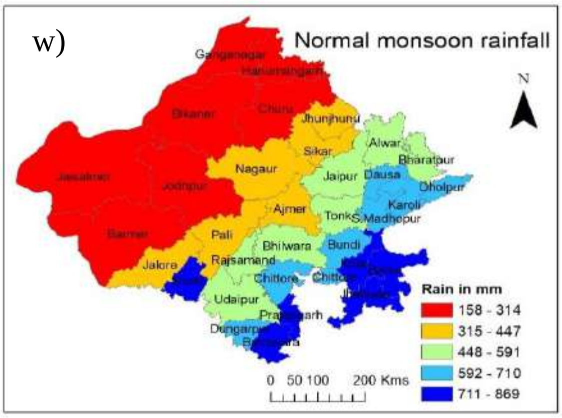
u)


Annual Normal Rainfall
Rain in mm
181 - 308
309 - 486
487 - 640
641 - 765
766 - 920
0 50 100 200 Kms

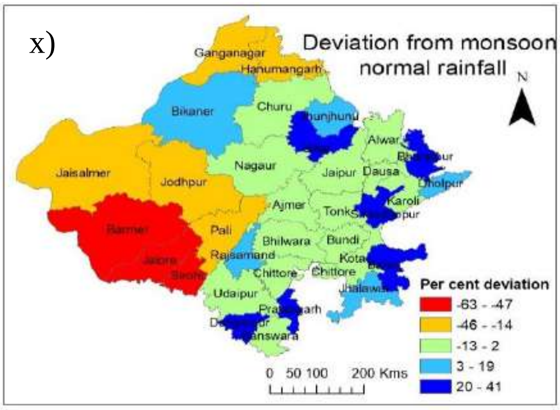
v)


Deviation from annual normal rainfall
Per cent deviation
-53.7 - -41.6
-41.5 - -27.8
-27.7 - 1.7
1.8 - 32.4
32.5 - 109.4
0 50 100 200 Kms

w)


Normal monsoon rainfall
Rain in mm
158 - 314
315 - 447
448 - 591
592 - 710
711 - 869
0 50 100 200 Kms

x)


Deviation from monsoon normal rainfall
Per cent deviation
-83 - -47
-46 - -14
-13 - 2
3 - 19
20 - 41
0 50 100 200 Kms

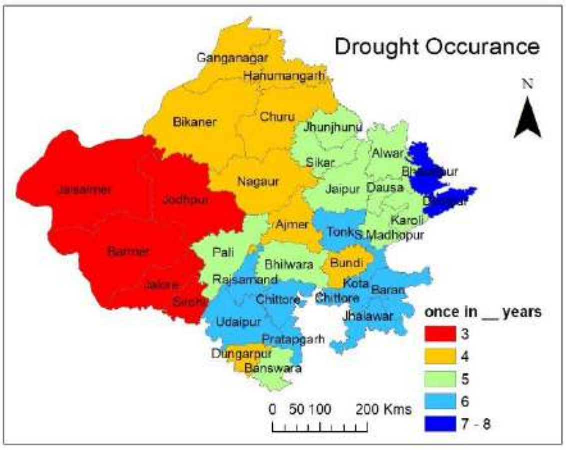


Figure 4.2. District-wise spatial representation of agriculture and hazard indicators.

The district-wise spatial profile of all the indicators is shown in Fig. 4.2. Besides the spatial variation of the selected indicators, we analyse the trend (changes over the years) for four variables: Crop diversification index (CDI) per year, CDI in kharif, CDI in rabi, and increase in the area under major crops.

CDI represents the specialisation of crops, and the Herfindahl Index is used to compute CDI over the years. Herfindahl Index is defined as the sum of squares of proportions of all crops (Biswas, 2016). The proportion of a crop is the ratio of 'area of the crop' with 'total cropped area'. Fig. 4.3 shows the variation in CDI per year, CDI in kharif, and CDI in rabi for the districts of Rajasthan for the period 2014 to 2020. The trend analysis helps us identify the districts which are performing better in crop diversification and the districts that need to adopt measures for better crop diversification. Ajmer, Alwar, Bharatpur, Dholpur, Pratapgarh and Rajasmand districts have shown an increase in the value of CDI, (i.e., a decrease in crop diversification over the years). Therefore, measures to improve CDI need to be taken in those districts. Districts such as Barmer, Bhilwara, Dausa, Jaipur, Jalore, Nagaur, and Pali have shown an increase in yearly CDI despite decreasing CDI in kharif or rabi. Jaisalmer has shown a great improvement in the diversification of crops over the years.

Climate change is one of the most important determinants of abandoning crops and switching to new crops (Tessema et al., 2019). The percentage change (rate of change (ROC)) in the area under major crops for each district in Rajasthan for the period 2014-20 is shown in Fig. 4.4.

Three crops that have the highest cropped areas in a district are chosen as 'major crops'. ROC is calculated for each crop using the following formula:

$$ROC = \left(\frac{Area\ under\ the\ crop\ in\ the\ current\ year}{Area\ under\ the\ crop\ in\ the\ previous\ year} - 1\right) * 100$$

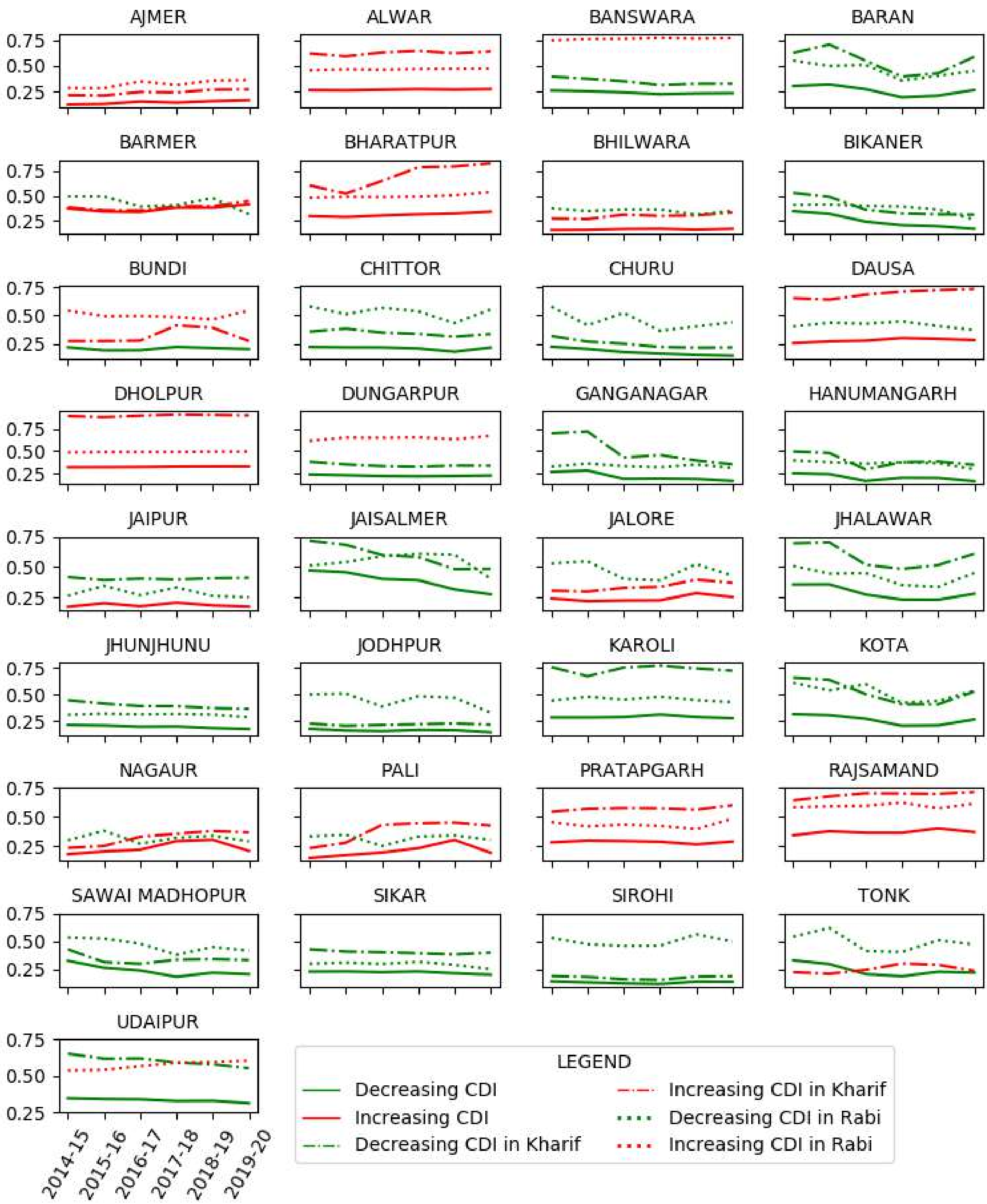
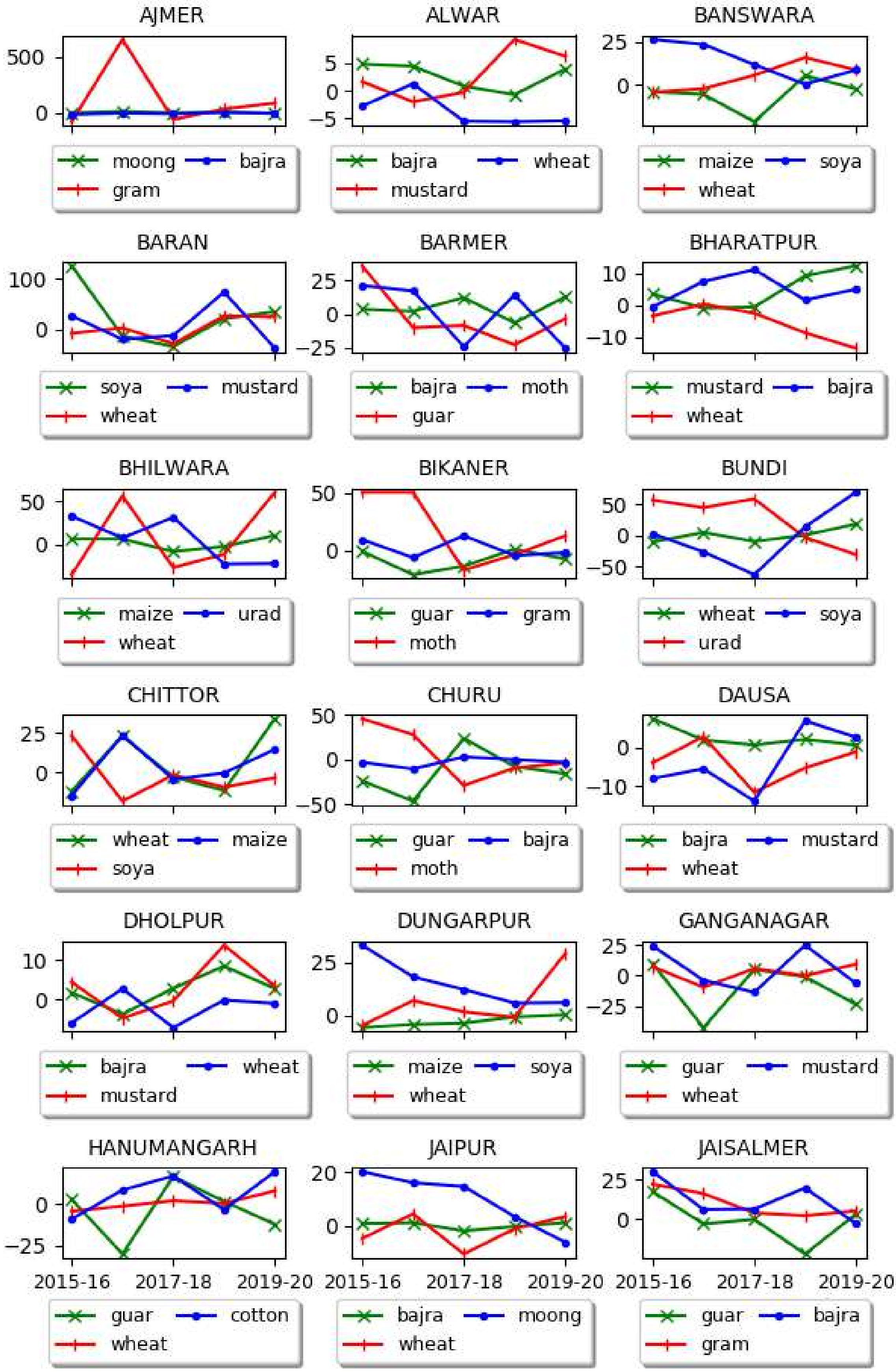


Figure 4.3. Changes in crop diversification index over the period 2014-20.


AJMER
500
0
moong
bajra
gram
ALWAR
5
0
−5
bajra
wheat
mustard
BANSWARA
25
0
maize
soya
wheat
BARAN
100
0
soya
mustard
wheat
BARMER
25
0
−25
bajra
moth
guar
BHARATPUR
10
0
−10
mustard
bajra
wheat
BHILWARA
50
0
maize
urad
wheat
BIKANER
50
0
guar
gram
moth
BUNDI
50
0
−50
wheat
soya
urad
CHITTOR
25
0
wheat
maize
soya
CHURU
50
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guar
bajra
moth
DAUSA
0
−10
bajra
mustard
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DHOLPUR
10
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bajra
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mustard
DUNGARPUR
25
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maize
soya
wheat
GANGANAGAR
25
0
−25
guar
mustard
wheat
HANUMANGARH
0
−25
2015-16
2017-18
2019-20
guar
cotton
wheat
JAIPUR
20
0
2015-16
2017-18
2019-20
bajra
moong
wheat
JAISALMER
25
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2015-16
2017-18
2019-20
guar
bajra
gram

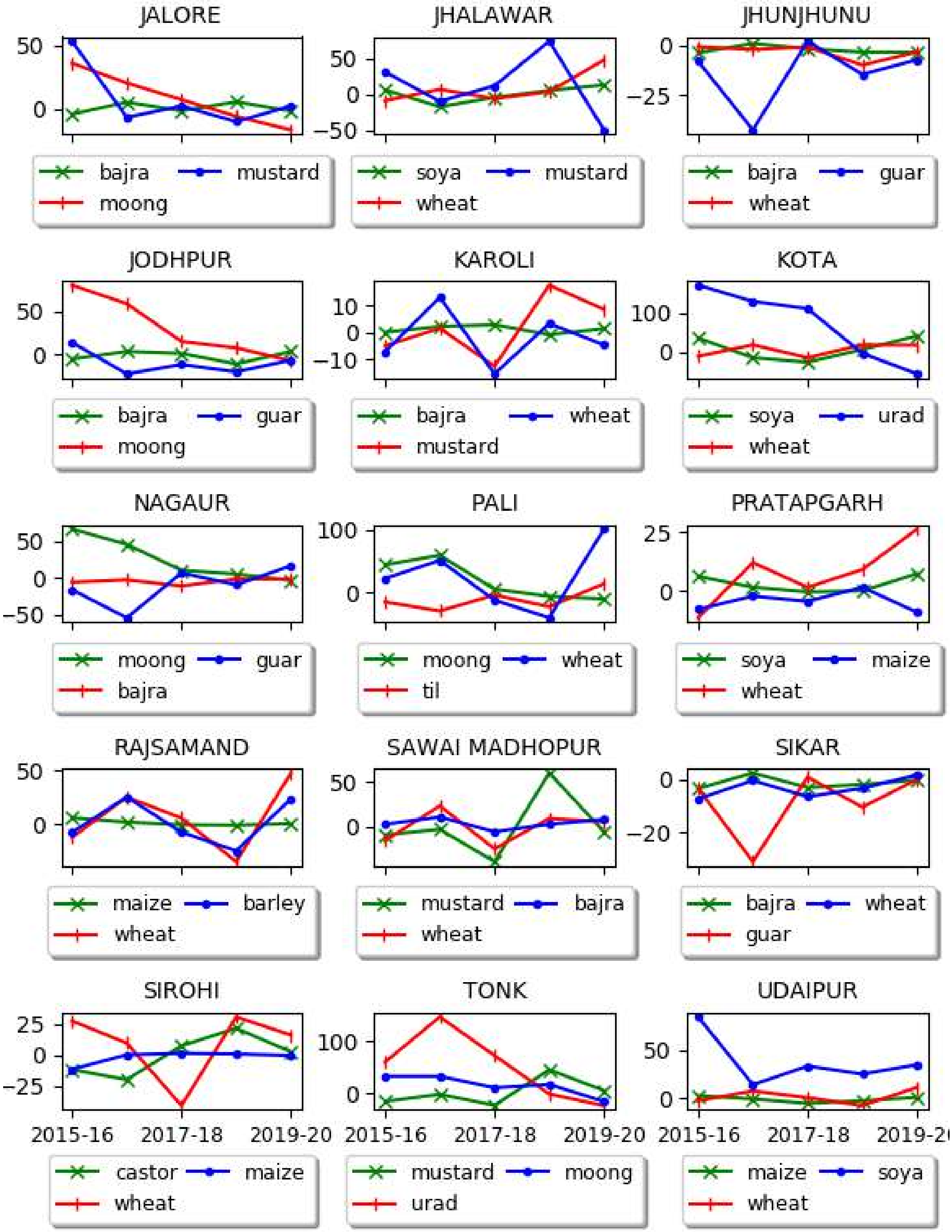

Figure 4.4. Rate of change in the area under major crops for each district in Rajasthan

4.4. Methodology

The various stages of the methodology are briefly explained below:

- Indicators that can measure agriculture and hazard variability in the state of Rajasthan are identified from the literature. Data for those indicators from the 33 districts of Rajasthan have been collected from the Department of Agriculture (Government of Rajasthan) and state government reports.
- After data pre-processing, a correlation matrix is constructed as part of the exploratory analysis to analyse the correlation among variables. Due to high correlation among variables, we adopted the principal component analysis (PCA) technique to transform the set of highly correlated variables into a smaller set of uncorrelated variables.
- The indicators have been standardised before doing PCA, as, without standardisation, the PCA tends to give more emphasis to the variables with higher variances. Z-score, a standard score, is used for the standardisation of the values.
- After data standardisation, we use the PCA technique to assign weights to all the indicators. In this study, we select the first principal component (PC) as it accounts for the maximum variance of the data. A PC is a linear combination of the original indicators, and the coefficients (called Factor loadings) of the first PC are used as weights for the indicators.
- We compute the indices as a linear combination of the original indicators and the weights. Agricultural vulnerability index (AVI) and hazard index (HI) are computed using the first PC for each district.
- We use the Moran's I statistic to quantify the spatial autocorrelation of the AVI and HI scores.
- The association or relationship between agriculture vulnerability and hazard is analysed using the Pearson correlation and Spearman correlation coefficients.
- Based on the results, measures to reduce the agriculture vulnerability in the state of Rajasthan are proposed.

4.5. Results and Discussions

4.5.1. Agriculture Vulnerability

After the data collection and data pre-processing, a correlation matrix is constructed for the 20 agriculture indicators to identify significant relationships among variables (Fig. 4.5). Coefficients of area of non-problematic soil and irrigation intensity are mostly negatively correlated with other indicators. In other words, the indicators of irrigation intensity and area of non-problematic soil decrease with an increase in other variables. We can also observe some strong correlations among other indicators. The pairs of indicators with strong correlations, coefficients above ±0.7, are listed in Table 4.3.

Table 4.3. Highly correlated indicator pairs

Variable-1	Variable-2	Correlation coefficient
Electrified wells & tube wells	Area of non-problematic soil	-0.77199
Area sown more than once	Number of tube wells	0.707615
Productivity in rabi	Fertiliser consumption in kharif	0.743686
Electrified wells & tube wells	Number of tube wells	0.744793
Productivity in rabi	Productivity in kharif	0.756581
Tube wells	Irrigated area in rabi	0.759262
Gross cropped area	Irrigated area in rabi	0.759576
CDI	CDI in kharif	0.765338
Area sown more than once	Cropping intensity	0.787248
Area sown more than once	Gross cropped area	0.840928
Irrigated area in rabi	Area sown more than once	0.857349
Gross cropped area	Net area sown	0.911101

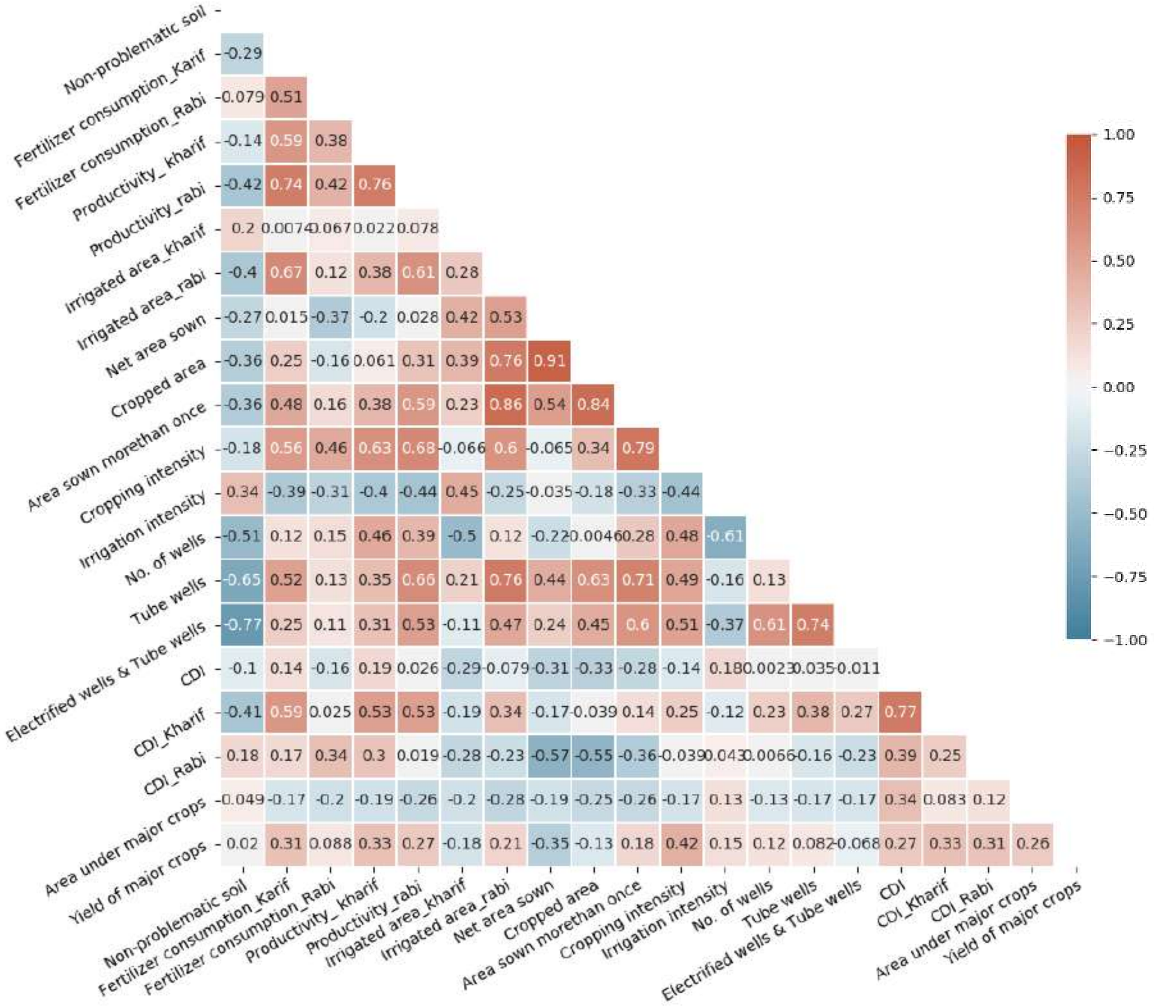

Figure 4.5. Correlation matrix of agriculture indicators.

From Table 4.3, we can observe that the area sown more than once tends to increase with an increase in the number of tube wells. Tube wells can act as the main source of irrigation in districts that have rainfall scarcity and as an alternative source of irrigation in districts during the non-monsoon months. Thus, an increase in the number of tube wells enables the farmers to grow crops more than once, even in months with rainfall scarcity. An increase in the number of tube wells indicates an increase in the area under irrigation, and hence the positive correlation between them. Likewise, with an increase in the area under irrigation (tube wells, etc.), there will be an increase in the area sown more than once and gross cropped area, hence the positive correlation between them.

There is a strong positive correlation between the following variables: area sown more than once and cropping intensity. An increase in cropping intensity implies an increase in the gross cropped area relative to the net cropped area, which means there is an increase in the area sown more than once. High cropping intensity indicates a higher proportion of land is being cropped more than once a year. This also explains the positive correlation of gross cropped area with area sown more than once and net area sown. We can also observe a strong positive correlation between agriculture productivity and fertiliser consumption, which stems from the fact that sustained crop productivity requires a constant supply of nutrients for better plant growth (Yousaf et al., 2017).

A high correlation among variables indicates redundancy, and PCA is used to reduce the redundancy in data. PCA reduces the original variables to fewer uncorrelated variables (PCs). PCA is applied on 20 agriculture indicators, and the first PC, which explains 89.55% of the variance in the data, is selected. The coefficients of the first PC are normalised to obtain the indicator weights (Table 4.4). Two indicators – productivity in kharif and productivity in rabi – contributed the most to agriculture vulnerability, together accounting for 92% weightage. Agriculture productivity in Rajasthan is dependent on fertiliser consumption, cropping intensity, crop diversification index, percentage of irrigated area, number of tube wells and number of electrified wells & tube wells (Based on correlation map, with correlations > 0.5)

Table 4.4. Coefficients of the first principal component

S. No.	**Indicator**	**Coefficients (N_{1j})**
1	Area of Non-problematic soil (%)	-0.116
2	Fertiliser consumption in kharif (Kg/ha)	1.752
3	Fertiliser consumption in rabi (Kg/ha)	1.270
4	Productivity in kharif (Kg/ht)	33.858
5	Productivity in rabi (Kg/ht)	57.937
6	Irrigated area in kharif (%)	0.043
7	Irrigated area in rabi (%)	0.651
8	Net area sown (%)	-0.042
9	Cropped area (%)	0.454
10	Area sown more than once (%)	0.496
11	Cropping intensity (%)	0.964

12	Irrigation intensity	-1.178
13	No. of wells (per km^2)	0.127
14	Tube wells (per km^2)	0.085
15	Electrified wells & tube wells (per km^2)	0.138
16	Crop Diversification Index (CDI)	0.0003
17	CDI kharif	0.007
18	CDI rabi	0.0008
19	Change in the area of major crops	-0.292
20	Change in the yield of major crops	0.581

Agriculture Vulnerability Index (AVI) for each district is computed using the first PC, which is a linear combination of original indicators. The AVI is computed using the following equation:

$$AVI = (-0.118)\ A_{soil} + 1.768\ A_{fert\_kharif} + 1.282\ A_{fert\_rabi} + 34.159\ A_{prod\_kharif} + 58.453\ A_{prod\_rabi} + 0.044\ A_{irri\_kharif} + 0.657\ A_{irri\_rabi} + (-0.043)\ A_{netArea} + 0.458\ A_{grossArea} + 0.501\ A_{MoreThan1} + 0.973\ A_{crop\_Int} + (-1.189)\ A_{irr\_Int} + 0.129\ A_{wells} + 0.087\ A_{tubewells} + 0.140\ A_{ele\_wells} + 0.0003\ (A_{cdi}) + 0.007(A_{cdi\_kharif}) + 0.0008\ (A_{ecdi\_rabi}) + (-0.292)\ (A_{area\_growth}) + 0.581\ (A_{yield\_growth})$$

The ranking of districts is based on the index value – the higher the vulnerability score, the lower the vulnerability. The AVI scores are represented spatially on a map (Fig. 4.6), and one can see the spatial clustering of districts. The districts with the highest agriculture vulnerability are clustered in the west, those with high vulnerability are clustered in the central part, and the districts with the least vulnerability are clustered in the east. To quantify the spatial autocorrelation of agriculture vulnerability, we compute the Moran's I index, and the details are shown in Table 4.5.

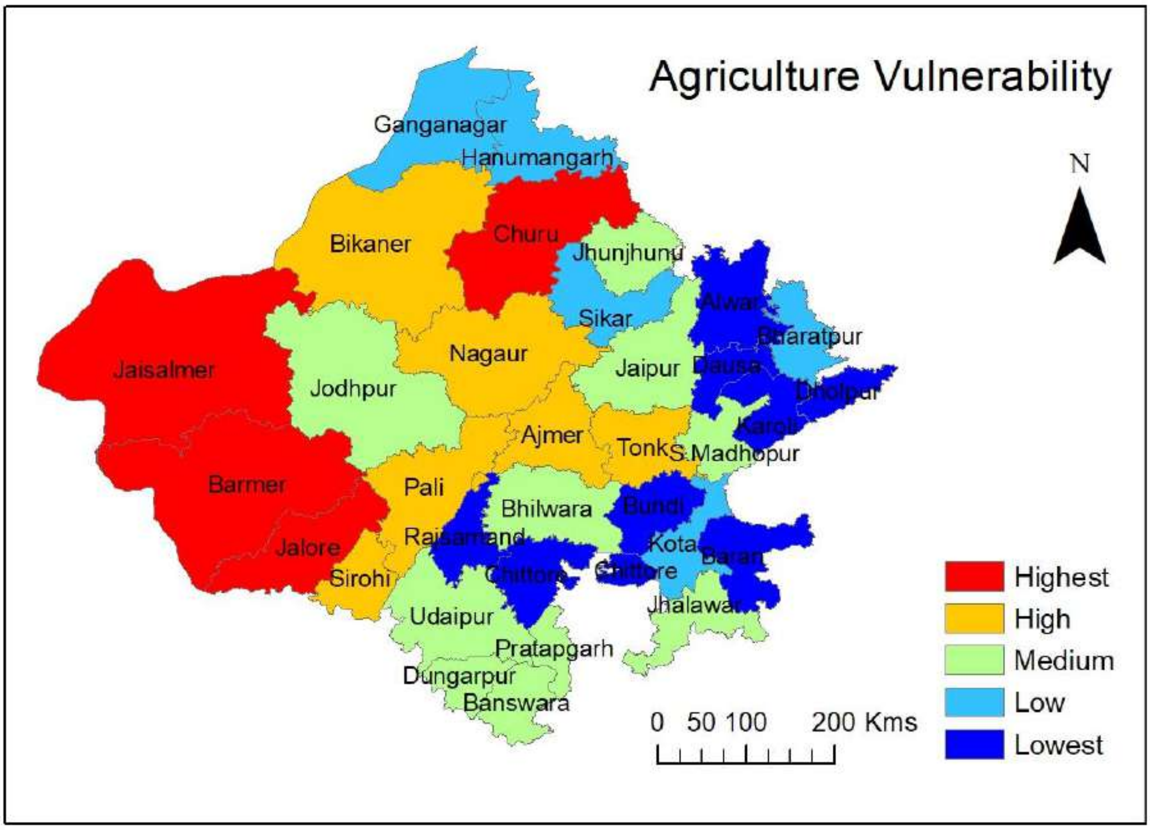

Figure 4.6. District-wise agriculture vulnerability in the state of Rajasthan

Table 4.5. Spatial autocorrelation details (Moran's I) of agriculture vulnerability

Measurement	**Value**
Moran's Index:	0.287
Expected Index:	-0.031
Variance:	0.009
z-score:	3.342
p-value:	0.000831

With a p-value less than 0.01, the observed autocorrelation of AVI is pretty significant. Given the z-score of 3.36, there is a less than 1% likelihood that this clustered pattern could be the result of random chance. Thus, agriculture vulnerability is spatially varying in the state of Rajasthan. To explain the spatial characteristics of agriculture vulnerability and measure its dependence on hazard variability in Rajasthan, we construct the Hazard index of the state.

4.5.2. Hazard

Variables that determine climate hazard variability are collected, such as annual rainfall, monsoon rainfall, deviation from normal rainfall, deviation from monsoon rainfall and drought occurrence. After the data pre-processing, a correlation matrix is constructed for the five variables (Fig. 4.7). The correlation between the variables normal annual rainfall and normal monsoon rainfall is 1, which means that the increase in the normal annual rainfall is perfectly correlated to the increase in monsoon rainfall. We can infer that the rainfall in the state mostly occurs in the monsoon season. Owing to the perfect linear relationship, we exclude one of the two indicators to reduce the redundancy of the data. From the correlation matrix, we can also observe that the indicator deviation from normal annual rainfall has negative correlations with the other indicators.

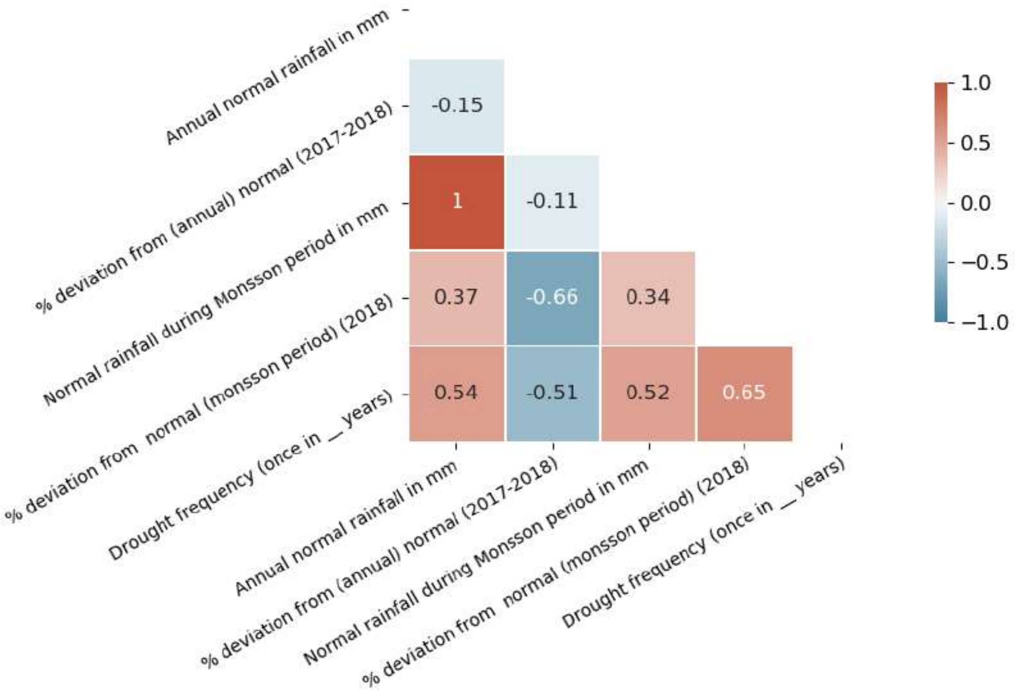

Figure 4.7. Correlation matrix of hazard indicators.

We used the same methodology and applied the PCA technique to assign weights for the hazard indicators. The first PC explained 94.9% of the variance in the hazard data. The coefficients of the first PC are normalised to obtain indicator weights; refer to Table 4.6. We can notice that the indicator- normal annual rainfall influences the most with more than 92% weightage. Each district’s hazard index (HI) is derived using the first PC, a linear combination of original indicators.

The equation used for deriving the HI score for each district is given as follows:

$HI = 92.57\ E_{annual\_rain} + (-2.996)\ E_{annual\_dev} + 1.282\ E_{mons\_dev} + 34.159\ E_{drought}$

Table 4.6. Coefficients of the first principal component in hazard analysis

Indicators	Coefficients (N_{1j})
Annual normal rainfall	92.57298
Deviation of annual rainfall from normal	-2.99634
Deviation of monsoon rainfall from normal	4.121522
Drought frequency (once in __ years)	0.309163

The HI scores of the districts are represented spatially (see Fig. 4.8), and there is clear spatial clustering of districts. Districts with the highest hazard variability are clustered along the west and north-west border of the state, and it coincides with the arid climate zone in that area. Districts with the lowest hazard variability are clustered towards the south of the state, and this coincides with the humid climate zone of the state. A Moran's I index value of 0.408 with a p-value of 0.000005 shows that the observed autocorrelation of hazard index is statistically significant; the details are shown in Table 4.7. Given the z-score of 4.58, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Table 4.7. Spatial autocorrelation details (Moran's I) of hazard

Measurement	**Value**
Moran's Index:	0.408407
Expected Index:	-0.031250
Variance:	0.009226
z-score:	4.577155
p-value:	0.000005

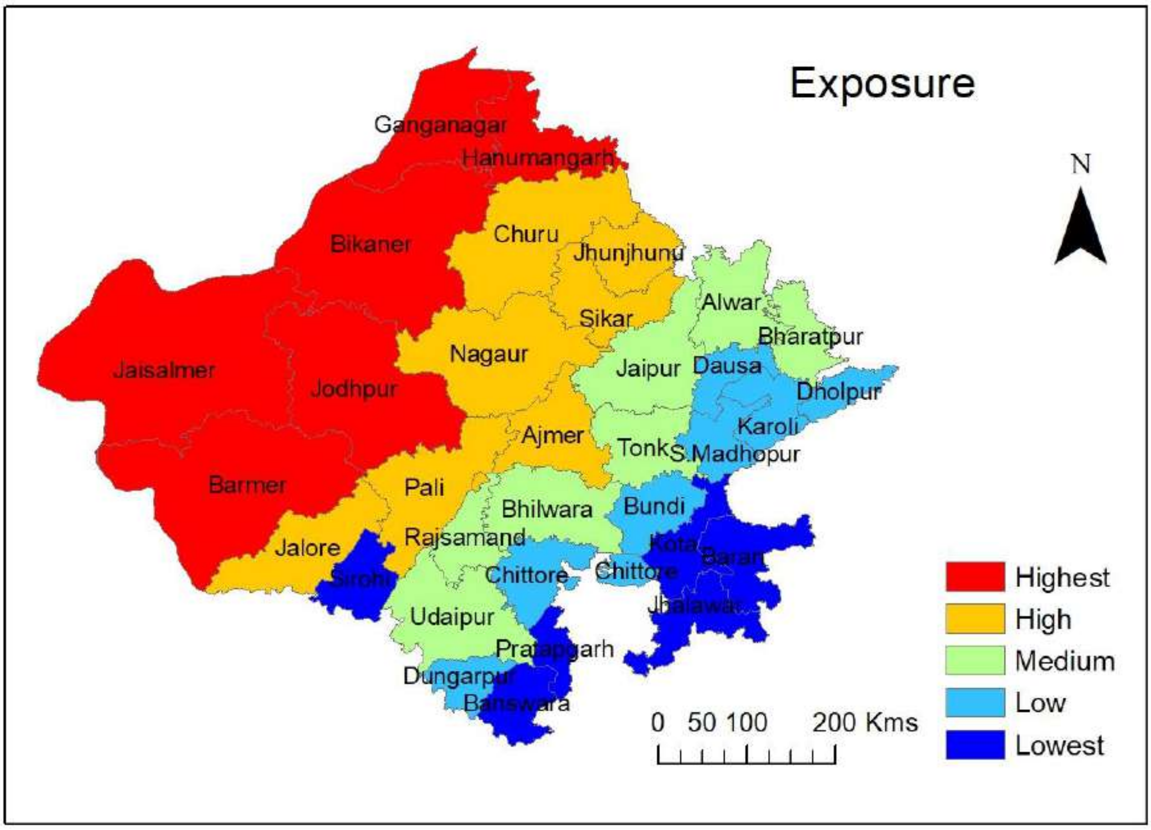

Figure 4.8. District-wise hazard in the state of Rajasthan.

Apart from spatial autocorrelation, we checked for a correlation between AVI and HI scores to understand the effect of hazard on agriculture vulnerability. The results show a positive correlation with a Pearson correlation coefficient of 0.487 and a Spearman correlation coefficient of 0.460. Thus, agriculture vulnerability in Rajasthan is linearly dependent on hazard variability in the state. That is, the districts with high hazard variability tend to have high agriculture vulnerability. The district-wise indices and district-wise ranking of agriculture vulnerability and hazard are given in Table 4.8.

Table 4.8. Ranking the districts of Rajasthan based on agriculture vulnerability and hazard.

Districts	**Agriculture Vulnerability Index**	**Rank**	**Hazard Index**	**Rank**
Barmer	0	1	11.47	3
Jaisalmer	6.18	2	0	1
Churu	12.72	3	25.76	7
Jalore	14.62	4	32.57	9

Pali	23.68	5	40.88	12
Bikaner	23.81	6	12.92	4
Sirohi	25.72	7	98.12	31
Tonk	31.29	8	58.67	16
Nagaur	31.56	9	29	8
Ajmer	34.06	10	38.14	10
Jodhpur	41.9	11	17.1	6
Dungarpur	42.5	12	67.23	22
Banswara	44.5	13	94.8	30
S.Madhopur	46.67	14	73.41	25
Jhunjhunu	49.22	15	40.88	13
Udaipur	51.34	16	61.93	20
Pratapgarh	51.35	17	99.3	32
Jhalawar	53.4	18	100	33
Jaipur	54.27	19	53.8	15
Bhilwara	55.3	20	60.81	18
Sikar	60.79	21	38.76	11
Hanumangarh	62.08	22	16.51	5
Bharatpur	62.76	23	59.93	17
Ganganagar	63.9	24	10.04	2
Kota	68.53	25	84.89	28
Bundi	70.78	26	71.06	24
Chittaurgarh	71.32	27	79	27
Dausa	71.62	28	66.98	21
Karoli	72.6	29	69.87	23
Rajsamand	73.28	30	50.47	14
Alwar	73.79	31	61.04	19
Baran	74.61	32	91.06	29
Dholpur	100	33	73.45	26

4.6. Summary

A positive correlation between agriculture vulnerability and hazard variability has been observed. Therefore, the districts with high hazard variability also tend to have high agriculture vulnerability. The four districts named Barmer, Jaisalmer, Churu, and Jalore have the highest agriculture vulnerability in the state of Rajasthan, and the districts of Bundi, Chittore, Dausa, Karoli, Rajsamand, Alwar, Baran, and Dholpur have the lowest agriculture vulnerability. Among the four districts which have the highest agriculture vulnerability, two districts named Barmer and Jaisalmer ranked highest in climate hazard variability, and the other two districts – Churu and Jalore, ranked high in hazard.

AVI and HI have shown only moderate linear correlation with a Pearson correlation coefficient of 0.487. We identified the districts that did not obey the linear correlation and found few districts with low agriculture vulnerability despite high hazard variability. For example, Ganganagar and Hanumangarh districts ranked very high in hazard but very low in agriculture vulnerability, which can be due to their very high irrigation intensity and net area sown. In contrast, despite ranking very low in hazard, the district of Sirohi ranked highest in the agricultural vulnerability, which can be due to extremely low productivity in kharif and rabi seasons. Only 9.6% of the total Sirohi district area is irrigated in the rabi season, as against 68% of irrigated areas in the Bharatpur district. Sirohi district is also among the bottom ten districts in terms of cropped area, net area sown, percentage of irrigated area, area sown more than once, etc. Therefore, we can infer that even if rainfall is scarce in a district, agriculture will not be adversely affected if the irrigation facilities are adequate. An increase in the irrigation facilities such as canals, tube wells and wells can reduce the dependence of agriculture on rainfall and increase the security for crops, thus increasing the cropped area and productivity.

From the PCA analysis, it is found that crop productivity is the single most important factor influencing agriculture vulnerability. Agriculture productivity in Rajasthan is highly correlated with fertiliser consumption, cropping intensity, percentage of irrigated area, number of tube wells, and number of electrified wells & tube wells. It is beneficial to study and probe the means available to improve agriculture productivity in the state. Therefore, measures to enhance crop productivity and reduce the dependence of agriculture on climate change induced extreme weather events are proposed for the state of Rajasthan.

4.7. Measures & Recommendations to Reduce Agriculture Vulnerability

1. There is an increase in the intensity and magnitude of extreme weather events, and it is further expected to increase due to climate change. The agriculture sector's share in gross value added in Rajasthan has declined from 28.56% in 2011-12 to 25.19% in 2019-20 (at constant prices). Therefore, more investment is required in the agriculture sector to increase agriculture productivity despite increasing climate exposure.
2. An increase in the use of technology and infrastructure can increase the adaptive capacity and reduce the agriculture vulnerability of the state. Advanced devices and technologies such as temperature and moisture sensors, rain gauges, GPS, aerial and satellite imagery, solar irrigation and drip irrigation facilities can make agriculture practices more environmentally friendly and safer for farmers. The state should encourage technological aids for agricultural operations and marketing (For example, mKRISHI app can help farmers get personalised advice and updated information on their mobile phones about factors that may affect their crops, such as weather).
3. Farmers need to be periodically educated on the impacts of climate change on agriculture, efforts that can reduce climate impacts, the threat of climate change on farmers' livelihood, agricultural developments and adaptation strategies. Since human perceptions depend not just on an individual's personality but also on the community, awareness campaigns for farmers at the community level should be encouraged.
4. Due to issues such as scant rainfall and water shortage in the major part of the state, several measures need to be taken by the state and farmers to **increase agricultural crop productivity.** Despite high levels of production, agricultural yield in India is lower than that in other large producing countries. Various measures that can be taken to improve crop productivity are as follows:
    A. **Diversification of crops** can shield farmers against the vagaries of nature by giving them a wider choice. Farmers can opt for value-added crops and new crop species/varieties. They can rotate crops based on water availability to bring down the possible risk of crop failure. For example,

where water is scarce, farmers should switch from water-intensive crops such as wheat and barley to less water-intensive crops such as millets, soybean and legumes. The focus should be on the districts in high vulnerability clusters and the districts of Jaisalmer, Barmer, and Rajasmand, which have the least diversification of crops in the state of Rajasthan.

B. Indiscriminate use of groundwater for water-intensive crops will lead to rapid depletion of underground water. Sensitising farmers on **less water-intensive crops** and training them on **arid horticulture** will help mitigate the water crisis. Farmers should sow crops consuming less irrigation water and join the efforts for water conservation. Krishi Vigyan Kendra (KVK), which periodically tests soil and informs the farmers about feasible crops, also needs to educate and train farmers on arid horticulture.

C. Farmers should be encouraged to **adopt rainwater harvesting** to collect run-off rainwater for use in crop irrigation, which will make farming more sustainable. Construction of rainwater tanks at the household level and construction of ponds or tanks at the community or village level should be promoted. Optimum use of water resources will deliver positive results in the future. Provision for rainwater harvesting should be made essential for digging tube wells.

D. Farmers should adopt **water management systems** such as sprinklers and drip irrigation systems. While drip irrigation is more cost-effective for individual plant watering, the sprinkler system can easily cover a large area of land. Farmers can adopt a combination of both based on their requirements. Automated water irrigation systems need to be encouraged. The government should train farmers on water management and how to use water for different crops.

E. Irrigation efficiency can be improved by altering farming practices such as crop rotation and conservation tillage. Farmers should be encouraged to do conservation tillage to reduce erosion by protecting the soil surface and allowing water to infiltrate instead of running off.

F. Farmers should adopt **soil conservation practices** to improve soil health. The districts of Sikar, Alwar, Jaipur, Dausa and Bharatpur have the highest percentage of problematic soil in Rajasthan.

a. Soil health can be improved by reducing inversion tillage and excessive tillage, using cover crops, reducing pesticide usage, increasing organic matter input, managing nutrients, and crop rotation.
b. The use of gypsum is an economical and long-term solution for soil conservation as it is used for reclamation of alkali soils and as a nutrient for the oilseed, pulses, and wheat crops. The department of agriculture should encourage small and marginal farmers to benefit from the ongoing gypsum distribution program in the state with the help of local agriculture supervisors at the *gram* level and assistant agriculture officers (AAO) at the panchayat samiti level.
c. Farmers should be encouraged to use organic manures before rains as it will conserve water in the soil. To promote the use of organic fertilisers by farmers, the government should provide fertiliser subsidies to the producers of fertiliser and/or farmers.
d. Soil health cards will help farmers select crop patterns based on the productivity of the land and local agro-climatic conditions.
e. Providing good quality seeds to the farmers will enable farmers to produce more yields per unit area.

G. **Increase in irrigation facilities:** Increase in the number of sources for irrigation water reduces the dependence of agriculture on seasonal rainfall. Jaisalmer, Barmer, Churu, Ajmer, Udaipur, Pratapgarh, Dungarpur, and Banswara districts have very low irrigated areas. The district-wise need for an increase in irrigation facilities is given in Table 4.9. The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) aims to give access to irrigation to all agricultural farms in the country (Har Khet Ko Pani), and the state should initially focus on increasing the number of irrigation facilities in the districts identified (see Table 4.9). Farm ponds which are a solution for storing as well as recharging groundwater, should be built under NREGA. Irrigation facilities such as wells and tube wells should be registered and linked with a renewable energy source.

5. Climate-related risks on the agriculture sector can be reduced by:
   - **A.** Accurate weather predictions & early warning: Disseminating the information through early warning systems about droughts and other climate extreme events will help in timely planning and management of water resources required for agriculture.
   - **B.** Better drought management systems: Measures such as restoring traditional rainwater harvesting systems in the state, rooftop rainwater harvesting, recycling wastewater, timely response for drought-prone population, allocation of irrigation water in drought-prone areas, and engaging communities in management will help the state manage the droughts.
   - **C.** Land use should be delineated based on arid, semi-arid, and assured irrigated areas.
6. **Promoting alternative energy sources** in the agriculture sector, such as solar irrigation, can transform agriculture and enhance the livelihood of small and marginal farmers. Solar irrigation will reduce farmers' dependence on electricity and enable them to irrigate the crops even in the absence of electricity. Solar irrigation is critical for farmers who are dependent on irrigation, and it can enhance cropping intensity and agriculture production.
   - A. The KUSUM Yojana scheme of 2021 aims to change the diesel and petrol operated irrigation pumps to solar operated pumps. Through the installation of solar pumps, the farmers' income will increase as their expenses reduce.
   - B. The small and marginal farmers should be encouraged to adopt solar irrigation with subsidised costs. Integrating solar water pumps with drip irrigation and sprinklers will save more water and ensure improved yield.
7. Considering the state's water scarcity, the government should subsidise water-saving micro-irrigation systems (such as drip or sprinkler irrigation) and solar water pumps for small and marginal farmers.

While these measures are being implemented in Rajasthan, it is important to prioritise the districts that are in dire need of such measures. Since crop productivity is very low for all the districts in the high vulnerability clusters, priority should be given to highly vulnerable districts. District-wise recommendations to reduce agriculture vulnerability are given below in Table 4.9.

Table 4.9. District-wise recommendations

Clusters	Districts	Recommendations
Highest Vulnerability	Barmer	Increase fertiliser consumption (organic), irrigated area, cropped area, area sown more than once, cropping intensity, CDI, number of wells and tube wells and their electrification
	Jaisalmer	Increase fertiliser consumption (organic), irrigated area, net area sown, cropped area, cropping intensity, CDI, number of wells & tube wells and their electrification
	Churu	Increase irrigated area in rabi, fertiliser consumption (organic), area sown more than once, cropping intensity, number of wells/tube wells and their electrification, and area & yield under major crops.
	Jalore	Increase fertiliser consumption (organic) in kharif, cropping intensity, irrigation intensity, number of tube wells and yield under major crops.
High Vulnerability	Pali	Measures to improve soil health; increase fertiliser consumption (organic), irrigated area, cropped area, cropping intensity, irrigation intensity, number of tube wells, and electrification of wells & tube wells
	Bikaner	Increase fertiliser consumption (organic), irrigated area in rabi, area sown more than once, cropping intensity, number of wells, electrification of wells and tube wells and yield under major crops.
	Sirohi	Increase irrigated area in rabi, net area sown, cropped area, area sown more than once, number of wells, tube wells and their electrification, and yield under major crops.
	Tonk	Increase fertiliser consumption (organic) in rabi, irrigated area in kharif, cropping intensity, irrigation intensity, number of tube wells and their electrification
	Nagaur	Increase fertiliser consumption (organic), irrigated area in rabi, area sown more than once, cropping intensity, yield

		under major crops, number of wells, tube wells and their electrification
	Ajmer	Increase fertiliser consumption (organic), irrigated area, irrigation intensity, number of tube wells and their electrification,
	Jodhpur	Increase fertiliser consumption (organic), irrigated area in rabi, area sown more than once, cropping intensity, number of wells and their electrification, and yield under major crops.
	Dungarpur	Increase fertiliser consumption (organic) in kharif, irrigated area, net area sown, cropped area, area sown more than once, cropping intensity, irrigation intensity, number of tube wells and their electrification, and CDI
Medium Vulnerability	Banswara	Irrigated area, cropped area, irrigation intensity, number of tube wells and their electrification, and CDI in rabi
	S.Madhopur	Measures to improve soil health; increase the irrigated area in kharif, irrigation intensity, and area under major crops.
	Jhunjhunu	Increase in fertiliser consumption (organic), irrigated area in kharif, irrigation intensity, and area & yield under major crops
	Udaipur	Increase in irrigated area, net area sown, cropped area, area sown more than once, cropping intensity, irrigation intensity, number of tube wells and their electrification, CDI and yield under major crops
	Pratapgarh	Measures to improve soil health; increase in the irrigated area in kharif, net area sown, cropped area, irrigation intensity, number of tube wells and CDI in kharif
	Jhalawar	Increase in the irrigated area in kharif, irrigation intensity, number of tube wells and area under major crops
	Jaipur	Measures to improve soil health; increase in the irrigated area in kharif, and irrigation intensity

	Bhilwara	Increase fertiliser consumption (organic) in kharif, irrigated area in rabi, net area sown, cropped area, area sown more than once, irrigation intensity and number of tube wells
Low Vulnerability	Sikar	Measures to improve soil health; increase fertiliser consumption (organic), cropping intensity, irrigation intensity, area and yield under major crops
	Hanumangarh	Increase in the number of wells and area under major crops
	Bharatpur	Measures to improve soil health; increase the irrigated area in kharif, irrigation intensity and CDI
	Ganganagar	Increase in the number of wells and their electrification, area and yield under major crops
	Kota	Increase in irrigation intensity and number of wells
Lowest Vulnerability	Bundi	Increase in net area sown, irrigation intensity and CDI in Rabi
	Chittore	Increase in the irrigated area in kharif, net area sown, cropped area, irrigation intensity and CDI in rabi
	Dausa	Measures to improve soil health; increase in the irrigated area in kharif, irrigation intensity, CDI, and area under major crops
	Karoli	Increase in net area sown, cropped area, irrigation intensity, CDI, and area under major crops
	Rajsamand	Increase fertiliser consumption (organic) in kharif, irrigated area, net area sown, cropped area, area sown more than once, irrigation intensity, number of tube wells and their electrification, and CDI
	Alwar	Measures to improve soil health; increase in the irrigation intensity, and CDI
	Baran	Increase in the irrigated area in kharif, irrigation intensity, and area under major crops
	Dholpur	Measures to improve soil health; increase net cropped area, irrigated area in kharif, irrigation intensity, and CDI

Chapter 5

Urban Governance and Sustainable Habitat

As one India's largest states in terms of area, Rajasthan is well known for its highly evolved urban planning practices. With arid lands and deserts characterizing its geographic and agro-climatic conditions, the cities of Rajasthan have evolved to become environmentally sensitive and climate responsible models to deal with problems of severe heat and cold, water scarcity, variable and low precipitation, droughts and heat waves. Town planning, urban design, water management (harvesting, collecting storing, and conservation), agro-forestry, building design, and common pool resource management – all of these offer rich models and insights to reimagine sustainable urban development pathways that can help Rajasthan's cities and population settlements to adapt better to climate change and reduce vulnerabilities.

5.1. Background

Rajasthan's urbanization has historically been lower compared to global and national trends, with around 25-30% of the population currently living in cities (Fig. 5.1). As per the 2011 census, the total urban population of the state is 1.7 crores (Fig. 5.2).

The state has a large number of small cities, while Jaipur, Jodhpur, Kota, Bikaner, Ajmer, and Udaipur constitute the main urban centres with fairly large populations (Fig. 5.3). They are continuing to grow due to industrialization, mining, tourism, education, etc. Kota, Jaipur, Ajmer, Jodhpur, Bikaner, Churu, and Ganganagar are the districts with 30% and above urban populations.

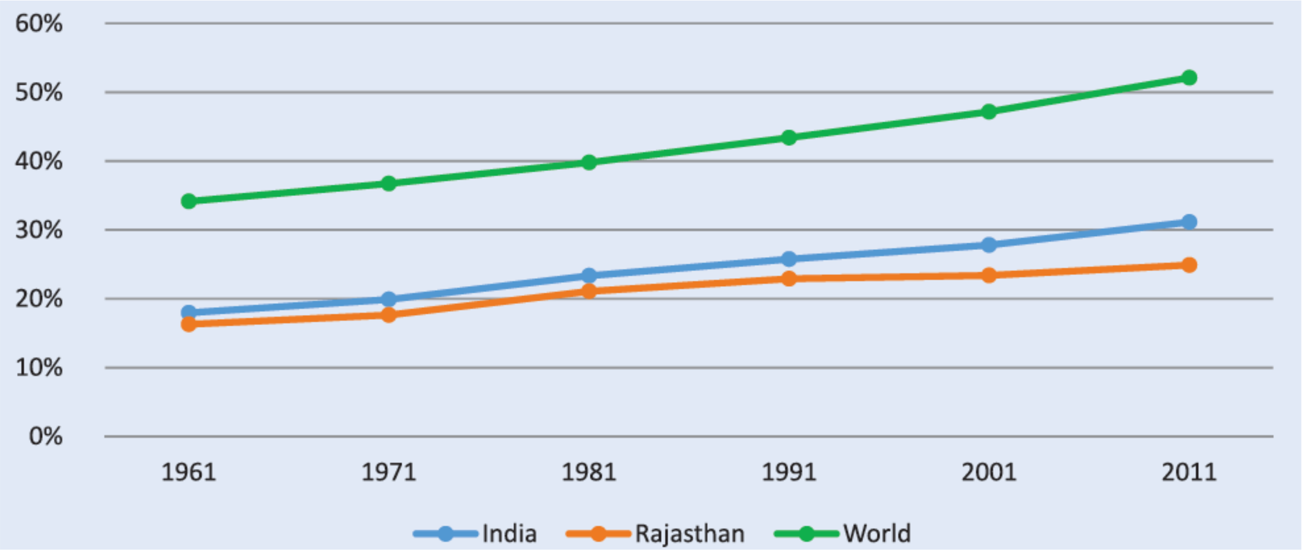

Figure 5.1. Urban population as percentage of total population.

Source: Rajasthan Economic Review, 2019-20

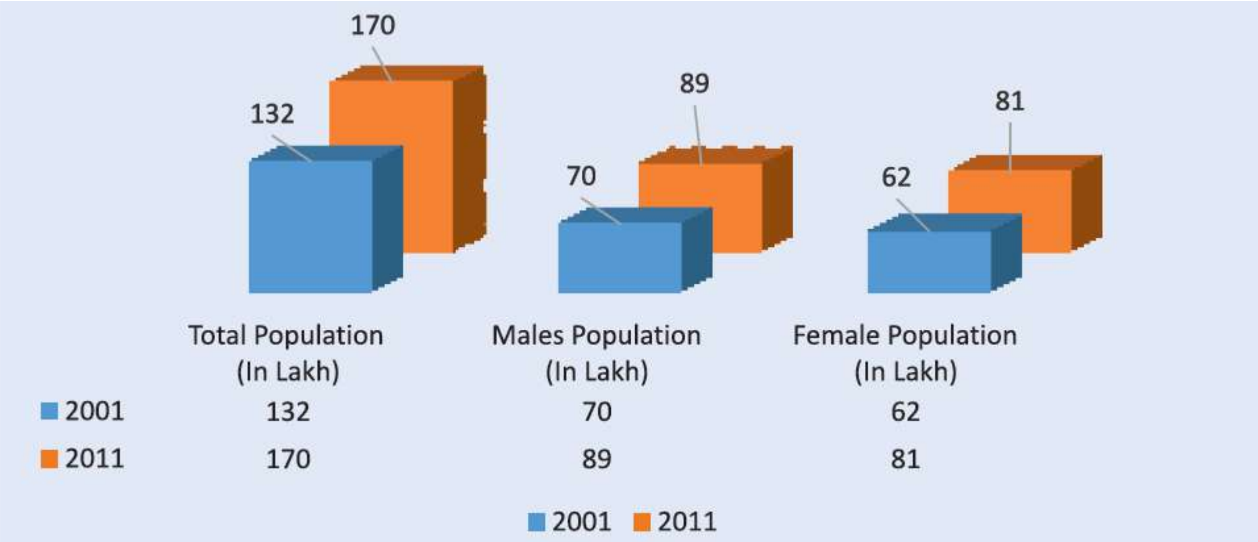

Figure 5.2. Break-up of urban population in Rajasthan.

Source: Rajasthan Economic Review, 2019-20

The first three are the most urbanized districts of Rajasthan, with more than a million people. While Jaipur is the largest city with a population of over three million, many more cities, both in the National Capital Region (NCR) region of eastern Rajasthan and in the tourist dominated cities of southern and western Rajasthan, are likely to join the million plus group, (Fig. 5.5). These will create new vulnerabilities especially as growing populations will put pressure on water, land, forests and air quality.

Figure 5.3. Map of Rajasthan showing main urban centres.

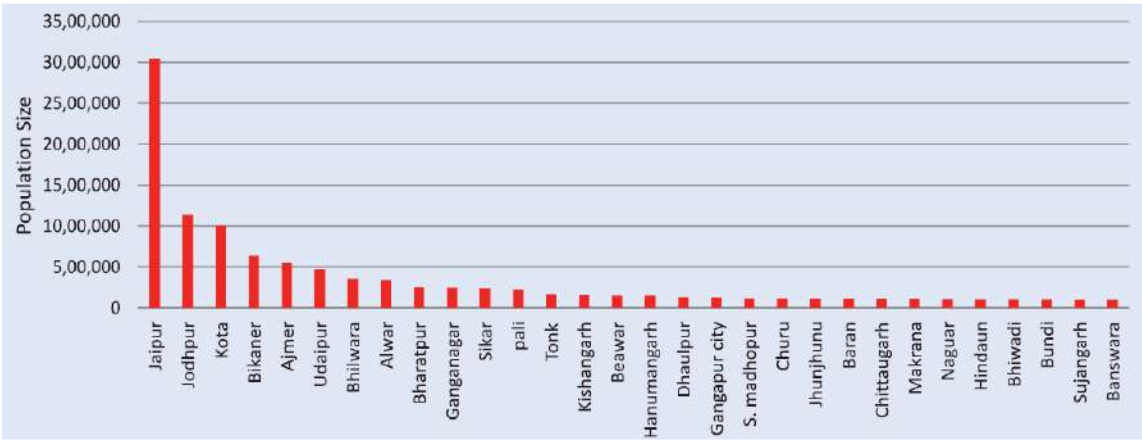

Figure 5.4. Cities of Rajasthan with population of one lakh and above.

Source: Rajasthan Economic Review, 2019-20

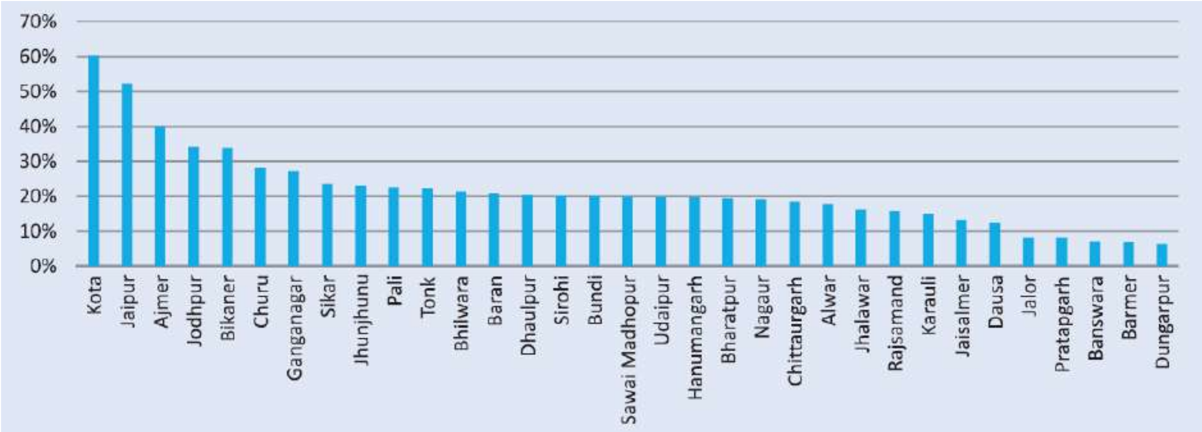

Figure 5.5. Urban population as percentage of total population of the district.

Source: Rajasthan Economic Review, 2019-20

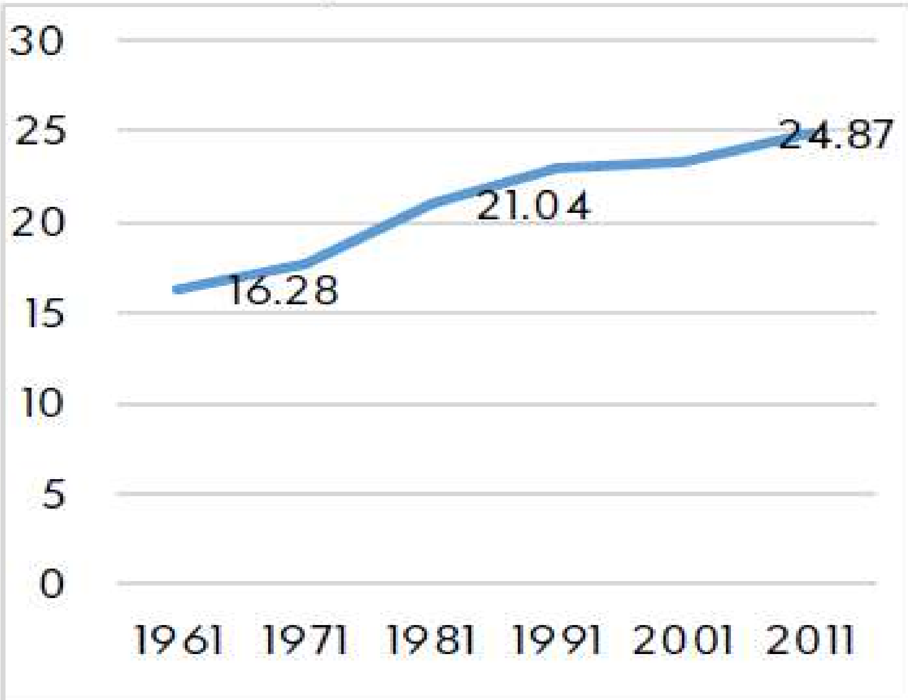

Figure 5.6. Increasing level of urbanisation in Rajasthan.

Source: Rajasthan urban development policy

As per current projections, Rajasthan's urban population is likely to increase from 24.96% of its total population in 2011 to 28.53% in 2036, which is still below the national average but higher than its neighbouring north India states such as Uttar Pradesh and Bihar (Fig. 5.6). Only Kota, Jaipur, Ajmer, Jodhpur and Bikaner have proportions of urban population higher than the national average, but the other 28 out of 33 districts are below the national average (see Table 5.1 and Table 5.2). In view of impending urban growth, and as is already evident from existing state urban development policies, there is immense scope for making urbanization in Rajasthan more climate friendly, better adapted to climate change impacts and environmentally sustainable. An analysis of 297 urban centres (as per 2011 Census) shows that increase in census towns in western Rajasthan districts is negligible, and urban growth is more concentrated in eastern and some parts of southern Rajasthan (Rajasthan Urban Development Policy 2017). However, with a CAGR of 3.19%, which is higher than the national average (Rajasthan Urban Development Policy 2017), Rajasthan is experiencing an urbanization boom due to the thriving and expanding tourism sector, rapid educational advancements, expansion of roads, freight / industrial corridors and highways, growth of the mining and industrial sector, and transport expansion. The steady growth of urban centres offers promise of economic and social development, while also posing new challenges for climate vulnerability, mitigation and adaptation.

Table 5.1. Level of urbanization in the districts of Rajasthan

S. No	**Level of Urbanization**	**Districts**
1	More than 40 per cent	Kota, Jaipur and Ajmer
2	24.1 per cent to 40 per cent	Ganaganagar, Churu, Bikaner and Jodhpur
3	16.1 per cent to 24.0 per cent	Jhalawar, Alwar, Chittaurgarh, Bharatpur, Hanumangarh, Udaipur, SawaiMadhopur, Bundi, Sirohi, Dhaulpur, Baran, Nagaur, Bhilwara, Tonk, Pali, Jhunjhunu and Sikar
4	8.4 per cent to 16.0 per cent	Dausa, Jaisalmer, Karauli and Rajsamand
5	8.3 per cent and below	Jalore, Pratapgarh, Banswara, Barmer and Dungarpur

Source: Census of India, 2011

Table 5.2. Level of urbanization in Rajasthan

Sr. No.	District	Total Population	Urban Population	Urban Pop. As % to Total Pop.
1	Kota	1951014	1176604	60.3
2	Jaipur	6626178	3471847	52.4
3	Ajmer	2583052	1035410	40.1
4	Jodhpur	3687165	1264614	34.3
5	Bikaner	2363937	800384	33.9
6	Churu	2039547	576235	28.3
7	Ganganagar	1969168	535432	27.2
8	Sikar	2677333	633906	23.7
9	Jhunjhun	2137045	489079	22.9
10	Pali	2037573	460006	22.6
11	Tonk	1421326	317723	22.4
12	Bhilwara	2408523	512654	21.3
13	Nagaur	3307743	637204	21.3
14	Baran	1222755	254214	20.8
15	Dhaulpur	1206516	247450	20.5
16	Sirohi	1036346	208654	20.1
17	Bundi	1110906	222701	20.0
18	Sawaimadhopur	1335551	266467	20.0
19	Udaipur	3068420	608426	19.8
20	Hanumangarh	1774692	350464	19.7
21	Bharatpur	2548462	495099	19.4
22	Chittaurgarh	1544338	285264	18.5
23	Alwar	3674179	654451	17.8
24	Jhalawar	1411129	229291	16.2
25	Rajsamand	1156597	183820	15.9
26	Karauli	1458248	218105	15.0

Sr. No. District Total Population Urban Population Urban Pop. As % to Total Pop.

27	Jaisalmer	669919	89025	13.3
28	Dausa	1634409	201793	12.3
29	Pratapgarh	867848	71807	8.3
30	Jalor	1828730	151755	8.3
31	Banswara	1797485	127621	7.1
32	Barmer	2603751	181837	7.0
33	Dungarpur	1388552	88743	6.4

Source: Census 2011

The spatial variation and skewness in urbanization in terms of regional spread and proportion of urban population (see Table 5.3) indicates the need for a more decentralized, regional and district wise approach to climate action plans, since it is the integrated variability of demographic factors and climate impact exposure that determines vulnerability and adaptive capacity.

Table 5.3. Spatial variation in the levels of urbanization in Rajasthan

Sr. No.	**Levels in Urbanization**	**Districts**
1	Very Low (8.3% and below)	Dungarpur, Barmer, Banswara, Jalor & Pratapgarh
2	Low (8.4 to 16.0%)	Dausa, Jaisalmer, Karauli & Rajsamand.
3	Moderate (16.1 to 24.0%)	Jhalwar, Alwar, Chittaurgarh, Bharatpur, Hanumangarh, Udaipur, Sawaimadhopur, Bundi, Sirohi, Dhaulpur, Baran, Nagaur, Bhilwara, Tonk, Pali, Jhunjhunun, Sikar, Ganganagar & Churu
4	High (24.1 to 40%)	Ganganagar, Churu, Bikaner & Jodhpur
5	Very High (More than 40%)	Ajmer, Jaipur & Kota

Source: Census 2011

5.2. Current Vulnerability

From heat waves to variability and changes in precipitation trends, floods and droughts, Rajasthan is experiencing/projected to be exposed to a multitude of climate hazards. Global climate change, regional variations and anthropogenic factors, including land use change and urbanization, affect sensitivity and exposure to climate change impact and in turn influence the state's vulnerability and adaptive capacity.

While high elevation regions such as Ajmer, Chittaurgarh, Bhilwara, Alwar, Udaipur and Sikar are not projected to be affected by high mean temperatures in the future, studies show that Jaipur, Nagaur, Bikaner, Banswara, Jhalawar and Jodhpur will all experience a significant increase in mean temperature (Sharma et al., 2018). The western region of the state close to the Thar desert are particularly like to experience heat waves and increase in mean and maximum temperatures (Sharma et al., 2018). Pradhan et al. (2019) analysed changes in rainfall patterns and simulated climate models for future projections over the state of Rajasthan. Future precipitation trends indicate a possible decrease in precipitation for short-and long-term periods up to 2100 across the state (Pradhan et al., 2019). However, there is some regional variability, with Banswara projected to experience maximum rainfall decrease, while Alwar, Churu and Ganganagar are slated to experience an increase in rainfall (Pradhan et al., 2019). This has implications for water scarcity in urban centres, flood risk management, groundwater recharge and economic development in general, particularly the tourism and industrial / mining sectors which are water intensive and sensitive to precipitation related extremes and disasters. Dry spells are projected to increase in the west and south-west parts of the state, while they are predicted to decrease in the eastern and central regions, especially in Ajmer district (Pradhan et al., 2019). Urban hydrologists and managers of sewerage, drinking water supply, wastewater and storm water drains need to constantly update the future scenarios in order comprehend the changing precipitation patterns and plan for mitigating water scarcity and flood related disasters.

Pingale et al. (2014), in their comprehensive assessment of climate change in cities in Rajasthan, have predicted significant warming trends on both annual and seasonal scales, across most of the cities by analysing changes in minimum, mean and maximum temperatures, as well as in extreme rainfall events. There is large variation across the state for both these indicators. Local stakeholders need to understand exposure, risks and vulnerabilities from changing trends in precipitation and temperature, and they need to develop spatial maps at the district, sub-district and city levels, especially in the north-eastern and western regions where statistically significant increasing trends in annual daily minimum temperatures and an increase in maximum temperatures are already being observed (Pingale et al., 2014). Urban areas in Sikar district are especially witnessing a significant increasing trend in annual minimum daily temperature. Cities in the south and eastern parts of Rajasthan (Banswara, Baran, Bundi, Chittorgarh, Jhalawar, Pali, Sirohi, Churu and Jaipur) as well as Jaisalmer in the west are witnessing a significant increasing trend in the daily maximum temperature (Pingale, 2014). Warming trends in urban areas of Rajasthan are indicated by the range in the annual maximum daily temperature – maximum value of Sen's slope (0.049°C/year) and percentage change (3.86%) in Jhalawar and the minimum value of slope (0.029°C/year) and percentage change (2.35%) in Sirohi (Pingale, 2014). Studies show that these warming trends can be attributed to anthropogenic factors, which are further exacerbated at local levels through changes in Land Use Land Cover, industrialization and urbanization. An increase of .01 to 0.05°C/year in average temperature is observed in around 80% of the cities and towns in Rajasthan (Pingale et al., 2014). Increase in temperature is also observed in the monsoon average maximum temperature, increasing discomfort for urban populations and possibly leading to an increase in cooling-related energy use and emissions. Cities in the south-eastern and south-western parts of the state are likely to be more affected by temperature rise due to climate change. The increase is likely to be in the range of 0.03 to 0.05 °C/year for some of the cities in the southern, eastern and western parts of the state – Banaswara, Baran, Bundi, Chittorgarh, Jhalawar, Pali, Sirohi, Churu, Jaipur and Jaisalmer (Pingale et al., 2014).

Overall projections for future anomalies in maximum mean surface temperature across different states in India, show that the changes in temperature in western dry regions of Rajasthan will be in the range of 1.63 to 4.6 degrees, making the cities in this region more vulnerable to heat waves and droughts and affecting water availability (Vishnoi et al., 2015). Under RCP 4.5 and 8.5 scenarios, Jaipur, Kota, Ajmer and Udaipur from Rajasthan are identified at the national level as cities located in severe drought prone regions. Along with temperature rise, humidity will also increase by 7%, exacerbating the impacts of heatwaves. When most parts of India faced an intense heatwave in 2010 for instance, the most affected state was Rajasthan, with Kota observing the highest ever temperature of 48.4 degrees (Feroz, 2012).

When it come trends in monsoon rainfall, it is well known that the low rainfall is a historical pattern in Rajasthan. Pingale et al. (2014) show that there is a significant decreasing trend of average monsoon rainfall in urban areas of Rajasthan, going up to -8.56 mm/hydrologic year for Tonk and -88.16% for Jodhpur. Interestingly, a significant increasing trend in non-monsoon rainfall is also predicted for some districts (Hanumangarh), while decrease in non-monsoon rainfall in projected for Chittaurgarh. Such trends are in alignment with regional climate models indicating significant spatial and temporal variability in precipitation patterns. An overall decrease in annual average rainfall is observed for Tonk and Jodhpur, which may possibly affect the tourism sector and the economics and livelihoods dependent on tourism in the latter city. While cities and towns in Hanumangarh, Karauli, Nagaur, Sikar and Tonk are witnessing significant decreasing trends as well as variability in annual extreme daily rainfall (ranging from -49.16% to -65.14%), a significant increasing trend was observed only in Jhalawar (45.97%). For a state that is already water scarce and faced with increasing demand for water, this trend is quite worrying and will most likely enhance existing vulnerabilities while contributing to emerging risks. Jodhpur is also seeing significant decreasing trends in average monsoon rainfall (-88.16%), indicating extreme vulnerability. Dungarpur and Chittaurgarh towns are also observing significant decrease in non-monsoon average rainfall (-58.1% and -80.29% respectively). However, it is predicted that Hanumangarh will see a significant increasing trend in non-monsoon precipitation (102.85%). The increase in precipitation in some cities and towns and decrease in other urban centres indicate different kinds of vulnerabilities relating to water scarcity, depletion of ground water and flooding / water logging in different urban areas of Rajasthan. Local level anthropogenic variables such as land use/land cover (LULC) may also contribute to these spatial variations and vulnerabilities. Also, studies show that in eastern Rajasthan, increase in frequency of rain days does not convert into increase in rainy days, indicating that the overall intensity of rainfall and quantity of rainfall is not increasing. On the other hand, some research also reveals an increase in high intensity rainfall events in the same region, pointing to both the uncertainty in climate models and the variability of precipitation trends (Pingale et al., 2014).

Studies for specific cities in Rajasthan such as Kota and Udaipur point to the serious nature of exposure to climate change impacts, as well as the specific nature of vulnerabilities for groups such as women, children, slum dwellers and the urban poor. These groups are much more exposed to the impacts of flooding and heat waves than others in a variety of ways. For Udaipur (Mani et al., 2017), the climate change impacts on the children from urban poor households include those on health, nutrition, education, child protection / abuse and WASH (water, sanitation and hygiene). These impacts are seen to be influenced by seasonal variations in local climate and weather, temperature variation and seasonal variability in rainfall. Projected changes in both temperature and rainfall indicate a severe quantum of emerging risks particularly for the urban poor children (Mani et al., 2017). While there is no significant trend in mean maximum temperature in Udaipur, there is a high increase in seasonal mean maximum temperature in the post-monsoon season, and an increasing trend in summer season maximum temperatures with an increase in number of days above 40° C (Mani et al., 2017). These two periods significantly affect schooling and the incidence of water-related illnesses and heat strokes among children. Higher temperatures in winter season are also observed. The number of hot days and warms nights are also slated to increase in Udaipur. Since the urban poor are spatially distributed in specific locations of Udaipur, vulnerable hotspots of climate change include flood risk zones and heat wave zones, as well as slums and informal settlements which are more exposed to these risks. Winter-season rise in temperatures affect disease vectors resulting in enhanced health-related risks for children in urban poor households in Udaipur (Mani et al., 2017).

Projections from RCM models for Udaipur indicate increase in mean annual rainfall by 6 to 10%, mean monsoon rainfall by 40-60 mm and slight decrease in post-monsoon rainfall (by the year 2050). Further, the frequency and intensity of extreme rainfall events are projected to rise and will increase vulnerabilities in localities that are unprepared or have less coping capacity (Mani et al., 2017).

Specific adverse impacts on children from changes in precipitation and temperature trends include malnourishment, underweight, disturbance to daily life, increased morbidity to water borne diseases, anaemia, heat strokes and mental trauma. Under 5 children are particularly at risk increasing under 5 morbidity and mortality (Mani et al., 2017). Droughts and WASH-related factors lead to "respiratory, gastroenterological and calorie and protein deficiency among a large proportion of children". Children below the age of 5, elderly persons with disabilities, persons affected by disease burden or malnutrition, poor women, inhabitants of slums, migrants, and people below the poverty line are all identified as groups sensitive to the impacts of climate change.

Like Udaipur, another major urban centre – Kota – has also been extensively studied in terms of climate change vulnerability and adaptation. With a large migrant youth population and economy focused on education, any climate change impact on Kota has wider regional and national consequences. Kota's climate is characterized by low rainfall and high temperature (exceeding a maximum of 48 degrees C). Given its location in the south-east part of Rajasthan which is predicted to have the highest temperature rise of 2°C by the 2041–2060 period, population growth, density, higher rates of evapotranspiration, changes in LULC and depletion of groundwater, all point to significant risks and vulnerability for Kota urban region (Wilk et al., 2018a). Heat waves, water quality, sanitation and sewage, solid waste management, flash floods, water pollution and groundwater depletion are identified by researchers as significant climate related challenges for Kota in the short and long term. A failure to effectively manage these challenges will result in increase in the intensity of droughts shortage of drinking water in Kota, contamination of surface water, increase in water and vector borne diseases, heart disease and economic losses. A novel aspect of assessing vulnerability in Kota was to incorporate the built environment and infrastructure-related characteristics to draw a scenario of social vulnerability of the city's slum population (Wilk et al., 2018a). This group is more affected as they also suffer from inadequate water supply, sewerage and drainage facilities, which makes the slums more flood prone and increases the possibility of spread of water-borne diseases and WASH-related illnesses (Jonsson et al., 2015).

Studies on hot desert cities (HDCs) reveal that Bikaner constitutes an exception to the relationship between land cover and temperature changes (Lazzarini et al., 2015). Usually, downtown areas in HDCs are becoming cooler than the suburbs during day-time (urban cool island) and warmer at night (classical urban heat island). In Bikaner, however, during the summer monsoon season (June to August), due to occasional spells of intense rainfall, suburbs are cooler in the day-time due to more permeable soil and bare land, as opposed to build and concretized surfaces in core city areas. The modulation impacts of suburban land surface temperature by the Indian summer monsoon indicate that urbanization does indeed contribute to warming trends in Indian cities. It also highlights the urgent need for more open land surface water bodies, and urban green zones for reducing temperature levels and their associated discomfort as well as unsustainable cooling solutions (Lazzarini et al., 2015).

A key and important aspect of the Government of Rajasthan's awareness and preparedness to deal with climate change issues is revealed in the plans for highways (Public Works

Department 2019). Government documents reveal high awareness of the vulnerability of roads, pavements and highways to heat. River flooding, urban flooding. Since the government agencies are already working on this, it is not taken up for detailed exposition here.

Due to an average increase in temperature in semi-arid Rajasthan of 0.60°C over the last 100 years, together with intensified rains during the summer monsoon, recurring droughts and extreme temperatures, the major rivers in Rajasthan (Kutch, Saurastra and Luni), accounting for almost 60% of the total water in the state, are likely to experience acute water scarcities (Jonsson et al., 2015). Since evapotranspiration is also influenced by temperature rise, cities in the south-east region are especially likely to face water shortages. With high poverty levels among the slum population in cities like Kota, in addition to adverse water situations, social vulnerability to climate change is mediated by gender, health status, age, income and literacy.

In general, the above details regarding vulnerability to climate change of urban settlements in Rajasthan reveal that climate vulnerability is subject to individual, spatial, temporal, community and household variability.

5.3. Policy Review

5.3.1. National Urban Policy Scenario

In order to reap the benefits of urbanization while simultaneously mitigating the environmental effects and promoting climate mitigation, national and state level urban policies need to explicitly incorporate climate change concerns and agendas. Over the last several decades the national and state governments have designed a number of policies to address sectors such as construction, housing, infrastructure, transport, environment, waste management, water, sanitation, economic growth, poverty alleviation, heritage, education and health. To integrate climate change vulnerability and adaptation into sustainable urban development policies, there are two levels at which policy integration and design need to take place.

The first is the coordination between related sectors. For instance, the building and construction sector, in order to enhance climate resilience and mitigate emissions, needs to integrate goals and objectives related to water management, energy demand management, energy efficiency and conservation measures. Likewise, in order to be sustainable and prevent emissions from landfills, municipal solid waste management needs to adopt an integrated municipal solid waste management plan to enhance urban energy security. In the case of urban transport – integrated land use and transport planning, modal shift from private to public mode of transport, use of non-motorized transport, improved fuel efficiency, travel demand management, etc. can provide climate friendly solutions. For urban planning in general, implementing smart growth principles like re-densification and mixed-use zones, increasing green cover by land use control, promoting urban agroforestry, restricting urban sprawl, adopting energy efficiency by-laws for buildings, and controlling/regulating land use are important principles for urban climate resilience.

Many of the national and state policies, including in Rajasthan, have begun to integrate these principles into diverse urban development and infrastructure policies. However, while some of them have addressed disaster management issues and others have incorporated climate risks, a more explicit and evidence-based integration of climate change concerns into policies at multiple scales is missing. Conversely, climate missions focused on urbanization and habitats, are not explicitly connected to the goals, objectives, or strategies of urban planning and urban development policies. These are evident, for example, in the JNNURM, National Mission on Sustainable Habitats and state-level slum rehabilitation township, infrastructure, transport and other policies.

At a second level, there is a need to bring in more specific climate risks, for example flood risk and heat wave impact on roads and highways, making building codes address issues of energy management, etc in urban planning and policies. Table 5.4 provides details of the major national and Rajasthan state urban related policies, institutions and programmes and the ways in which climate vulnerability and adaptation can be incorporated into these policies, plans and strategies to mitigate climate risks and reduce emissions.

Table 5.4. National and state policies, institutions and strategies

Policy or scheme	**Target sector**	**Potential for climate link**
Rajiv Awas Yojana	Housing, slum population	Energy efficient housing

Deendayal Antyodaya Yojana	Livelihoods to reduce social vulnerability	Urban Livelihoods for the poor in 193 local bodies
Urban Infrastructure Development Scheme for Small and Medium Towns	Infrastructure for water and sanitation	Infrastructure for the urban poor, especially access to water and sanitation
Smart City Mission	Smart solutions for diverse sectors	Clean and sustainable environment, smart solutions, decent quality of life
Atal Mission for Rejuvenation and Urban Transformation	29 cities in Rajasthan	Infrastructure for water supply, sewerage, transport, green spaces, drainage
Pradhan Mantri Awas Yojana (Urban)	Housing	Housing for the urban poor
	Rajasthan State Policies	
Rajasthan Housing Board	Affordable Public Housing	Housing for public, industrial and commercial purposes; energy efficient housing
Town Planning Office / Department	Urban planning	Integrating climate change into urban

		planning, regional plans and master plans
Jaipur Metro Rail Corporation	Transport	Public transport, reduced emissions from transport
Urban Development Authorities (Jaipur. Jodhpur, Ajmer)	Three cities in Rajasthan	Integrating climate change into urban planning, regional plans and master plans
Urban Improvement Trusts (Alwar, Abu, Barmer, Bharatpur, Bhilwara, Bikaner, Chittorgarh, Jaisalmer, Pali, Kota, Udaipur, Sri Ganganagar, Sikar, Sawai Madhopur	Selected cities in Rajasthan	Integrating climate change into urban planning, regional plans and master plans; integrating climate change with urban development and urban amenities provision
Master Plans for cities	All cities and towns	Integrating climate change into urban planning, regional plans and master plans
National Capital Region Development Plans	Cities in the NCR Region	Integrating climate change into urban planning, regional

		plans and master plans
Department of Local Self Government	All cities and towns	Capacity building for climate change adaptation and urban climate resilience; integrating climate change into urban governance
Shahari Jan Sahbhagi Yojana	Urban development and urban governance	Sanitation, public health, water saving, education, awareness, capacity building, decentralized climate governance, sustainable urban infrastructure and amenities.
Rajasthan Urban Development Fund	Urban amenities and infrastructure	Drinking Water, Sewerage, Infrastructure
LED Light project	191 Cities and Towns in Rajasthan	Streetlights with reduced energy consumption
Swachh Bharat Mission (Urban)	Sanitation	Household and community toilets, SWM
Rajasthan Transport Infrastructure Development Fund	Transport	Safe, pollution free, easy urban transport

Rajasthan Water Supply and Sewerage Corporation	Water	Asset creation, provision, operations and maintenance for water supply; 24 X 7 water supply projects in selected towns
Independent Utilities and PPPs, PHED, RUIDP	Water	City / town level water supply utilities; focus on surface water instead of ground water; does not address groundwater recharge
Rajasthan State Water Policy	Water	Regulation and provision of drinking water in urban areas; supply side augmentation; transfer of water, inter-basin transfer
Department of Urban Development, Housing and Local Self Government	Urban planning, development and housing, urban governance	Regional planning, land acquisition development scheme, urban planning
Town Planning Department	Urban planning and development	Urban planning, master plans, planning norms and standards, support for schemes and projects

Directorate of Local Bodies	Urban governance	Sale and allotment of land; implementation of state and central schemes
Rajasthan Urban Infrastructure Finance and Development Corporation Ltd	Urban infrastructure	Facilitator and coordinator, link between central government urban schemes and state level implementation
Rajasthan Urban Infrastructure Development Project	Urban infrastructure	Water supply, wastewater management, roads, bridges, flyovers, slums improvement projects, fire-fighting, emergency medical services, heritage
Urban Improvement Trusts	Urban development, urban amenities	Development schemes, preparation of master plan, land acquisition, sanitation, construction, public amenities in streets

Municipal bodies	Urban governance and amenities, urban infrastructure	Develop city level climate action plans; integrate climate risks and vulnerabilities to design urban climate adaptation strategies

Source: Compiled from various Rajasthan government websites and policy documents.

5.4. Gaps to be Addressed

The state of Rajasthan has in place a number of existing policies across different sectors – water, forestry, urban development, storm water, energy, transport, housing, urban green zones, infrastructure, environment and climate change. A review of these policies, the strategies resulting from these policies, and institutions set up or tasked with implementing the policies, suggests that that they are cognizant of issues related to environmental sustainability, disaster risk reduction and climate change. The Rajasthan Urban Development Policy is sensitive to issues of disaster management and sustainability. The Rajasthan State Highway Investment Program (2019) has carried out an evidence-based and well-researched assessment of the vulnerability of roads and highways to climate change related hazards. The Rajasthan Urban Housing and Habitat Policy document (2017) also explicitly incorporates climate resilience issues. However, these are exceptions, as most of the policies and strategies tend to be generic and recognize climate change or disaster risks in a nonspecific manner, without incorporating local or regional scale projected impacts, risks and vulnerability. A plethora of research exists in different sectors, especially on urban settlements and habitats, which have assessed district-wise, city-wise or ward-wise risks and vulnerabilities and offered recommendations for adaptation. Climate change vulnerabilities and adaptation are dynamic phenomena and processes, and they require constant updating of evidence, plans and strategies in order to enhance resilience. Exposure and sensitivity need to be assessed and uncertainties levels need to be reduced for more effective risk reduction. Hence some of the key gaps to be addressed are briefly outlined in this section.

1. Unplanned urban growth and informal settlements affect the design and implementation of climate resilience policies such as green zones, protection of urban forests and urban water bodies, and mitigation of climate risks including heat waves and floods.
2. While strategies are made and institutions are identified/created to address climate change hazards and risks, vulnerabilities persist, leading to failures in implementation.
3. Inability or unwillingness of populations to relocate can increase climate related vulnerabilities.
4. Green belts, green zones and urban forests offer significant mitigation potential and reduce risks from heat waves and flash floods. However, the actual implementation of these well-conceived projects is adversely affected by a lack of clear definition of these concepts and strategies.
5. In city-level action plans and disaster management plans (e.g., Kota), local knowledge or indigenous knowledge have not been adequately incorporated or used in planning and policies.
6. Very few local government bodies directly include climate in their agendas or plans. This is in spite of explicit advances in climate action plans both at the central and state levels.
7. In cases where a few local bodies do recognize climate change as a concern, they merely list hazards, objectives, or instruments without prioritizing them or recognizing emerging risks and vulnerabilities at the local level or developing ward-wise plans or recognizing vulnerable sections such as children, urban poor, slum dwellers and the elderly.
8. Implementation problems of well-designed policies and strategies continues to be an issue.
9. National and state formulation of climate risks need to be converted into locally relevant priorities and strategies.
10. Stakeholder consultant processes are not robust in designing city- or town-level climate action plans.
11. Rather than generic or specific problem formulation of environmental sustainability, a more explicit focus on exposure and sensitivity will help develop more concrete plans for addressing issues of urban pollution, storm water drains, sewerage, water supply, green zones, housing, energy and transport.
12. Over the last couple of decades, the Rajasthan government has been proactive in enhancing water supply to urban areas in order to meet residential, commercial,

industrial and mining needs. While there is a recognition of the need to conserve groundwater, the emphasis on water transfer and use of surface water may affect hydrological cycles and land-water-atmosphere feedback, thereby impacting micro-climate, heat islands and extreme precipitation.

13. For a few cities like Kota, extensive documentation of the vulnerabilities due to climate related floods or heat waves has been carried out. This includes detailed studies of solid waste management, water supply, toilet facilities, sewerage and storm water drain connectivity and infrastructure, and flood risks. Risk assessments and infrastructure readiness are conducted at the ward level by, paying special attention to vulnerable hot spots and social groups. Similar assessments and evaluations are missing for a large number of cities and towns, however.
14. While a few city master plans do acknowledge climate change or disaster risks, most do not take cognizance of climate change directly. NAPCC and the Rajasthan SAPCC do address development sectors such as water, sanitation, housing, energy, forestry, agriculture and so on. However, a similar effort towards integrating climate change with development strategies that provide co-benefits is not evident in the master plans. A few master plans do mention solar panels, afforestation, water conservation, indigenous knowledge, green zones, etc., but there is a failure to realistically recognize and address climate risks.
15. Adaptive capacity is not only about mitigating climate risks but also about addressing sustainable development goals (SDGs). As such amenities and infrastructure need to combine development benefits with adaptation benefits. There is also a gap when it comes integrating related functionalities, for example, increasing adaptive capacity in water resource planning should also address the three issues of storm water, wastewater and potable water.
16. Regional planning to prevent cities from becoming high concentrations of poverty and slums are not robustly formulated and implemented.

5.5. Climate Actions and Strategies

1. Design city level climate action plans to integrate climate risks and responses into urban planning/development processes

A. Prepare a resilience plan for each city in light of existing vulnerabilities and future risks.
B. Restrict/control land use in areas prone to flash flood/cyclonic storms and areas reserved for forests; protect and conserve water bodies in and around cities since these provide ponding effects during extreme rainfall events and prevent inundation.
C. Adopt and implement National Building Codes for climate resilience, especially to provide more ventilation and greater cooling from natural wind and to reduce energy needs for heating during winter and cooling during summer.

2. Promote sustainable transportation
    A. Prepare comprehensive mobility plans (CMPs) for all major cities and towns and inter-city transport within each region to reduce energy consumption in the transport sector and increase the share of public transport and electric vehicles. Increase modal share of public/non-motorized transportation.
    B. Promote more efficient and sustainable commuting through zoning and planning; create more mixed land-use zones along the lines of indigenous urban planning strategies in old Jaipur.
    C. Invest in road construction and maintenance to cope with heat waves, extreme precipitation and floods, all of which can destroy road infrastructure.
3. Improvement in urban infrastructure (physical and social)
    A. Urban storm water drainage infrastructure improvement; build better drainage and sewage infrastructure in all cities and towns; create additional medical facilities and health infrastructure and train medical personnel for climate disaster emergencies; create more green zones for temperature control and prevent soil erosion/water run-off in urban areas; improve road infrastructure in flood-prone areas for fast access to relief and rehabilitation during disasters in risk-prone areas.
4. Strengthen disaster preparedness at the local level
    A. Prepare flood management plan at the local level (ward-wise); identify vulnerable sections of the population and livestock; identify flood-prone areas keeping in mind future risk scenarios generated from climate models and predictions; create incident response teams in each ward as per the guidelines of the National Disaster Management Act; involve all stakeholders and utilize

local/indigenous knowledge in disaster management and climate action plans at the local level.

5. Design and implement integrated environmental solutions
    A. As is done in cities in Japan and in Mumbai, use rainwater harvesting for flood risk mitigation and groundwater recharge; practice decentralized solid waste management, since inefficient municipal SWM practices contribute to flooding.
6. Bring area under urban forests and green spaces above the WHO mandate figure of 9 m^2 green open space per city dweller.
7. Create multifunctional landscapes and support protection and development of adjoining forest lands in urban areas and sequential restoration and enrichment of local biodiversity.
8. Support and enhance ongoing policies, schemes and programmes
    A. Integrate climate-friendly strategies and adaptation goals into state and central housing policies.
    B. Slum development policies: carry out risk assessment and implement heat wave and flood risk mitigation strategies in informal settlements.
    C. Conduct state-wide mapping and planning for location of new cities and urban expansion; avoid new settlements in flood plains or in forest areas; include plans for agroforestry, effective storm water drainage systems, and water bodies in all greenfield projects (industrial, residential, commercial, recreational, tourist, mining).
    D. Through public and private and PPP initiatives, encourage off-grid and decentralized energy solutions for residential, commercial and tourism sectors.
    E. Follow green architecture norms and National Building Code guidelines for all public housing projects.
    F. For creating sustainable and climate resilient habitats, a) better implement energy conservation building codes, b) green certification for infrastructure and development projects, c) green and fuel-efficient transport networks and d) capturing emissions from urban landfills.
9. Technical and governance issues: create multifunctional institutional and policy landscapes to enhance urban climate resilience and well-being of the population across all kinds of human settlements at different scales
    A. Create and strengthen urban green spaces, networks and corridors to protect from heat waves, from flood risks and for carbon capture; urban forests should

be conceptualized and designed as multifunctional ecosystems to address mitigation, adaptation and provide livelihoods.

B. Provide connectivity between backyard habitats, domestic gardens, parks and urban forests.

C. Maintain species diversity to reap ecosystem benefits, allow for groundwater recharge, arrest land and soil erosion and provide livelihoods; three-tier vegetation (herbs, shrubs and trees); follow state, national and international urban biodiversity guidelines and norms.

D. Design and utilize technical systems for using wastewater for urban green spaces.

E. Create a special taskforce for urban governance and sustainable habitats; it should have oversight over the urban local body of each city or town which will be the nodal agency, which in turn will have oversight over sectoral task forces to integrate climate resilience initiatives with sector specific functionalities: water resources, sanitation, sewage, pollution, human health, education, solid waste, energy, transport and infrastructure. The nodal agency will identify and create a consortium of local academic, private sector, CSO, NGO and government institutions to produce strategic knowledge to support the task force. For each sector, a governance structure can be identified to coordinate across different relevant departments. For example, water resources management will coordinate with forestry, horticulture, housing, poverty alleviation, sanitation and sewage, water, housing board, urban local body, ward offices, town planning office, district collector, *zilla parishad*, urban improvement trust, PWD, PHED and groundwater departments.

10. Interventions to be designed for targeted challenges: e.g., heat wave, flooding, extreme precipitation events, droughts

A. Urban greening, green corridors, tree plantations and shelter belts to mitigate the effects of heat waves.

B. Shelters and homes for migrants and street-based workers to protect them from intense heat.

C. Reduction in concrete surface area of cities and towns.

D. Rooftop horticulture as a city-wide measure.

E. Regular cleaning of *nallahs* and diversion channels and creation of holding ponds, lakes and water harvesting structures.

F. Identifying and removing solid waste waterway barriers on a regular basis.

G. Early warning systems and efficient communication for heat waves, floods and extreme events.

H. Shelters for humans and animals and safe / secure storage spaces for property during floods.

I. Involve schools and educational institutions in risk reduction, awareness building, education, early warning and capacity-building exercises.

J. Models developed (for Indian conditions) for Jaipur and other cities for methane estimation from landfill sites may be validated and deployed in all local bodies in Rajasthan; waste-to-energy technological options and scientific methods of landfill management to comply with emissions standards should be deployed in all cities and towns of the state. Appropriate mathematical and optimization models can be applied by carrying out life cycle analysis of MSWM practices and scenarios.

K. Increase the number of groundwater recharge projects across all cites, encourage use of traditional methods – *anka*, *khadin* – and make water harvesting in urban residential buildings mandatory.

L. Since surface water and dams have serious climate change and climate hazard consequences, de-emphasize, decommission and phase out large surface water and dam projects.

M. Ensure availability of a minimum of 9 m^2 green open space per city dweller; for example, for a future population scenario of 6.50 million for Jaipur by 2025, the city would require 5850 ha (58.50 km2) of urban green zones, which works out to at least one medium sized mature tree per household.

N. Urban trees should be used for carbon sequestration and pollution removal (O_3, PM^{10}, NO_2, SO_2, CO); urban trees can also minimize urban heat island effects, by increasing evapotranspiration rate.

11. All local bodies to carry out assessment of mean and extreme events for different climate change scenarios; these should be done at seasonal and annual time scales; these assessments should be used for planning, management, risk reduction, vulnerability assessment and designing adaptation strategies.

12. Climate resilience of cities should be conceptualized in terms of meeting SDGs and by considering the city’s inclusive and sustainable development, including the needs of the

marginalized and the excluded. Climate risks and responses should be integrated into urban planning/development processes

13. Carry out specially commissioned studies to assess vulnerability and enhance adaptive capacity for cities located in river basins, especially for flood risks, water scarcity and related matters.

Chapter 6

Health

6.1. Introduction

Climate change is one of the alarming causes of environmental hazards, which in turn raises health risks resulting from increased frequency and intensity of heat and cold waves, floods and droughts (Ministry of Health & Family Welfare, Government of India, 2018). Ground-level ozone and increased CO_2 emissions due to climate change have worsened cardiovascular and respiratory diseases (Ministry of Health & Family Welfare, Government of India, 2018). The state of Rajasthan is one of the most populous states with the largest geographic area, which makes it more vulnerable to the impacts of climate change. Rajasthan faces severe heat and cold waves and has varied geographic regions –arid in the west and flood-prone in the east. Due to the high rural-urban divide, the impact of climate change is accentuated on the most vulnerable communities in rural Rajasthan. Lack of health infrastructure, cultural barriers, malnutrition, poverty and other socio-economic factors are an added burden on the already poor health indicators in the state.

Adapting to the health risks of climate change is paramount to ensuring populations' well-being. Adjustment to climate change is planned and implemented at the local level and is context-specific. One of the significant needs is the adaptation to climate-related risks. Climate-sensitive health risks have often received less attention in adaptation planning (Sahay, 2019). Adaptation to climate-change-related health risks contributes to resilience and sustainability and remains a challenge for planners and policymakers. Very few adjustment initiatives have addressed the mitigation of health risks. Also, most of the initiatives centre around developed nations – specifically heat stress – thus overlooking the adaptation strategies for other climate-sensitive health outcomes like vector borne diseases (VBDs). Limited evidence of institutional adaptation at the municipal level in urban areas in the Global South; lack of information-based adaptation initiatives; poor focus on initiatives addressing infectious disease risks; and absence of monitoring, reporting and evaluation are the significant limitations of urban public health adjustment programmes.

According to Araos et al. (2016), nearly 29% and 17% of health-risk adaptation strategies focus on heatwaves and general disasters, respectively, but only 7-9% focus on air quality, water, food security and VBDs. They also found that 90% of the urban areas surveyed (n = 401) did not report any health-risk adaptation strategies due to climate change. There is a huge blind spot between the risks faced by cities and municipal responses to these risks. This study emphasized monitoring, reporting and evaluating (MRE) the adaptive health measures as a significant step.

An empirical decision tool for effective health adaptation is primarily necessary to support policymaking, which can further provide information on economic viability and empirical evidence on the effectiveness of the adaptation measures. A study conducted in Rajasthan presented in-home treatment of drinking water – using cloth-filters, ceramic filters and boiling – as an adaptive/averting/coping measure for treating water-related diseases (Jessoe, 2013). A decision support tool, developed by WHO-European centre (WHO Regional Office for Europe, 2013), specifically for health adjustment works essentially in a top-down manner, passing down the benefits of health adaptation by the health ministry at the national and sub-national level. The tool uses cost-benefit analysis (CBA) for decision making. CBA is one of the most commonly used decision support tools for the evaluation of adaptation but has very limited use in health adaptation (Chambwera et al., 2014; Watkiss, 2015). Also, the health production function (HPF) approach proves to be an efficient tool as it contributes to the planning of adaptation measures along with monitoring and evaluation of the measures. The outcome of this approach focuses on the monetary benefits and is based on information about cost of coping, treatment cost and loss of work-days. Sahay (2019) proposed an empirical decision support tool for health adaptation utilising a cyclical framework for monitoring, economic evaluation of the coping/adjustment and decision making at any given time. The framework follows an *adaptation pathway* approach. The cyclical framework can be applied at any point of time in the future. A fixed interval of five years is recommended between two successive evaluation cycles. This eliminates the need for scenario building and future projection of disease incidence.

Combustion of fossil fuels (target of Sustainable Development Goal (SDG) #13) plays a key role in the process of climate change, which places food, air and water supplies at risk and poses a major threat to human health. Since SDGs are a universal agenda, NITI Aayog built robust statistical systems and metrics to translate these goals into action for implementation and assess the state's achievement towards SDGs. It created the SDG India index, which classifies goal achievement into four categories Achiever: = 100; Front Runner: 65 to 99 (including both); Performer: 50 to 64 (including both); and Aspirant: <50). In the year 2020, Rajasthan ranked 19th in India, in the performer category for climate action, which was a 12 rank drop from the year 2019 (NITI Aayog, 2021). However, the state's rank in the health and well-being domain improved from 17th in 2019 to 15th in 2020 (NITI Aayog, 2021).

6.1.1. Public Health Infrastructure in Rajasthan

The state of Rajasthan has witnessed an upgrade in terms of health status and outcomes in the recent years. Yet, there is room for holistic improvement in integrating policies concerning health and other allied fields like drinking water, sanitation and nutrition. Rajasthan is one of the EAG[1] states which have demonstrated improvement in the health sector in the recent past. As per the report titled *The Healthy States Progressive India Report on the Ranks of States and Union Territories*[2], published in June 2019, Rajasthan was one of the top three states in terms of incremental performances, against the base year of 2015-16 and for the reference year 2017-18. The overall index score[3] saw an improvement of 6.30 points (from 36.79 in 2015-16 to 43.10 in 2017-18).

Fig. 6.1 presents a comparative analysis of the current status of India and Rajasthan on primary health indicators. The current infant mortality rate (IMR) as per the Sample Registration System Bulletin (SRS) (2021) has been recorded at 35 per 1000 live births, a stark dip from 59 per 1000 live births in the past two decades (SRS Bulletin, 2009) Despite the decrease, Rajasthan is yet to achieve the SDG target for IMR, which is less than 12 per 1000 live births. The current life expectancy at birth rate in Rajasthan is 67.5 years. This is projected to increase from 68.6 to 69.6 for males and from 71.9 to 73.1 for females (Fig. 6.3).

[1] EAG States - Empowered Action Group states includes Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Rajasthan, Uttarakhand, Uttar Pradesh, and Odisha.
[2] The report "Healthy States Progressive India" Report on the Ranks of States and Union Territories: Health Index, was published in June 2019 by NITI Aayog, Ministry of Health & Family Welfare Government of India and The World Bank. (http://social.niti.gov.in/uploads/sample/health_index_report.pdf, accessed November 16, 2020)
[3] The Health Index is a weighted composite index based on 23 indicators grouped into the domains of health outcomes; governance and information; and key inputs/processes. For details, refer to Table 2.2 and 2.3 of the report mentioned above.

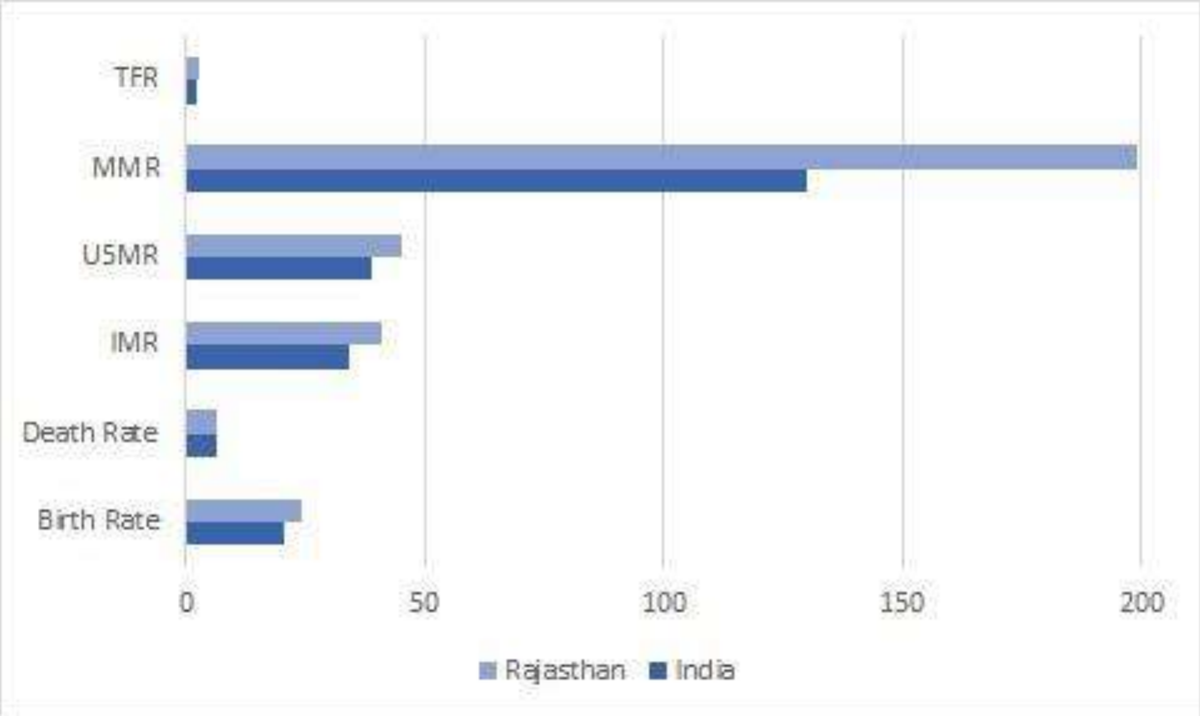

Figure 6.1. Comparative health indicators of India & Rajasthan
Source: National Health Profile 2018, pp 35.

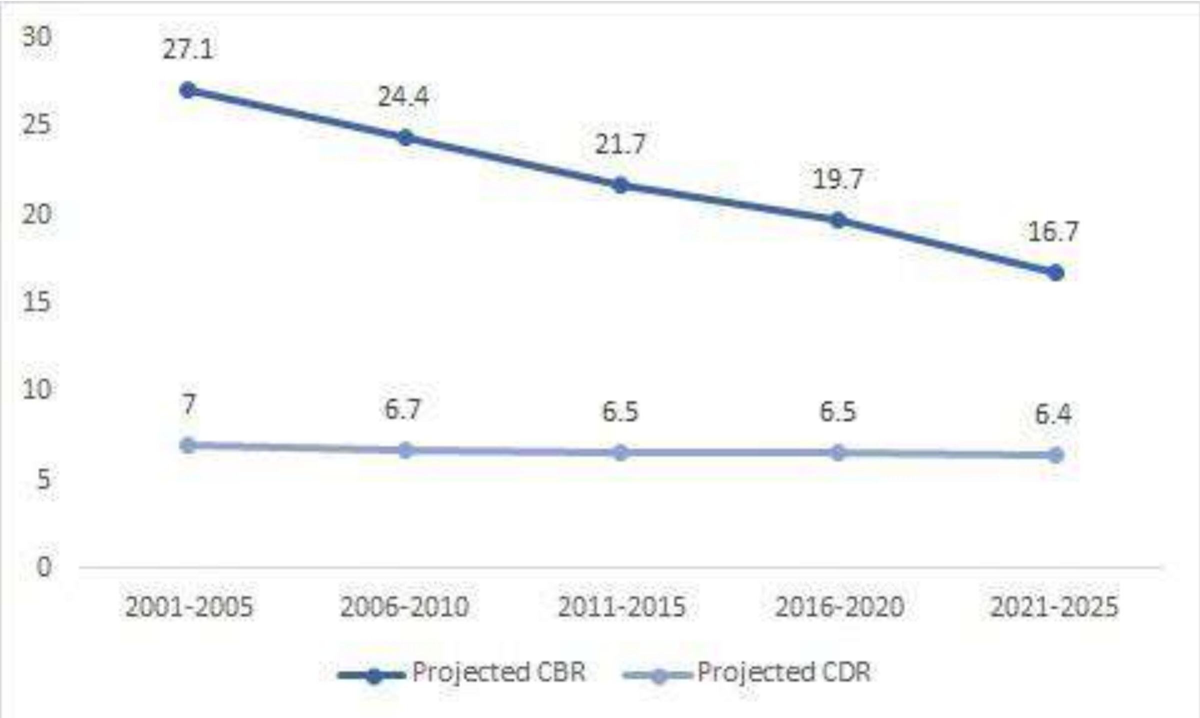

Figure 6.2. Projected crude birth and death rates in Rajasthan from 2001 to 2025.
Source: National Health Profile 2018, pp. 24 and 25.
(The current reported birth rate and death rate in Rajasthan is 23.7 and 5.7, respectively. [SRS, 2021])

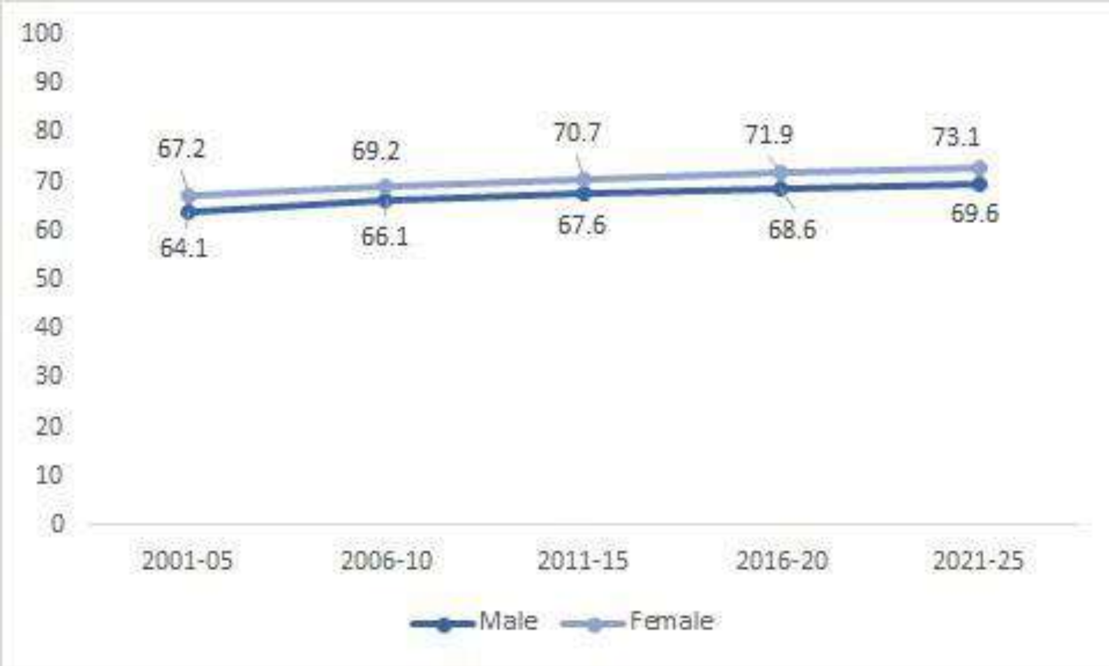

Figure 6.3. Projected levels of life expectancy at birth in Rajasthan, 2001– 2025.
Source: National Health Profile 2018, pp. 27

6.2. How Climate Change Affects Health?

Climate change has a significant direct and indirect impact on human health, and the urban populations are expected to be highly sensitive (Smith et al., 2014).

1. Direct effect of climate change on health: Health is affected on account of changes in the frequency of extreme weather conditions, including drought, heavy rain, floods, heatwaves, storms and wildfires.
2. Indirect effect of climate change on health: Health is also affected by poor environmental conditions, i.e., vector-borne diseases (VBDs), water-borne diseases and diseases caused by air pollution. Human interaction and interventions also mediate climate effects on health via economic and social disruption (i.e., occupational diseases, poor nutrition, mental status and so on).

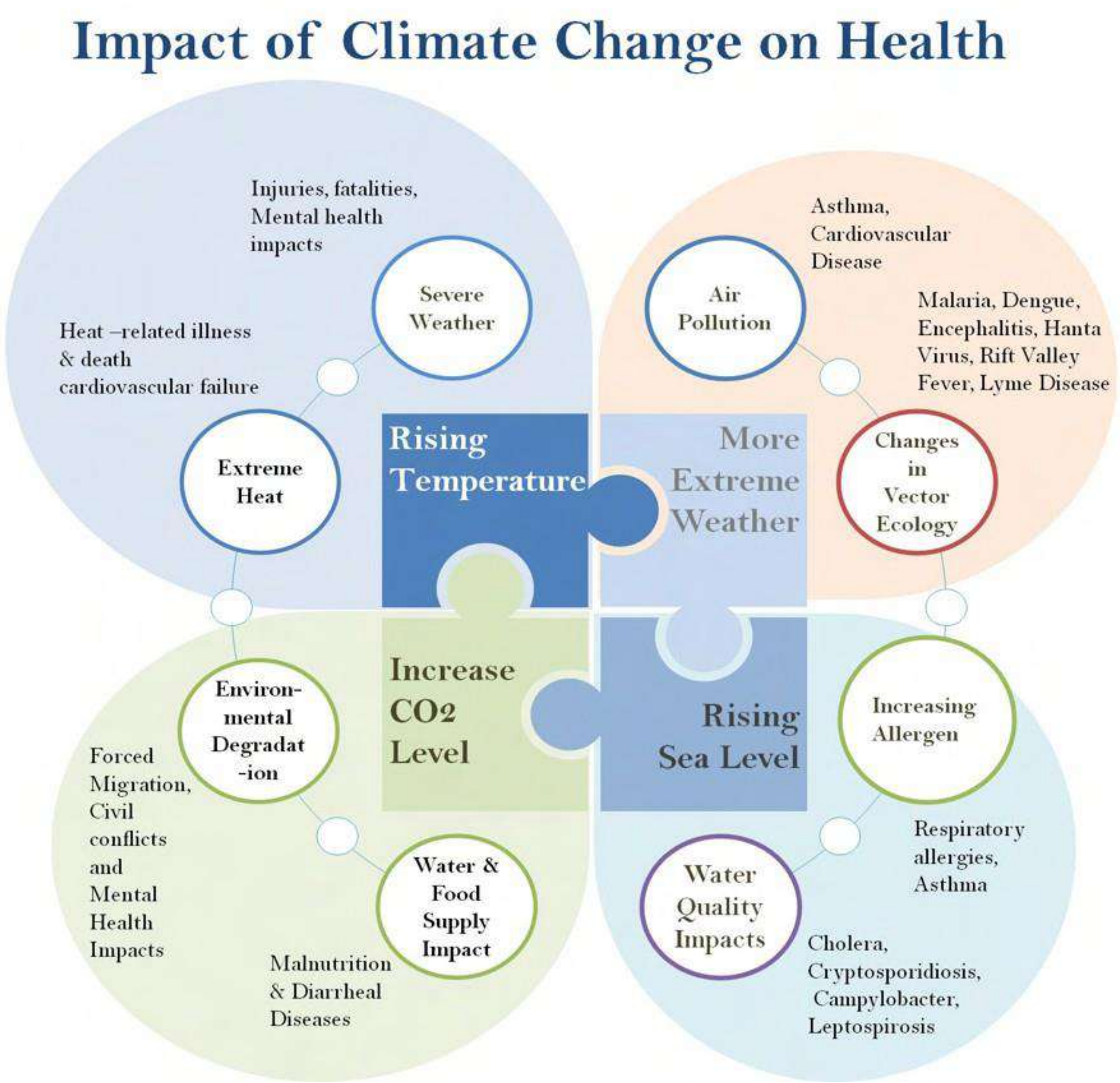

Figure 6.4. Conceptual diagram showing three primary exposure pathways by which climate change affects health.

Table 6.1. Number of cold waves in various states in India

State	Epochs				
	1901-1910	1911-67	1968-77	1978-99	1901-99
West Bengal	2	14	3	28	47
Bihar	7	27	8	67	109
Uttar Pradesh	21	51	8	47	127
Rajasthan	11	124	7	53	195
Gujarat, Saurashtra & Kutch	2	85	6	6	99
Punjab	3	34	4	19	60
Himachal Pradesh	-	-	4	18	22

Source: Adapted from (De et al., 2005)

6.2.1. Effect of Direct Exposure to Climate Change on Health

6.2.1.1. Heat and cold related impacts

During heat waves, the human body is exposed to hotter climatic conditions, which compromise the individual's ability to regulate body temperature. This results in heat cramps, heat exhaustion, heatstroke and hyperthermia. Extreme temperature worsens chronic conditions, including cardiovascular, respiratory and cerebrovascular disease and diabetes-related conditions.

Rajasthan has a high exposure to heat waves, and with limited adaptive capacity, impacts are quite severe and can lead to severe heat stress and increased mortality (Murari et al., 2015). Increased heat waves in India have resulted in increased deaths, particularly in the north-western regions such as Rajasthan (Rajasthan State Action Plan onClimate Change, 2014). In 2015, loss of life (2300) due to extreme heat was the highest in Rajasthan within in India. Extreme temperature in the desert districts of Rajasthan increases thermal stress, leading to thermal discomfort and distress on the one hand and increased risk of vector exposure on the other hand, ultimately resulting in malaria, malnutrition, injuries and premature death.

Over the past 100 years, Rajasthan is the second state, after Jammu and Kashmir, to experience the maximum number of cold waves (De et al., 2005). The cold wave casualties due to cold stress have been rising in India as a consequence of climate change. The number of cold waves that affected Rajasthan across various epochs totalled to almost 195 events between the years 1901-1999.

Exposure to extreme cold waves leads to raised mortality due to hypothermia and frostbite. The problems are aggravated by homelessness and among the elderly. As per the Rajasthan Climate Change Project (Cold Action Plan) 2017, Rajasthan experiences the lowest temperatures during the month of January, and the dip in night temperatures is due to the presence of sandy soil (Government of Rajasthan, 2017). The reported number of deaths related to cold temperature were approximately 350 in the year 2000-2005 (Government of Rajasthan, 2017). Climate change increases the severity of these cold-related mortalities and morbidities.

Table 6.2. Observed minimum temperatures, their departures and 24-hour tendency over the plains of north India dated 20.12.2020

Station	**Min. temperature**	**Departure from normal**	**24-hour tendency**
		West Rajasthan	
Ganganagar	5.9	-0.4	1.4
Churu	1.6	-3.6	1.7
Bikaner	7.6	-0.5	1.6
Jaisalmer	10.1	2	-
Barmer	11.7	0.2	2.5

Source: Earth System Science Organization Ministry of Earth Sciences India Meteorological Department, 2020

6.2.1.2. Flood and storm

Floods result in drowning cases, injuries, hypothermia, water-borne diseases, rodent-borne diseases, VBDs, and cholera (Schnitzler et al., 2007; Jakubicka et al., 2010). Flood also deplete drinking water sources causing faeco-oral diseases. Diarrhoea has been well-evidenced as a potential threat to Rajasthan population and economy, with a continuous rising trend. Apart from impacting human related cost and increasing financial burden, diarrhoea, which originates from inequity often has negatively influenced the well-being of the people of Rajasthan. Well-established practices such as adapting healthy practices, building sanitation infrastructure, and consumption of safely managed water should be implemented in Rajasthan to reduce diarrhoea-associated mortality.

6.2.1.3. Ultraviolet radiation

Ultraviolet (UV) rays affect human health via the skin, eyes, and the immune system. UVA increases oxidative stress in the cells causing skin cancers, whereas UVB causes sunburn, which increases the likelihood of developing cancer. It also affects the eye through photokeratitis, photo conjunctivitis, pterygium, cataracts and cancer of the eye (Radiation, n.d, WHO.). UV rays alter and subsequently damage the immune system, reducing vaccine effectiveness and promoting cancer. Reduced effectiveness of the immune system also results in the reactivation of the herpes simplex infection (Radiation, n.d, WHO.).

The incidence rate (per 100,000) of cancer in Rajasthan has increased from 58.8% in 1990 to 72.6% in 2016. A study by Dhillon et al., (2018) demonstrated that in 2016, the number of crude death rates attributed to myeloma ranked 18th (for males) and 19th (for females) in Rajasthan among 20 varying cancer-related crude-deaths. A nationwide study was conducted to determine the prevalence of blindness in India. The study suggested that cataract is a causal factor for 66.2% of blindness, and two districts in Rajasthan – Sirohi (2.58%) and Sikar (2.81%) – were among the top five places in terms of blindness among the population aged ≥ 50 years (National Blindness and visual impairment survey, 2015-19).

6.2.1.4. Air quality (acute air pollution episodes, aeroallergens)

The use of unprocessed bio-fuels for cooking purposes has huge health impacts, particularly on the women and the elderly. A study was conducted by Laxmi et al. (2003), covering 6,403 females and 5,552 males from 1989 households in 13 villages, to gauge household energy consumption patterns, women's hardships and health impacts in the rural belts of Rajasthan. The results revealed that women endure many hardships due to the consumption of biofuel. Unaffordability and unavailability have restricted women's access to kerosene, as a cooking fuel, in rural and tribal belts. The health impacts of biofuel (fire wood) use were quite high especially among adult women. Household air pollution (HAP) caused by fuel combustion also led a high incidence of upper respiratory diseases like asthma, chest illness, and wheezing among women. The study also found that the prevalence of respiratory diseases was as high as 15% among the surveyed population (n = 11955). Also, 9% of the surveyed individuals reported symptoms of breathlessness.

6.2.2. Effects of Indirect Exposure to Climate Change on Health

6.2.2.1. Vector-borne and other infectious diseases (malaria, dengue, tick-borne diseases, other vector-borne diseases)

A number of VBDs in India are transmitted by mosquitoes, such as malaria, dengue, Japanese encephalitis, chikungunya, sand-fly fever, kala azar (Ghosh & Ghosh, 2020). Epidemics of dengue infection (Chaturvedi et al., 2014) and malaria (Gupta et al., 2012) are highly prevalent in Rajasthan. Dengue is a viral disease transmitted by the arthropod *Aedes Agyepti*. These mosquitoes have proliferated in the past few years due to global warming and climate change. With rising temperature, the dengue virus development rate has also risen, thereby increasing the mosquito's biting rate (Kothari et al., 2019).

Another challenge observed in Rajasthan is the lack of adequate water supply, which calls for storage of water. However, these water-storage tanks like *tanka* and *beri* often act as breeding grounds for mosquitoes, advertently leading to high incidence of dengue and chikungunya. Studies on VBDs in 2008 reported high entomological indices in urban areas of two semi-arid dengue-endemic districts of Rajasthan. The study conducted longitudinal assessments in those areas. Schools and educational institutes also pose the threat of potential breeding grounds (Angel et al., 2017), which indicates that regular monitoring and preventive measures might be essential to break the chain. A study by Rathore et al. (2017) found that following three episodes of surge in dengue cases in 2001, 2006 and 2009, there was a constant load of dengue cases every year in Rajasthan (Rathore & Bairwa, 2019). A trend analysis by Rathore et al. (2019) suggests a constant increase in the number of dengue cases.

Thar Desert in north-western India, 90% of which is in Rajasthan, has been traditionally regarded as hypo-endemic for sporadic malaria outbreaks from 1990s to 2019, especially in the flood-prone lower reaches of the Luni river basin (Duggal et al., 2020; Sweeney et al., 1996). The landscape of western Rajasthan's Thar region has changed due to variation in climatic conditions and continuous water supply from the Indira Gandhi Canal, which has led to variation in the flora and fauna of the place (Singh et al., 2013). In their report on Rajasthan Action Plan for Climate Change, The Energy and Resource Institute (TERI) (2010) has documented that canal irrigation work for Indira Gandhi Nahar Pariyojana (IGNP) in the villages of Thar has increased the incidence of malaria. The ecological changes linked to irrigation activities in the Thar region have aggravatedmalaria vector transmission.

A year-long study done in the city of Jodhpur by Singh et al. (2013) established the consistent presence and breeding of a predatory breed of mosquito – *Culex (Lutzia) fuscanus* – which was previously absent due to sparse population and very dry climate. However, the availability of water in this region has stabilized breeding (Singh et al., 2013). Stabilization of predatory species also indicates the presence of the mosquito population on which the *Culex* larvae feed. Widespread water clogging in soil in the Thar region has also resulted in the increase of the *Anopheles* population (Akhtar & McMichael, 1996).

Most importantly, habitation in adverse geographic and climatic conditions, such as persistent drought in the desert districts of Rajasthan, has also been correlated with high incidence of malnutrition and respiratory illnesses. Poor water availability in the state also leads to food insecurity, agricultural problems, and heavy dependence on other resources. With increased probability of drought occurrence (as projected) and high evapo-transpiration rates due to global climate change, the situation will turn more adverse, especially for the resource-constrained and fragile zones of Rajasthan ecosystem. This phenomenon is also reported to increase the prevalence of water-borne diseases such as diarrhoea and malaria. The current population of Rajasthan is mainly vulnerable to the health impacts of increased incidence of heat waves and heat-stress and water-borne and VBDs like dengue and malaria. Reducing these risks through intervention or adaptation measures in cities, therefore, becomes necessary to increase the adaptive capacity of the residents.

Other than the rising number of cases of malaria and dengue, Rajasthan in the past has also seen cases of VBDs that were endemic to other countries and largely absent in India. For instance, the first case of the Zika virus in India and two suspected cases of Crimean-Congo haemorrhagic fever were reported in Rajasthan (Ghosh & Ghosh, 2020). These diseases are considered highly sensitive to climate change parameters.

6.2.2.2. Water-borne infections

Water-borne diseases intensify due to heavy rainfall, flooding and extreme high temperatures (Semenza, 2020). Heavy rainfall and flooding lead to change in the flow of water, which in turn leads to the formation of a channel that may also include sewage water from non-potable sources (Hunter, 2003). Also, heavy rainfall can lead to overflowing water bodies merging with sewage water and eventually polluting the main water source. The change in temperature also makes the environment suitable for hazardous planktonic species (Hunter, 2003). For example, cyanobacteria cause respiratory illnesses, dermatitis and hepatitis, whereas V. cholerae cause cholera (Hunter, 2003).

From 2010 to 2015, seven districts in Rajasthan were affected by cholera. Jaipur, Sikar, Tonk, Dausa and Banswara were identified as the high-risk districts and 28.56% of the total population were infected (Ali et al., 2017). Hence, Rajasthan is identified as a cholera-endemic state (Ali et al., 2017). The causal factors for this are poor environmental hygiene, lack of access to potable water and poor sanitation habits (Ali et al., 2017).

6.2.2.3. Nutrition

Socio-economic factors, diseases and agricultural produce affect nutrition (Smith et al., 2014). This chapter has examined the climatic implications on health that mediate through socio-economic factors and diseases. Understandably, agricultural produce also plays a role in acute and chronic malnutrition, i.e., stunting, wasting and being underweight (Smith et al., 2014). Increased frequency and severity of climate extremes affects agricultural produce, resulting in food insecurity especially among the marginalized population. High temperatures, reduced optimal rainfall and droughts affect food security directly by reducing the quantity and quality of food harvested, and indirectly by increasing food prices.

While India's public distribution system (PDS) has been critical to ensuring food security in poor households, the prevalence of food insecurity can be attributed to high undernutrition in Rajasthan (Smith et al., 2014). The food security index measures food affordability, availability, quality and safety, as well as natural resources and resilience of the state, and Rajasthan has been deficient in food security. However, from 2005 to 2015, stunting in Rajasthan has reduced from 43.7% to 39.1%, wasting has reduced from 20.4% to 23.0%, and underweight from 39.9% to 36.7% (NFHS 3 and 4).

6.2.2.4. Occupational health (heat strain, heat stroke, heat exhaustion, work capacity loss and other occupational health concerns)

Health risks during heat extremes are greater in people who are physically active (e.g., manual labourers). The results of a study conducted on brick kiln workers of Rajasthan showed that 79.23% workers were suffering from musculoskeletal disorders in their shoulders, wrists and lower back areas. Various other respiratory and skin diseases were also found in a significant number of workers (Sain & Meena, 2017).

6.2.2.5. Mental health

Extreme weather events causing mortality, displacement, loss of wage, loss of shelter, etc. can have long-term mental health impact on the suffering population (WHO, 2003). Bourque and Willox (2014) established extensive linkages between climate change and its impact on mental health; they presented evidence related to higher psychological disorders associated with agricultural loss due to sudden climatic changes. They also suggested potential ways in which climate change can impact mental health as mentioned below:

Table 6.3. Direct and indirect impact of climate events

Type of climate events	Direct impacts	Indirect impacts
Acute or extreme weather events (e.g., hurricanes, severestorms, floods)	Exposure to danger, injury and death; acute stress and traumatic responses; increased risk of post-traumatic stress disorder.	Damage/loss of home and infrastructure; disruption of community and healthcare re-sources
Subacute weather events (e.g., drought, heat waves)	Heat-related exacerbation of pre-existing mental health issues, increased rates of violence and aggressive behaviour	Unemployment from agricultural activities, increasedsocio-economic disparities and community strain; relocation and urban shift
Long-term environmental changes (e.g., desertification, erosion, biodiversity loss)	Sadness, helplessness and anxiety; loss of sense of place (solace) and grief reactions.	Loss of livelihood or economic means; involuntary migration and related mental health impacts; potential for increased conflicts due to migration and resource scarcity

Source: Adapted from (Bourque & Willox, 2014).

Torrential rains followed by spells of dry period have damaged agricultural produce for many farmers in Rajasthan. These erratic rainfalls also lead to stress migration, which can have longer mental health implications.

6.3. Understanding Vulnerability to Disease and Injury Due to Climate Variability and Climate Change

In the IPCC assessments, vulnerability is defined as the propensity or predisposition to be adversely affected. In this section, we consider causes of vulnerability to ill health associated with climate change and climate variability, including individual and population characteristics and factors in the physical environment. The following sections help us in understanding the causes of vulnerability.

6.3.1. Demographics

The child (aged 0-6) sex ratio in Rajasthan is 888 females per 1000 males. According to 2011 census data, the problem is significant in a few districts. The district with the lowest sex ratio reports 800-850 females per 1000 males. Of the 33 districts in Rajasthan, 21 fall in the 900 range. Only 13 districts are in the range of 950-1000.

6.3.2. Geographic: Presence of fluoride and other contaminants due to groundwater pollution

Recent studies have strongly established the high prevalence of fluoride in Rajasthan's groundwater. This has led to the incidence of adverse health hazards such as hydrofluorosis, which leads to dental and skeletal issues (Choubisa, 2018; Hussain et al., 2004; Jain & Singh, 2014; Suthar et al., 2008; Kumar & Kumari, 2011; Sharma, 2010). The most deteriorated health conditions are seen especially among the elderly and children. Rajasthan has a high share of tube wells, which are used as a drinking water source (12.2%). Furthermore 64% of the population in Rajasthan reportedly practises open defecation. This, along with high fluoride content has led to groundwater pollution. Hydrofluorosis, caused by fluoride-rich water, gained prominence with the commencement of the guinea-worm eradication programme in Rajasthan in 1986, where numerous bore and tube wells fitted with hand-pumps were built in rural zones. The groundwater, extracted from these wells, was highly contaminated with fluoride, greatly exceeding the limit of 1.0-1.5 ppm. Choubisa, (2018b) noted an extremely high amount of fluoride in the potable water of the Thar district in Rajasthan. Fig. 6.6 demonstrates the current map of Rajasthan, showing district-wise fluoride distribution in groundwater sources. According to Choubisa (2018b), out of 33 districts in Rajasthan, 7 districts suffer from extremely high fluoride contamination (F >20.0 ppm), 13 districts have fluoride levels between 10.1–20.0 ppm, 5 districts have levels between 5.1–10.0 ppm, and 8 districts have levels between 1.0–5.0 ppm. Until 2001, around 10343 villages reported a fluoride content of 3 mg/l in their groundwater (Jain & Singh, 2014).

This alarming situation calls for elimination of fluoride from water. There is an urgent need for the provision of fluoride-free water in all fluoride-endemic villages of Rajasthan. A study by Hussain et al. (2004) on effects of fluoride on human health in Rajasthan reported the following conditions: damage of dental enamel; osteoporosis; skeleton fluorosis; deformities and crippling fluorosis; adverse cardiovascular effects; gastrointestinal and endocrine effects; immunological and lymph reticular effects; and most importantly, neurological and reproductive effects. Fluoride can also cause changes at the molecular level and have carcinogenic effects.

Sharma (2010) conducted a detailed fluorosis study in 41 out of 60 villages in the Bhilwara district of Rajasthan, all of which had a fluoride level above 5.0 mg/l. A total of 4252 individuals above 5 years of age were examined for evidence of dental fluorosis, while 1998 individuals above 21 years of age were examined for evidence of skeletal fluorosis. The overall prevalence of dental and skeletal fluorosis was found to be 3,270/4,252 (76.9%) and 949/1,998 (47.5%), respectively. Of these, 374 (8.8%) individuals had severe dental fluorosis while 566 (28.3%) had Grade I type of skeletal fluorosis. Only 0.6% (12) individuals had Grade III skeletal fluorosis. Briefly, the incidence and severity of fluorosis supported the growing fluoride concentration. In some villages, the prevalence and severity of fluorosis were the highest in subjects belonging to the economically weak sections. Also, male labourers displayed the highest occurrence of fluorosis.

Other than fluoride, recently geogenic and anthropogenic contaminants have also been found in the groundwater of 243 wells in Rajasthan (Coyte et al., 2019). A high concentration of radon has also been found in the groundwater of Khetri district of Rajasthan (Duggal et al., 2020). Another study on geochemical modelling of high fluoride concentration in groundwater of Pokhran area of Rajasthan showed that geochemical processes such as ion-exchange and weathering from granite rocks and its dissolution in groundwater was responsible for the fluoride concentration in northern and western parts of Rajasthan's Pokhran district (Kumar & Kumari, 2011).

There are several de-fluoridation and water treatment methods that can be applied for controlling excess fluoride in water. These approaches can be largely classified into three categories: i) precipitation, ii) adsorption/ion exchange and iii) electrochemical methods and membrane technique. Steps should be taken towards the adoption of these water treatment methods, especially in fluoride-epidemic areas of Rajasthan.

F 1.0-5.0 ppm	F 5.1-10.0 ppm	F 10.1-20.0 ppm	F >20.0 ppm
• Jhalawar	• Chittorgarh	• Bikaner	• Udaipur
• Baran	• Bundi	• Jaishalmer	• Jodhpur
• Rajsamand	• Hanumangarh	• Barmer	• Bhilwara
• Karauli	• Alwar	• Dungarpur	• Jaipur
• Banswara	• Sawai Madhopur	• Jhunjhunu	• Ganganagar
• Pratapgarh		• Jalore	• Churu
• Kota		• Dausa	• Nagaur
• Dholpur		• Sika	
		• Tonk	
		• Sirohi	
		• Ajmer	
		• Pali	
		• Bharatpur	

Figure 6.5. Districts having fluoride in the range 1.5–5.0, 5.1–10.0, 10.1–20.0 and >20.0 ppm in drinking water (Choubisa, 2018b).

6.3.3. Healthcare System

Experimental and survey-based studies by Nobel laureate Abhijit Banerjee in 100 hamlets of Udaipur district of rural Rajasthan found that the quality of public healthcare service was extremely low and that unqualified private providers account for the bulk of healthcare provision (Banerjee et al., 2004a). The research also documented that the poor quality public healthcare services had an adverse effect on the habitants' health. However, apart from the poor conditions of the healthcare delivery systems, which may have improved over the years, certain climate-related factors still persist and tend to impact human health in Rajasthan. Among a wide range of factors, this report focuses on the climate-sensitive factors that play a critical role in determining the vulnerability of the population in terms of their sensitivity and surviving capacity. However, it is to be noted that there has been substantial improvement in healthcare infrastructure in the state over the last decade.

Rajasthan currently has a total of 696 community healthcare centres. It has 2,174 primary healthcare centres and 14,418 health sub-centres.

6.3.4. Human Resources

Human resources are an integral component of the public health policy. Adequate availability of human resources, with a suitable skill mix, and their deployment at different levels of the healthcare infrastructure are essential for delivering efficient healthcare services to the population. While information on human resources is often unreliable in India, the National Health Profile Report 2018 has aimed to document Rajasthan's health workforce in an attempt to correct this deficit (Ministry of Health & Family Welfare, 2018). The current human resource indicators include details about allopathic doctors, dental surgeons, AYUSH-registered practitioners, nursing personnel and various para-medical health personnel in Rajasthan. The allopathic doctor to patient ratio is 1:10976. That is, an average of 10976 people are currently served by a single allopathic doctor (Ministry of Health & Family Welfare, 2018). Rajasthan ranks 10th state in India in the number of AYUSH-registered doctors (18563 doctors) after Bihar, Maharashtra, Jharkhand, Uttar Pradesh, Tamil Nadu, Telangana, West Bengal, Madhya Pradesh, Karnataka and Kerala.

6.4. Strategies to Adapt to Climate Change Related Health Risks

In this section, various policies related to climate change and health are discussed. The National Climate Action Plan of 2008 covered various missions related to wind, water, sustainable agriculture, etc. to combat climate change. The Ministry of Health and Family Welfare, via the National Health Mission and other financial schemes, has devised several programmes and policies that can prevent the impact of climate change on public health, include the recent ones of AB-PMJAY, POSHAN Abhiyan etc.

6.4.1. Mission to Mitigate Climate Action Adapted by Rajasthan

In 2008, India identified eight national missions in the National Action Plan on climate change to address the impact of climate change on health. Taking into account contextual factors, Rajasthan has adopted seven missions as follows:

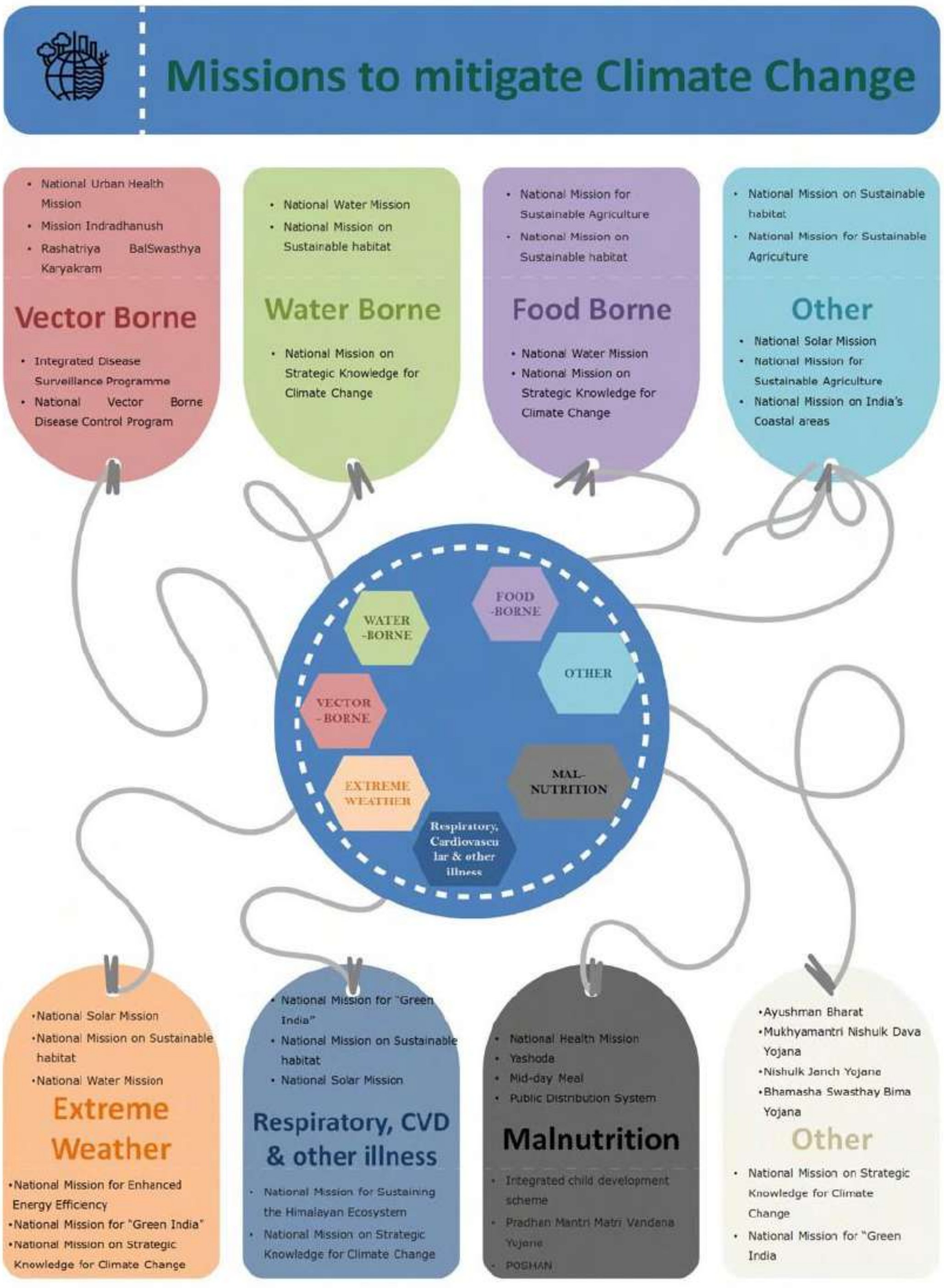

Figure 6.6. Missions to mitigate climate change in Rajasthan.

Table 6.4. List of national missions and their goals to mitigate climate change

S. No.	National Missions	Goal
1	National mission on strategic knowledge for climate change	To identify the need for research in specific areas of climate science to better understand the climate processes impacting the state
2	National mission on sustainable habitat	To provide policy support and guidance in terms of encouraging action for various sectors like sustainable habitats, water supply, sanitation, solid waste management, transport, urban planning and urban governance leading to sustainable development
3	National water mission	To conserve water, minimize wastage and ensure better equitable distribution both across and within states through integrated water resources development and management
4	National mission for sustainable agriculture	To make agriculture more productive, sustainable, remunerative and climate resilient by promoting location-specific integrated/composite farming systems
5	National mission for enhanced energy efficiency	To strengthen the market for energy efficiency through implementation of innovative business models in the energy efficiency sector
6	National mission for "Green India"	To protect, restore and enhance India's diminishing forest cover and respond to climate change through a combination of adjustment and mitigation measures
7	National solar mission	To establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible.

6.4.2. Rajasthan Health Policy Review

As per the SDG India Index published by NITI Aayog, Rajasthan is in the *performer* category. This indicates that while Rajasthan is on the path to better health and well being, there is scope for further improvement in terms of service delivery, health personnel allocations, improvement of maternal and child health, together with disease-specific interventions. This calls for emphasizing the development of the healthcare infrastructure and providing quality healthcare services to the people. Also, many state government schemes have aimed at delivering solutions like telemedicine, emergency ambulance care, and free IPD and OPD healthcare to low-income families.

Overall, the current health issues that still persist in Rajasthan are high MMR, IMR, malnutrition among children and women, declining sex ratio under six years of age, and high incidence of childhood diseases. The direct as well as indirect factors contributing to this problem majorly include low female literacy compared to the national average, inadequacies in water supply and sanitation, poor health and poor socio-economic status of women along with social discrimination. Thus, there is a discernible need for an in-depth investigation into the current vulnerabilities and challenges in the health sector of Rajasthan. Moreover, factors contributing to declining health issues, specifically of natural, climatic and socio-economic origins, needs to be further explored in order to probe into policy recommendations and modifications under Rajasthan Action Plan on Climate change.

A number of existing health and health-related policies in Rajasthan have direct implications on the impact of climate change on health. The policies are divided as per the major health impacts rendered: VBDs, malnutrition, availability of health infrastructure and services etc. An example of one such policy is discussed next.

6.4.2.1. Mukhyamantri Nishulk Dava Yojana (through RMSC)

Mukhya Mantri Nishulk Dava Yojna was launched on 2nd October 2011. Under this scheme, all outdoor and indoor patients visiting hospitals attached to medical colleges, district hospitals, community health centres, primary health centres and sub centres are provided essential medicines free of cost. Rajasthan Medical Services Corporation (RMSC) has been constituted as a central procurement agency for purchase of medicines, surgical equipment, and sutures for the Medical Department and Medical Education department. RMSC also supplies medicines etc., to all government health institutions through 40 district drug warehouses (DDWs), established across 33 districts of the state. As per the Essential drug list, 711 medicines, 181 surgical & 77 sutures are listed. The quality of drugs being supplied is ensured by testing of drugs at empanelled drug testing laboratories. The list of drugs, which is provided by free drug distribution centres, has been displayed in government medical institutions. Medicines are available for outdoor patients according to OPD timings and 24-hour for indoor and emergency patients. In this scheme according to the need of hospitals, 10% of annual budget can be used for local purchase. Under the scheme, medicines for the treatment of critical and severe disease are also available like drugs for cancer, heart diseases, diabetes and asthma. To maintain the stock of drugs, DDWs are computerized, and a special E-aushadhi system has been established, which lists all the medical institutions and medicines available. The E-aushadhi software helps with tendering, indent sending, determining drug consumption status at hospitals, issuing of purchase orders, confirming of expiry dates, ensuring the quality of drugs and submitting information about debarred medicines. Descriptions of drugs given to hospitals are also entered in this software so that report can be accessed when needed.

6.4.2.2. Current Initiatives

The Government of Rajasthan has recently launched two notable public health schemes in May 2022, to uphold the health and well-being of Rajasthan population. While the first scheme 'Mukhyamantri Chiranjeevi Swasthaya Bima Yojana' focuses on provision of family health insurance, the second scheme 'Mukhyamantri Nishulk Nirogi Rajasthan Yojana' benefits the state population with free testing and medicines. Both the schemes are posed to be vital in the context to the climate-change related health risks in Rajasthan. The details of the afore-mentioned schemes are given below:

Mukhyamantri Chiranjeevi Swasthaya Bima Yojana

Considering the well-being of the population, the importance of health insurance schemes is paramount especially for the disadvantaged masses. In line with this, the scheme was launched on 1st May, 2022 towards achieving the goal of Universal Health Care as defined in the SDGs. Under the scheme families of NFSA, SECC, small and marginal farmers, contractual workers and beneficiaries of COVID-19 ex-gratia scheme have been given health insurance at zero cost. The rest of the population can onboard the scheme by paying Rs. 850 per family per year which is 50 percent of the premium cost to the government. The remaining 50 percent premium cost is being borne by the State Government. It is to be noted that the State Government employees and pensioners are being covered under another scheme i.e., "Rajasthan Government Health Scheme (RGHS)". The USP of this scheme is that there is no restriction of age, income and family size as well as this scheme covers pre-existing chronic diseases. This scheme offers flexibility in terms of provision of private/semi-private rooms in fully accredited and entry level NABH hospitals in cases where beneficiary is willing to avail private/semi-private room at its own cost instead of general ward under the scheme.

Registration of the family is through Jan Aadhar Card which is a state specific family identity card used in various other cash or non-cash individual beneficiary schemes of the state. Cashless IPD treatment up to Rs. 5 lakhs (Rs. 50,000 for secondary and Rs. 450,000 for tertiary illnesses) on Insurance mode and up to Rs. 5 lakhs on trust mode. A total of 1633 packages are offered in the scheme covering 23 important specialities and super specialities. Out of these, 61 packages are being implemented on trust mode.

Mukhyamantri Nishulk Nirogi Rajasthan Yojana

The Chief Minister Free Medicine Scheme was implemented in the state from the year 2011 and Chief Minister Free Testing Scheme from the year 2012. To further augment the effectiveness of the above schemes, the *Mukhyamantri Nishulk Nirogi Rajasthan Scheme* was started from 1st May, 2022. Under the schemes, 100 percent medicines and tests are being provided free of cost to the residents of Rajasthan. A total of 3,375 medicines, surgical and sutures are currently available.

More than Rs. 500 crore rupees are likely to be spent on the patients under this scheme. Jan Aadhar card has been made mandatory for the treatment of patients. Imprest money is being given so that 24X7 medicine/testing arrangements can be done. In emergency situations, up to Rs 15,000 has been made available to the medical in-charge for cash payment for getting medicines and tests done if required from a private medical store or diagnostic centre. Feedback from the benefitted patients is collected through call centres.

6.4.2.3. Other

Various national programmes, such as the Family Planning, Child Survival and Safe Motherhood and Reproductive and Child Health (phase 1 and 2), have tried to improve maternal health; yet, they have not elucidated the desired impact due to various reasons as explained by Iyengar et al. (2009). The recent schemes of *Janani Suraksha Yojana*, *Kalewa Yojana*, *Deshi Ghee Scheme*, *Yashoda*, *Hamari Beti Act*, *Mukhbir Yojana*, *Mukhya Mantri Balika Sambal Yojana* provide ample opportunities to improve maternal and neonatal health, provided the quality issues can be adequately addressed.

Additionally, a unique e-governance project for pregnancy and child health services was implemented on 15 December 2009, where online data of more than 13000 government health institutions, including health facility details, are available. It also facilitates monthly reporting of progress within the state. Furthermore, in order to increase awareness regarding maternal and girl child health, state schemes like *Swasthya Sandesh Sewa* (2011), *Dati Sumangla Scheme* (2010), *Swasthya Mitra Yojna*, *Janani Express* (2012), along with family planning schemes like *Janmangal Programme* (1992), *Jyoti scheme* (2011), *Parivar Kalyan Bima Yojana* have been launched. Details of some schemes are elucidated below. These schemes may be continued further to reduce the burden of diseases, which may be aggravated due to climate change-related uncertainties.

Table 6.5. List of some of the health initiatives to improve health status in Rajasthan

National Vector Borne Disease Control Programme (NVBDCP)	To have integrated accelerated action towards reducing mortality on account of malaria, dengue, JE, and kala-azar
Mission Indradhanush	To address the unvaccinated or partially vaccinated and those who were not covered during the rounds of routine immunization for various reasons
Integrated Disease Surveillance Programme	To detect early warning signals of impending outbreaks and help initiate an effective response in a timely manner
Integrated Child Development Scheme	To provide access to basic nutrition and health to children below the age of 6 years and women in the reproductive age group, pregnant women and nursing mothers
POSHAN	To improve nutritional outcomes for children, pregnant women and lactating mothers
Targeted Public Distribution System and National Food Security Act, 2013	To provide for food and nutritional security in human life cycle approach by ensuring access to adequate quantity of quality food at affordable prices so people live a life with dignity
Iodine Deficiency Disorder Control Programme Action Plan	To prevent iodine deficiency disorders like the incidence of goitre, physical and mental disorders, cretinism and deaf mutism
Rajasthan Telemedicine	Telemedicine utilizes telecommunication and information technology to provide clinical healthcare from a distance to overcome distance barriers and improve healthcare access.

Nishulk Janch Yojana	To strengthen the existing laboratories and other diagnostic facilities (and to create additional facilities if required) in all the public health institutions so as to provide essential diagnostic services, free of cost to all patients visiting government hospitals To meet gaps and to provide adequately equipped quality diagnostic service packages at various levels of healthcare
Bhamashah Swasthay Bima Yojana	To provide cashless healthcare services to poor families of Rajasthan, thus providing social and financial security against illness to these families and reducing out-of-pocket expenditure

6.5. Key Recommendations

Direct and indirect health impacts of climate change in Rajasthan are evident and inevitable. Therefore, adaptation to these direct health impacts needs strengthening through various measures. Firstly, warning systems should be in place for extreme events, along with effective contingency planning and identification of the most vulnerable and exposed communities. Then actions should be undertaken to reduce the burden of heatwaves such as installation of reflective, transpiring shading, promoting air-flow-providing vegetation-covered surfaces and training healthcare workers and integrated heatwave early warning systems (HEWS). Adaptation should also include increasing green infrastructure and urban green spaces; improving the design of social care facilities, schools, other public spaces; and developing more climate-responsive public transport. This also entails mitigation efforts to reduce air pollutants. Meanwhile, to mitigate floods and storms, adaptive structural measures should begin with robust built infrastructure. Along the same lines, non-structural measures should also be pursued, such as flood insurance, development policies, zoning laws, flood-plain regulations, building codes, flood-proofing, tax incentives, emergency preparedness, flood forecasting, and post-flood recovery.

Action for resilience against the indirect impacts of climate change will be faced with new challenges over the years. However, policy action should integrate adaptive measures by enhancing food security, increasing investments in agricultural research and human capital, and improving rural and water infrastructure. And most importantly, efforts should be made to enhance international collaboration towards a common cause by scaling up safety nets in food-insecure regions. These adaptive and resilient approaches need to be assessed and prioritized so that they address the gaps in each particular case and location. For each measure suggested, assessments must appraise the costs, benefits, effectiveness, and barriers to implementation. After mapping the impacts of climate change and the policy processes for adaptation, we now recommend that over the next 5 years the Rajasthan government can consider implementing the following recommendations

- **Recommendation 1: Invest research, monitoring and surveillance of climate change and public health to ensure a better understanding of the adaptation needs and the potential health-related co-benefits of climate mitigation at the local and national level.**
  With the launch of School of Public Health (SPH) in the year 2021 in Rajasthan, schools have turned their focus to surveillance and climate change, as one of the major areas of research, in order to help state policymakers make equitable policies. Rajasthan has also been declared the first state to have a Climate Resilience Heat Action Plan for rural areas – consisting of an interdisciplinary team of experts from climate change, health, and weather – to combat extreme weather events and their impact on health. The increased investment on surveillance of zoonotic diseases, which clearly saw a rise in Rajasthan following the changes in rain patterns, is a much-needed call for action. With new outbreaks of COVID-19 cases and its variants, along with the outbreaks of already existing disease like dengue and malaria, early identification and reporting of outbreaks and clusters is of prime importance now.

- **Recommendation 2: Protect cardiovascular and respiratory health by ensuring a rapid phase out of coal from the state energy mix.**
  Particulate matter and short-lived climate pollutants released by coal-based plants have severe effects on cardiovascular and respiratory health. There are approximately 9 functional coal-based thermal power plants in Rajasthan currently. NTPC has commissioned one solar-based plant in Bhadla to shift to greener renewable sources of energy for electricity production, and approximately 8 projects in various parts of

Rajasthan are under implementation. With the new solar mission in place, a cleaner energy mix is essential to protecting the cardiovascular and respiratory health of the residents. However, according to the Global Burden of Disease Report 2016, approximately 60,000 people died in Rajasthan due to household air pollution. In fact, as per NFHS-5 data, only 15% of rural households in Rajasthan use clean fuel for cooking. Moving away the use of solid fuels, like coal, biomass gas stoves or LPG, especially in the rural areas of Rajasthan is highly recommended.

- **Recommendation 3: Rapidly expand access to renewable energy, providing reliable electricity for communities and health facilities; unlocking substantial economic gains available from this transition.**

  The state of Rajasthan has initiated a transition to renewable energy via the revised Solar Energy Policy 2019 and Wind and Hybrid Energy Policy 2019. Through the introduction of Rajasthan Renewable Energy Development Fund (RREDF), the state aims to promote solar energy and establish itself as a national leader in wind energy supply in a phased manner. Such mobilization and investment in renewable energy need rigorous monitoring to facilitate successful execution that goes beyond physical infrastructure. Successful execution means that the public should have direct access to such sources of energy, and they should stop relying on unsafe and unsustainable use of natural resources. Renewable energy also has the potential to generate employment opportunities in low-carbon industries, which will result in improved occupational health for the employee. Most importantly, such expansion will slowly reduce the state's dependency on fossil fuels.

  Rapid action and mitigation are called for because if the state is not aware and prepared for any further crisis, the impact may be felt on the local economy; that is, economic losses can persist for years. As policy options, we recommend investing in renewable energy and public health, both of which play a key role in vulnerability reduction and resilience. It also important to strengthen the state’s capacity to collect data from public health surveillance or monitoring systems, determine health impact burdens and trends, identify vulnerable people and communities, understand health impact patterns and prepare response plans and interventions.

Lack of finance is commonly cited major obstacle to adaptation, especially in the poorest regions and communities. In such cases, community and informal networks may provide financial support, but regional, national, and international funds as well as private sector funding will be required for adjustment responses at a larger scale.

- **Recommendation 4: Support accurate quantification of the avoided burden of disease, reduced healthcare costs, and enhance economic productivity associated with climate change mitigation. These will be most effective when combined with adequate local capacity and political support to develop low-carbon healthy energy choices.**

  To have an equipped and resilient community, various steps have to be undertaken, such as identifying vulnerable populations and assessing the capacity of public health systems. Then a case-specific model should be developed, which invests in preparedness measures and emphasizes community resilience and equity. For this, a public health perspective has to be established: bringing everyone together for a common cause. Ideally, such a public health perspective should resonate with the cause and build on the public's existing understanding of climate change and key health determinants. The common cause can be maximized effectively through public and political engagement, i.e., through media coverage; public participation and engagement; government engagement; and corporate engagement towards low-carbon infrastructure and activities.

  It is technically feasible to transition to a low-carbon infrastructure with new technologies, use of alternate materials, changing patterns of demand, and by creating additional sinks for GHGs. This requires challenging the deeply entrenched use of fossil fuels. Any significant deployment to meeting CO_2 targets will require the reduction of costs of mitigation options, carbon pricing, improvement in the research and development process and the implementation of policies and regulations that act as enabling mechanisms, as well as recognition of the strong near-term and long-term co-benefits to health.

- **Recommendation 5: Adopt mechanisms to facilitate collaboration between the ministries of health and other government departments; empower health**

professionals and ensure that health and climate considerations are thoroughly integrated into government-wide strategies.

A one-way approach to addressing health and climate change will not work. As we know, health professionals have a vital role to play in accelerating the progress towards tackling climate change. Health workers work to protect against various health threats and understand the benefit of maximizing the short-term and long-term benefits of intervention. Therefore, there is a need for capacity-building activities and to take up such responsibility. Private and public entities should collaborate to address the extent of preparedness we can expect. Capacity-building activities can be initiated by undertaking national assessments of climate-induced human health impacts in the state and subsequently identifying and addressing priority areas, such as cases of drought, land degradation and famine. Then, adaptation strategies and preventive and mitigating measures can be designed effectively to reduce possible adverse health impacts and build resilience to climate change. To fulfil this, the ministries of health and other government departments must ensure that free access to information is permitted.

- **Recommendation 6: Agree and implement an international treaty that facilitates the transition to a low-carbon economy.**

  The transition to a low-carbon economy is possible when all the states in the country recognize the gravity of the correlation that exists between health and climate change. A consensus is required because Rajasthan alone cannot facilitate the mitigation and adaptation process effectively without the collaboration of its neighbouring states. When state governments in the country actively divert investments towards green energy, it will encourage the corporate sector to reduce their financial interest in fossil fuels, increase investment in a low-carbon economy and recognize the future of renewable energy. The process is long but attainable.

  In December 2015, India was part of 195 countries that signed the Paris Agreement, which provides a framework for enhanced mitigation and adjustment and pledges to keep the global mean temperature rise to well below 2°C. Going forward, an enhanced programme dedicated to health within the UN Framework Convention on Climate Change will provide a clear and vital entry point for health professionals at the national level. This will ensure that the implementation of the Paris Agreement maximizes the health opportunities for populations around the world.

- **Recommendation 7: Develop a new, independent collaboration to provide expertise in implementing policies that mitigate climate change, promote public health and monitor progress over the next 15 years.**

  COVID-19 has already given us a glimpse of what the future may hold: the whole world will come to a standstill if health is threatened on a global scale. These threats will continue to grow, and the impact of climate change can be quite serious in the coming 50 years. The National Missions in NAPCC were formulated to spread awareness about the climate change process and its resultant consequences. Currently, public awareness regarding climate change is quite low in India. They do understand variability in climate change and its associated consequences, but many believe that these consequences are inevitable changes resulting from human development. Hence, it is necessary to communicate the risk factors and the required adaptation measures. Forming an independent multidisciplinary assessment team will likely bring in innovative ideas and strategies to identify existing research, if any, and prioritize vital research gaps. Building alliances with various healthcare professionals, environmentalists, policy makers and policy implementers would result in improved awareness, especially if increased community engagement is ensured through healthcare professionals at the ground level. This team will identify implementation that is urgent and develop tools to mitigate upcoming problems. They will also monitor and report the progress over the next 15 years, which is mandatory according to the indicators of the 2020 report of the Lancet Countdown on health and climate change that are contextualised to Rajasthan.

  In light of the projected changes in climate, future population trends, socio-economic scenarios, existing vulnerabilities in the health sector and consequent potential risks to human health, the following priorities have been identified for the health sector of Rajasthan:

  - Better disease surveillance coupled with strengthening of state-level health data collection system is the need of the hour. Lack of consistent, precise, accurate, high resolution and good quality data is a barrier to producing precise knowledge on disease incidence rates. This calls for immediate investigations into enhancement of monitoring systems and community-level surveillance of climate-sensitive diseases as well as further development of health-related climate services and early warning systems.

- Discrete training of health-sector staff on potential risks of climate change.
- Rigorous investments in research related to climate change and health integration are vital. Future research activities should aim towards climate-sensitive health impacts, grounded in an understanding of region-specific risks.
- Preventives measures becomes imperative in hotspots such as by:
  - Mobilising sentinel surveillance system
  - Reducing vector abundance through elimination of breeding areas
  - Breaking the female mosquito intra salivary cycle
  - Empowering and engaging community in spreading awareness about dengue and its manifestations through various IEC activities

6.6. Action Plan

- Develop early warning tools with relevant meteorological agencies for different end-users. An example is early warning systems for heat waves to share information with rural and urban populations, especially with farming communities, so as to provide community climate services and promote health advisories. Rajasthan also needs a real-time health information system comprising a digital health database (e.g., daily reported cases, mortality and morbidity, hospital beds availability) at a granular-level. Spatial and temporal scales should also be developed for climate-sensitive diseases, including VBDs like malaria and dengue; water-borne diseases like cholera and diarrhoea; heat stress; and nutrition related disorders especially among mother both at the pre- and post-natal stages and children. Along with Jaipur city, other districts like Jaisalmer and Barmer districts in the Thar Desert region of Rajasthan should be prioritized.

- Promote community surveillance programmes and awareness programmes (e.g., for management of groundwater pollution). Fluoride-endemic districts like Bhilwara, Nagaur, Jodhpur, Jaipur, Churu and Udaipur with >20.0 ppm fluoride and other vulnerable districts with anthropogenic contaminants like Kota should be prioritized.

- The Khetri copper belt with high radon content in drinking water should also be taken care of through periodic testing of water quality. Local level water testing labs should be implemented for continuous monitoring.

- Changing trends and triggering of events in terms of climate-sensitive disease outbreaks (including malaria, dengue, diarrhoea and cholera) should be identified by studying regional patterns. State surveillance units should be provided with interval-based feedback.

- Brick kiln workers and other construction labourers should be offered working environments with a lesser amount of direct exposure to heat and daylight. This can be done by introducing norms for working hours and also constructing shelters near working sites, especially in the districts where the temperature rise is projected to be high, such as Churu, Kota, Bikaner, Barmer, Ganganagar, Jaisalmer, Jaipur, Ajmer and Udaipur.

- Investments should be directed towards research that identifies linkages between climate indicators (like temperature and rainfall rise) and disease incidence rates, mutations and emergence of new diseases. Policy interventions are needed for managing and mitigating new diseases resulting from temperature fluctuations and changes in humidity patterns.

- The state public health institute should introduce discrete training modules on climate change risks and impacts on health. Modular attempts should be made for all health workers (including grassroot level workers) to ensure better surveillance of disease occurrences and improved health status and health outcomes for the people of Rajasthan.

- The social security nets in terms of family health insurance needs to be strengthened and augmented, together with provisioning of free diagnosis, testing and distribution of medicines and other health related services. This can greatly reduce the burden of diseases on the general population, especially the disadvantaged masses.

Adaptive Action I: Improved surveillance and reporting for climate-sensitive diseases to detect early outbreaks

- Inclusion of private players as partners for sentinel surveillance and regular reporting of cases
- Local pilot studies to identify health practitioners to be included as long-term partners.
- Engagement with private players through the right framework rather than mere regulation or mandated reporting.
- Training and tools for reporting.
- IDSP - Programme officers to engage, supervise and monitor private sector and intermediary staff for disease reporting.

Adaptive Action II: Improved data sharing of climate-sensitive diseases to improve response time and capacity (IDSP specific action)

- Coverage: Rural and urban
- Category: State-wide; technology deployment capacity building
- Duration: Short term (can be continued in the long term), continuous integration of the feedback
- Relevance: Improved disease surveillance coupled with strengthening of state-level health data collection system is a pressing need. Unavailability of consistent, and good quality data is a barrier to producing precise knowledge on disease incidence rates. Enhancement of monitoring systems and community-level surveillance of climate-sensitive diseases as well as further development of health-related climate services and early warning systems is recommended. Enhanced monitoring can not only permit improved prevention and control of health risks caused by changing climate but also limit response time when changes are detected in disease patterns.
- Key components of the action
    - A real-time health information system should be developed, comprising a digital health database (e.g., daily reported cases, mortality and morbidity, hospital beds availability) at a granular-level. Districts with a concentration of tribal population can be prioritized: Banswara, Dungarpur, Pratapgarh and villages in Sirohi, Pali, and Chittorgarh.
    - Quality of data, interval for data collection and extent of coverage should be prioritized.
    - Specific guidelines should be issued for quality control of data collected.

    - Regular data analysis at the district and sub-district level should be undertaken to identify any changing temporal and spatial trends in diseases.
    - Feedback should be provided to surveillance units at regular intervals.
    - Early warning tools need to be developed with relevant meteorological agencies for different end-users.
    - Community awareness programmes should be expanded. The expected outcome is creating a digital state-level real time and logged digital health database with improved data quality and extent of coverage.
- Implementation
    - Nodal department: State Public Health Department
    - Other departments: Medical and Health department schemes, Department of Statistics, Department of Medical Education, Department of Medical Health and Family Welfare, state as well as central universities (for example, Desert Medicine Research Institute, Rajasthan University for Health Sciences), state remote-sensing application centre, public health laboratories, medical colleges, meteorological departments and other research organizations within and outside the state, NGOs (for data collection and analysis), Rajasthan University of Health Sciences, State Institute of Health and Family Welfare, Regional Institute of Health Medicine and Research in Jaipur, along with a number of regional and district training institutes, and block training centres. Health and Family Welfare Training Centres, Disaster Management cell, Telemedicine service centres, State Meteorological Department, Department of Medical Education, Public Health Engineering Department, private medical institutions, and Desert Medicine Research Centre, Jodhpur.
    - Timeframe: 1-2 years for a gap assessment to identify districts/blocks in the existing surveillance systems, followed by 3-5 years for developing adequate infrastructure and capacity.
    - Associations with ongoing government initiatives: Infrastructure, institutions and human resources recognized for present systems of surveillance can be utilized and improvised to specifically address climate-related risks. The current schemes of investigation include Integrated Disease Surveillance Programme, National Surveillance Programme for Communicable Diseases, Arogya Online and National Vector Borne Disease Control Programme.

    - Specific capacity needs: Infrastructure provision of both computer hardware and software, strong broadband internet connection and eligible human resources, training for staff that handles information, including data managers, data entry operators, epidemiologists, microbiologists, health workers etc.
    - Financial needs: Donors such as the World Bank, Asian Development Bank, Japan International Cooperation Agency and other donor agencies who have previously funded disease surveillance programmes in the country may be approached for funding.

Adaptive Action III: Entomological surveillance for proper entomological and epidemiological control strategy of VBDs.

This section highlights the importance of extensive entomological surveillance and vector behaviour study.

- Study on vector behaviour and responses to existing drugs and insecticides
- Study of cattle as zoonotic hosts for various vectors
- Monitoring of resistance amongst vectors
- Study on introduction of bio-control agents (predatory mosquitoes) for restricted habitats (Singh et al., 2013).
- Implementation
    - Nodal department: State Public Health Department.
    - Timeframe: 5-10 years

Adaptive Action IV: Research-based ranking of areas and interventions to address health risks from climate change

- Coverage: Region-specific
- Category: State-wide; Research and development
- Duration: Short term
- Relevance: Vulnerable regions and population groups should be identified through focused research for a better understanding of the impact on different aspects of human health. The research will inform the planning and efficient application of activities and interventions; it will also facilitate post-implementation analysis and assessment at the field-level, which are currently lacking in the state.
- Key components of the action

- Identification of data needs and existing gaps in order to undertake assessments on the impact of climate change on various dimensions of human health.
- Studies on the regional patterns of different climate-sensitive diseases and disease outbreaks (such as malaria, dengue, chikungunya, diarrhoea, cholera, heat stress etc.) through regular data analysis at the district and sub-district level. Recognition of changing trends and delivery of interval-oriented feedback to the established state surveillance units. This should definitely involve identification of trigger events (climatic and non-climatic factors) that influence the infection-transmission-spread of climate-sensitive diseases. Data generated from Adaptive Action 1 (described above) can directly feed into this field of research.
- Assessment of potential impact through procurement/development or customization of health impact models and climate prediction models; validation of predictive modelling results through qualitative and quantitative data.
- Interdisciplinary research through improved coordination between various departments can be facilitated owing to the intrinsic interlinkages between human health, water and sanitation, urban planning, etc.

* Expected outcomes: High-quality research outputs that can help generate evidence on the most important effects and the most vulnerable groups in order to prioritize areas for interventions.
* Implementation
    - Nodal department: State Public Health Department
    - Timeframe: 5-8 years
    - Associations with ongoing government initiatives: Association with current schemes of investigation such as Integrated Disease Surveillance Programme, National Vector Borne Disease Control Programme, which are engaged in data collection on various diseases apart from trend analyses of diseases.
    - Specific capacity needs: Specific training of epidemiologists to carry out research in vulnerability and impact assessments by facilitating hands-on training on different software packages for spatial analysis and other statistical modelling

    - Financial needs: Special programmes specifically on climate change and health can be launched under National Mission on Strategic Knowledge on Climate Change. ICMR, agency for medical research can be another potential source of research funding.

Adaptive Action V: Training and skill development of new cadre or existing healthcare staff (both private and public) to understand climate change related diseases.

- Coverage: Region-specific
- Category: State-wide; Training and capacity building; particularly for health sector staff
- Duration: Short term and further continued in the long term
- Relevance: Sustained measures are essential for capacity building, awareness action and practical training of the personnel responsible for and involved in planning and implementation of adaptive strategies and outlining agendas. They should be made aware of the potential risks posed by climate change so that they may devise effective acclimatization measures. Lack of scientific understanding of the relatively new domain of "climate change and human health" calls for urgent training of all health sector staff.
- Key components of the action:
    - A training needs assessment (TNA) should be conducted. This TNA should be specific to different tiers of health sector staff, such as physicians, data handlers (operators and managers), epidemiologists, microbiologists, laboratory staff and ground-level health and sanitation workers.
    - Scientific and technical hand-on-training should be provided to epidemiologists, other policy-level researchers and health-sector and urban planners to carry out research on health impact assessment.
    - Module-based additional training on climate change aspects, their potential risks and effects should be organised regularly by the State Public Health Institute.
    - Involvement of local NGOs, women's self-help groups, ASHA workers and different cooperatives is essential. The expected outcomes should be enhanced awareness among the health sector staff about the effects of climate change on human health and potential response strategies and plans.
- Implementation

    - Timeframe: 1-2 years to conduct TNA, followed by 1 year to prepare substantial material for training and awareness sessions, followed by regular and periodic training programmes (long term)
    - Nodal department: State Public Health Department
    - Associations with ongoing government initiatives: Association with current schemes like National Rural Health Mission and National Health Mission.
    - Specific capacity needs: Apart from community sensitization, special focus should be on urban planners, health officials, public health department planners, and policymakers, to train them on health risks of climate change and mitigation strategies.
    - Financial needs: National Rural Health Mission can be a potential source of funding for training-related activities.

Adaptive Action VI: Improve primary, secondary and tertiary healthcare system and involved facilities to handle and better manage climate risks and their potential health impacts

- Coverage: District-specific; state-level.
- Category: State-wide; infrastructure development
- Duration: Long term
- Relevance: Lack of discrete medical units and specialised treatment facilities for climate- change induced tropical diseases calls for upgradation of the healthcare system at all levels, where improved facilities are available for better treatment of patients.
- Key components of the action
    - Firstly, tele-medicine and tele-health facilities should be enabled in remote places, especially in Thar Desert areas and tribal districts.
    - Mobile health units specifically designed for climate-change induced disease treatments should be strengthened.
    - Strengthening of disaster management plans especially for the health sector, which should cover management of injury and casualties; provision of emergency shelter, sanitation, food, water, and medicines; and management of communicable diseases (through constant surveillance and response). This should include preparation of specific emergency health support plans for

different climate hazards such as heat waves, floods and droughts. A long-term support plan can be drawn for identified vulnerable groups such as the tribal populations and the rural poor.
    - Separate medical units and sub-divisions and emergency units in district hospitals for treating climate-change induced diseases. VBD units should be prioritized.
    - Private-sector investment in developing specific medical and healthcare institutions, paramedical training institutes, blood banks, testing labs, tropical disease based medical units to promote private-sector involvement in the health sector of Rajasthan.

- Implementation
    - Timeframe: 1-2 years to prioritize the hospitals and needs assessment, followed by 1-2 years to design possible strategies and implementation outlines, followed by development of infrastructure facilities and setting up of treatment units in different hospitals (long term)
    - Associations with ongoing government initiatives: Association with current schemes like National Rural Health Mission and National Urban Health Mission.
    - Financial needs: National Rural Health Mission can be a potential source of funding for training-related activities.

Adaptive Action VII: Provision of health insurance and facilitation of health service delivery to all - Enabling Universal Health Care as defined in the SDGs

- Coverage: All population.
- Category: State-wide;
- Duration: Long term
- Relevance: Enabling enrolment in coverage supports the health and well-being of individuals and communities. Health coverage improves access to care, health outcomes, and reduces financial burden (out of pocket expenditure) on individuals, families and communities.
- Key components of the action

- Enabling all population to enrol for the family health insurance scheme without the financial burden. Recently launched scheme, the *Mukhyamantri Chiranjeevi Swasthaya Bima Yojana,* might enable all section of the population to avail healthcare facilities seamlessly across the state of Rajasthan and improve the health outcomes.
- Additionally, there is a need to augment the delivery of existing health services through schemes (that are supported through financial and resource allocations) that would enable people access health care services seamlessly and timely, even without insurances. Current schemes such as *Mukhyamantri Nishulk Nirogi Rajasthan Scheme* might encourage people to avail services timely without financial burden.

- Implementation
    - Timeframe: 3-5 years to ensure enrolment of medical insurance to all masses. Monitoring the district wise enrolment rate as well as the percentage of claims that are being processed.
    - Feedback from the benefitted people, families and communities need to be analysed and strategies should be formulated to address the grievances (if any) timely.

Adaptive Action VIII: COVID-19 Vs VBDs

Efforts should be made to ensure steady supply of health infrastructure, drugs, and workforce to cater to climate change related diseases while battling the COVID-19 pandemic. The following points should be considered:

- Amphotericin B for kala-azar treatment (CL) endemic to Rajasthan.
- Surveillance by frontline workers for VBDs along with COVID-19.
- Inpatient bed availability for outbreaks like dengue, cholera, etc.

Chapter 7

Forestry and Biodiversity

7.1. Introduction

The first step towards preparation of a detailed state action plan on climate change (SAPCC) is to identify state-specific risks and impacts and opportunities in the context of climate change. Subsequently, areas for research and policy action need to be prioritized in response to identified current and future vulnerabilities and projected impacts of climate change. Effective policy design for adaptation should integrate identified strategies with national priorities and missions. The various government agencies in Rajasthan, especially departments related to forests, pollution, environment, agriculture and urban development have already been involved in such activities and strategies for the past few decades.

Chorran et al. (2021) and Rathore and Verma (2013) state that Rajasthan has a very high climate sensitivity compared to other states in India. This is essentially ascribed to more severe as well as more frequent spells of drought. Given that the livelihoods of Rajasthan's people largely depend on agriculture, animal husbandry, and forestry, this creates additional vulnerability since over 75% of the population is dependent on these climate-sensitive sectors. Considering that Rajasthan has only 1.2% of India's water and cultivable land resources, and over 20% of rural Rajasthan is landless (Rathore, 2005), there is substantial dependence on forests, agro-forestry and pasture as sources of primary and secondary income; food and nutrition security; and livelihoods. Further, this also increases the importance of protection and conservation of common property resources (CPRs), as a large section of the rural population depend critically on forests, pastures, waste lands and natural water bodies (especially women, Adivasis and landless households). The vulnerability of CPRs to both climate change and anthropogenic degradation and encroachment is thus crucial to address in adaptation strategies.

Studies have shown that Rajasthan falls in areas of greatest climate sensitivity, maximum vulnerability and lowest adaptive capacity (Chorran et al., 2021; Rathore & Verma, 2013). Already, water resources in the state are scarce and have a highly uneven distribution both temporally and spatially. The state also has the highest probability of drought occurrence in the country (Singh et al., 2010; Rathore & Verma, 2013). Deserts and forests constitute two significant ecological zones and ecosystems that are particularly significant for Rajasthan in terms of geographical area, source of livelihoods and ecosystem services they provide (Singh et al., 2010). Changes in area and biodiversity of forests and deserts are affected by both climate and anthropogenic factors. More importantly, they also affect the vulnerability contexts of human settlements and populations in proximate areas.

The state of Rajasthan has been identified in various studies as being among those areas in India that are likely to come under most pressure due to climate change (Singh et al., 2010; Rathore & Verma, 2013; Gopalakrishnan et al., 2011; Kaushik & Sharma, 2015). Largely characterized by arid and semi-arid zones, the state is affected to a significant degree by water stress in different regions (Singh et al., 2019; Singh & Kumar, 2015). Evidence indicates that Rajasthan has a fairly high degree of forest biodiversity, which supports a high number of livestock, and the state's number one status in the dairy sector (Nikfarjam, 2020; Tripathi, 2000; Niwas et al., 2021; Sharma and Joshi nd). The forest sector generates a huge amount of secondary employment and provides a social safety net for millions of people, especially considering the frequency and intensity of droughts in arid and semi-arid agro-ecological zones (Rajasthan Livestock Development Board, 2014). Hence, forestry, biodiversity, grassland pastures and water bodies are critical to ensure more efficient adaptation to climate change in Rajasthan.

7.2. Rajasthan Forestry Profile

Rajasthan is India's largest state with 10.40% of the geographical area of India. The state is broadly divided into two unequal halves by the Aravalli hill ranges that run from south-west to north-east. Two-thirds of the state that lies to the west of Aravalli is primarily arid and semi-arid and is a part of the Great Indian Thar Desert, 61% of which lies in Rajasthan. The areas to the east of Aravalli and the south-western part are better in term of agro-climatic conditions and are home to the good forests of Rajasthan. Rivers and streams drain into the Vindhyan intrusions on the east and the south-eastern part of the state, which is well endowed with vegetation and wildlife. They are as significant to the ecology of the state as the desert and grassland ecology of the arid regions in the western part. Forests and forestry in Rajasthan therefore have to be understood not in terms of vegetal cover or tree density but in terms of ecological units and the ecosystem services they provide as well as the livelihoods they support, offering food, nutrition and income security to many. As per the Champion & Seth classification of Forest Types (1968), the forests in Rajasthan belong to two groups: tropical dry deciduous forests and tropical thorn forests, which are further divided into 20 types. The major types found in Rajasthan are northern dry deciduous forests (40.07%), *Anogeissus* *pendula* forests (15.21%), dry deciduous scrub forests (10.96%), desert dune scrub forests (6.62%) and desert thorn forests (6.1%).

The recorded forest area (RFA) in the state is 32,862 sq. km of which 12,176.24 sq. km is reserved forest; 18,543 sq. km is protected forest; and 2,143.04 sq. km is unclassed forests (as per SFD Adm. Report 2020- 21). During the period 1st January 2015 to 5th February 2019, a total of 2834 hectares of forest land was diverted for non-forestry purposes under the Forest Conservation Act, 1980 (India State of Forests Report, 2019). The state has 3 national parks (NP), 27 wildlife (WL) sanctuaries and 14 conservation reserves, which constitute the protected areas. There are 3 tiger reserve projects (Ranthambhore, Sariska and Mukundra hills) and two Ramsar sites (Keoladeo Ghana National Park and Sambbar lake) (as per SFD Annual Adm. Report 2020-21).

Class	Area	% of Geoprahical area
Very Dense Forest (VDF),	77.81	0.02
Moderately Dense Forest (MDF)	4341.90	1.27
Open Forest (OF)	12209.80	3.57
Total	16629.51	4.86
Scrub	4760.04	1.39

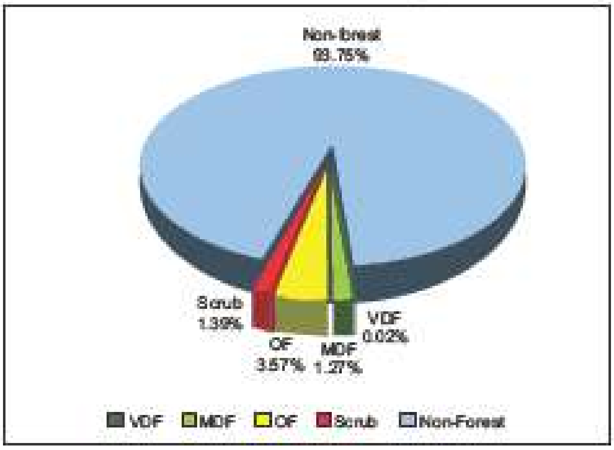

Figure 7.1. Forest cover and forest types in Rajasthan

Source: Rajasthan Van Report 2019

Singh et al. (2010) showed that the forest cover in Rajasthan increased from 1.25 to 1.33 to 1.58 million ha in the years 1982, 1992, 2002 respectively. They also showed an increase in the availability of biomass (tonnes ha–1) from 13.46 to 13.61, and finally to 28.32 tonnes per ha in the same years. A worrying aspect, however, is the low soil organic carbon in the state, which at 70.08 tonnes per ha, is lowest among all Indian states. Since the soils in Rajasthan are carbon-limited, they reduce soil fertility, constrain agricultural productivity and impose additional pressure on livestock and forest sector as secondary income sources, social safety net, and sources of food security. Together with desertification and land degradation, low soil carbon has the potential to enhance vulnerability resulting from climate hazards such as droughts, cyclonic winds, flooding and non-climatic factors such as land degradation. Over the years very dense forests and moderately dense forests have declined, with low tree canopy density forests (open forests) constituting the major forest type, which is highly vulnerable to degradation from anthropogenic and climate change factors (Fig. 7.1). These forests also have less biomass and low biodiversity.

Forests are an important constituent and protector of biodiversity, together with deserts and wetlands, which house a wide array of flora and fauna. These have ecological, economic and food security significance. The essential features of Rajasthan's biodiversity include

- Some species specific to the region, and hence in need of urgent conservation; particular species endemic to the Thar Desert and Aravallis
- Presence of 3000 known species of flora and fauna
- Species with evolved capacities and abilities to survive in harsh climatic conditions
- Large number of threatened and endangered species

Forests and biodiversity (and their conservation / protection) are important for several reasons:

- They provide significant adaptation and mitigation potential with respect to climate change.
- They support sustainable livelihoods among millions of households.
- They support tourism – a vital contributor to the state's GDP and a major source of employment.

Given the above and given the high amount of forest and non-protected area biodiversity in Rajasthan, the state's high economic contribution to livestock and the dairy sector, a rich history of innovations and institutional development of customary practices, and its rules for forest and non-forest commons (pasture), the state has the potential to offer insights and lessons for the rest of country to design effective climate adaptation strategies and vulnerability reduction policies. These policies can simultaneously address issues of livelihoods, poverty reduction and participatory/collective management of natural resources. Rajasthan enacted the Rajasthan Common Land Policy in 2010 and formulated operational guidelines for pastureland and grassland development through MGNRES in 2011. In compliance with a Supreme Court judgement, the state government also ordered removal of all encroachments on Oran lands and grazing land in the state. The state has been proactive in addressing problems related to common land encroachment and diversion and has attempted to restore commons to the communities. The Panchayati Raj department in the state has also passed several orders to promote common pool resources protection, allocate revenue wasteland for grazing, and integrate programmes and schemes related to wasteland and MGNREGS. These positive developments however may be adversely impacted if the protection and conservation of commons are not linked to scientific assessments of climate risks for these commons.

7.3. Climate Change Impacts: Assessment of Current Vulnerabilities and Future Risk Scenarios

The earlier Rajasthan state climate action plan, as well as several other studies, has identified climate change impacts and assessed vulnerabilities by exploring future risk scenarios. For the forest and biodiversity sectors, the specific vulnerabilities due to climate change impacts include the following

1. Area of and biodiversity within protected forests
2. Reduced biodiversity outside of protected forests
3. Desertification, especially in the western parts of the state
4. Land degradation in arid and semi-arid zones, in the hilly areas, in the forested tracts of southern Rajasthan, in and around mines, and in urbanizing regions
5. Possibility of loss of traditional ecological knowledge and indigenous practices for conservation, sustainability and meeting climate challenges owing to increased urbanization migration (Pareek & Trivedi, 2011)
6. Loss of habitats for diverse human and non-human species
7. Loss of commons, which have traditionally supported sustainable livelihoods, and provided solutions for climate change adaptation
8. Loss of sustainable livelihood patterns (agro-pastoralism, dairy and nomadism) that have been significant for the state’s economy and its population

9. Decline in urban forests and agro-forestry, which may reduce mitigation options and create flood risks, heat island effects, and reduce social safety nets under increasing drought scenarios
10. Increase in species facing threats of extinction
11. Possibility of enhanced stress on the structure and functions of forests ecosystems
12. Changes in forest types due to invasive species, non-native species and excessive planting of commercial species, which will have both positive and negative impacts for mitigation, carbon absorption, soil erosion, soil moisture and livelihoods
13. Possible changes in human and animal/bird migratory patterns, as predicted by several studies

7.4. Forestry and Biodiversity: Assessment of Vulnerability

The above vulnerabilities have significant adverse social, economic and environmental impacts which are briefly outlined and discussed below.

While actual forest cover is either increasing or decreasing in different districts of Rajasthan, what is of importance is to assess available forest resources for livelihoods, food security, livestock economy and for climate change adaptation and mitigation. It was earlier observed that previous clearing of forests for various projects, poor afforestation and compensatory forestation resulted in changes in the amount of natural forest cover (Kaushik & Sharma, 2015). This had reduced the availability of fodder and food for humans and livestock. However, subsequent action by the Forest Department through the State Compensatory Afforestation Fund Management and Planning Authority (CAMPA) and the implementation of the Rajasthan State Forest Policy may have increased forest cover (as per Rajasthan State Annual Plan, Chapter on Forests, 2016-27); this needs to be assessed. Even where forest cover has increased, this has been accompanied by declining forest biodiversity and low biomass production affecting livelihoods, decreasing dependence on agro-forestry and disturbing the “traditional decision-making strategies for farming”, which rely on “faunal indicators and signals”. Modern weather forecasting is not always reliable, comprehensible or usable by farmers, especially in the context of monsoon variability and weather uncertainty. Likewise, maintaining livestock earlier provided additional resilience and safety nets when droughts led to crop failure, but this strategy too is no longer available due to weather uncertainties, land use change and land degradation. Scientists and farmers point out that grass diversity in the pastures and commons have declined (Singh et al., 2010; Parthasarathy, 2018; Krishna et al., 2014; Kaushik & Sharma, 2015), impacting livestock, health and productivity, flock sizes of herders, and the dairy sector. The livestock sector is particularly affected by fodder quality and availability in pastures and grassland, and in a context where private lands are unable to support livestock, there is additional pressure on forests. As a consequence, adaptive and coping capacities are reduced both for farmers and livestock herders.

Another mechanism for coping with climate impacts on forestry is agro-forestry. It has the scope for increasing resilience and reducing vulnerability. In Rajasthan, agro-forestry has been a traditional adaptation strategy for livelihood security and provision of food, fodder and firewood. Agro-forestry has been practiced on both private and common land. These come under increased pressure because of climate change as droughts, land erosion, flooding and cyclonic winds affect their health.

Given the significance of forestry and agro-forestry for the livestock sector (De & Dhote, 2021), especially for tribal and forest dependent communities, impacts of climate change can indirectly affect animals, which constitute significant sources of income and food / nutrition (Kaushik & Sharma, 2015). Global warming-induced rise in temperatures imposes physiological stresses on cattle, goats, sheep, and camels, reducing milk, wool and meat productivity (Kaushik & Sharma, 2015). These stresses can be amplified with climate change induced vulnerability of forests, grasslands and agroforests. Climate scientists have predicted that heat stress will also enhance livestock and human water and food needs and affect their health, increasing disease probabilities arising from nutritional and water stresses. In vulnerable livestock populations – those which may be suffering from nutritional or water stress – the probability of disease spread will be even greater. Changes in water availability, fodder availability, and grassland species can result from disturbances to forestry and biodiversity caused by climate change (Singh et al., 2010). These vulnerability scenarios have a greater chance of being realized since hybrid and imported species of livestock are less adapted to the local climate and water and fodder availability. Rajasthan's status as one of India's major milk producers faces uncertainty in the near- and long-term future, if the forestry-biodiversity-livestock nexus is not clearly recognized and addressed by diverse stakeholders.

Bose (2012) has documented how well-meaning climate action policies may result in vulnerabilities to climate change among forest-dependent women. This occurs by affecting the existing adaptation strategies in harsh agro-climatic zones and drought-prone areas. Van Dijk and Bose (2016) argue that forest ecosystems provide diversity of resources to women, tribal people, lower castes, pastoralists and landless and small farmers. Hence this requires a shift away from a forestry approach to a landscape approach that connects different forest and non-forest resources. From a climate change perspective this interconnectedness and its significance for marginalized groups such as women, Adivasis and pastoralists need to be incorporated into forest and biodiversity policies; further there is a constant need to update our knowledge about the dynamic processes of climate change impact on these ecosystems and their livelihood dependence. Bose (2015) using a gender analysis framework finds that "local integrated landscape strategies (help) to cope with climate vulnerability", especially in the case of dryland agro-forestry, which are susceptible to climate variability and droughts.

It is well known that vulnerability to stresses and shocks among households, a community or a geographic area is a function of changes in various forms of capital (Sustainable Livelihoods Framework). Hence healthy stocks of natural capital including forests, pastures and surface / groundwater are necessary to cope with climate change impacts such as droughts, monsoon variability and floods. Forest ecosystems play an important role in drought-proofing vulnerable agricultural and livestock economies. Gopalakrishnan et al. (2011) assessing the impact of climate change on forest ecosystems, have reported that the forests of Rajasthan are significantly more vulnerable than those in all other states in India, with the exception of Jammu and Kashmir (Table 7.1). Projected changes to forest cover in the near term (2035) are the highest in Rajasthan and the second highest in the long term (2085).

Table 7.1. Projected changes to forest cover due to climate change

State	**Number of FSI grids**	**Projected to change by 2035 (%)**	**Projected to change by 2085 (%)**
Rajasthan	802	61.22	78.18
Jammu and Kashmir	910	57.03	88.35
Chhattisgarh	3292	48.00	75.85
Himachal Pradesh	838	47.49	65.39
Andhra Pradesh	2288	39.20	51.57
Karnataka	1947	38.37	62.20
Tamil Nadu	776	27.45	47.04

Madhya Pradesh	4432	22.59	48.17
Maharashtra	2197	21.21	45.33
Uttaranchal	1203	19.04	31.92
Arunachal Pradesh	2666	12.27	6.90
Orissa	2564	9.71	13.53
Meghalaya	829	7.96	0.00
Assam	1261	5.23	1.11
Jharkhand	1148	0.00	24.30

Source: Gopalakrishnan et al. 2011

An integrated strategy of climate change adaptation, drought risk mitigation, carbon sequestration and livelihoods enhancement needs to address the role of forests in combating further desertification. Climate scientists have predicted a significant increase in the desert area in Rajasthan as a result of global warming. Desert dune systems may get reactivated and remobilized in the Thar Desert due to rising temperatures. Reactivated sand drift mediated by climate change and anthropogenic impacts may threaten the sustainability of agriculture, infrastructure and land resources in Rajasthan. Arid forests and dune vegetation, if not properly managed and sustained, may aid the above processes. The Thar Desert experiences low and erratic rainfall, high air and soil temperature, intense solar radiation and high wind velocity. With climate change related changes to precipitation and temperature, the frequency of droughts in the region will make regional livelihoods highly vulnerable. While the implementation of Desert Development Programme (DDP) and Combating Desertification Programme (CDP) have achieved results in terms of fixation of sand dunes and monoculture of *Acacia tortilis* trees and single layer vegetation, they have also led to dune reactivation due to biotic and natural causes (Singh et al., 2010; Singh & Rathod, 2002; Singh, 2004; Pandey, 2007). They in turn results in tree uprooting, thinning of forests, and decline of agro-forestry in the desert margins.

As far as protected forests are concerned, evidence of the ecological impacts of recent climate change, create considerable cause for concern in the state. Ecological changes and declining biodiversity have led to extensive range contractions and species extinctions in forests. The Millennium Ecosystem Assessment scenarios suggests that at least 400 species are projected to suffer >50% range reductions by the year 2050 (over 900 by the year 2100). Rajasthan, which is blessed with centuries old lakes, has historically been a wintering-ground for many species of birds, which supports the state's tourism economy. Protected area tourism is very important for the state's economy. Any decline in this biodiversity due to climate change creates significant ecological and socio-economic vulnerabilities.

As mentioned earlier, climate change – through changes in rainfall patterns and temperature, as well as floods and droughts – also has an ecological impact on the common pool resources, which in turn increases dependence on CPRs, forests, pasture and water bodies, in an already stressed environment. Climate change can influence how communities govern and manage resources, compounding vulnerabilities and creating new natural resource conflicts. Studies in Udaipur district for instance provide evidence of major climate risks such as erratic precipitation trends (dry spells, wet spells, onset and retreat of monsoons, intensity of rainfall) and cyclonic storms. In Bhilwara district, studies report significant temperature rise and high-intensity precipitation events. CPRs are also repositories and inventories of biodiversity. They regulate water and nutrient flow, process solid and liquid waste and support livestock-based farming systems. As community assets, any impacts on CPRs due to climate change, will make them more vulnerable to climate shocks.

In the recent years, forest fires have emerged as another source of vulnerability and risk for forest-dependent communities and for forest ecologies around the world, and Rajasthan is no exception. While anthropogenic factors play a key role, climate change, through global warming adds to the causes of forest fires. Forest fire occurrence is increasing in frequency and fire seasons are growing longer due to global warming and rising temperatures. As yet, knowledge and research regarding fire ecology in diverse forest types and climates are under-researched, and existing studies tend to focus more on human factors rather than climatic variables. Fires have long-term impacts on forest degradation in Rajasthan; it is possible to get early signals from droughts and rainfall patterns combined with an assessment of forest ecology and fire lines to predict forest fires and efficiently manage the risks.

Weather and climate are both implicated in fire intensity and extent. While short-term weather patterns influence the likelihood of fires, their growth and spread, seasonal weather patterns determine the onset, duration, and severity of the fire season. Climatic shifts due to global warming are observed to modify the forest landscape and which part of the forest is more affected. In the absence of a sound understanding, assessment and mapping, vulnerability of natural systems and socio-ecological systems may increase. Since the Indian summer monsoon (and ENSO) has a key role in influencing the seasonal nature of forest fires, understanding climate change impacts on monsoon variability at regional levels is crucial for reducing vulnerability due to forest fires in Rajasthan. In Rajasthan, the months of March, April and May constitute the main season for forest fires. Major forest fires in the recent years in Mount Abu, Udaipur and Sirohi indicate an upswing in forest fires fuelled by climate change in the state. Furthermore, forest fires are observed during the winter season as well, especially during years of severe drought. Using satellite data for six years between 2005 and 2010, Krishna and Reddy (2012) posited that forest fires in Rajasthan occur mostly in the southern Aravalli range (Fig. 7.2). The area affected by forest fires steadily increased from 53,023.5 ha in 2005 to 144,816 ha in 2010. In 2009 – the warmest year since 1901– forest fires were witnessed across an area of 199,837 ha, which was more than double the area of the previous year. Dry deciduous forests – the major forest type in Rajasthan – are the most susceptible to forest fires, accounting for more than 90% of the burnt forests (Fig. 7.2). With close to 20% of the forest cover in the southern Aravallis affected each year, forest fires constitute a significant hazard for the state.

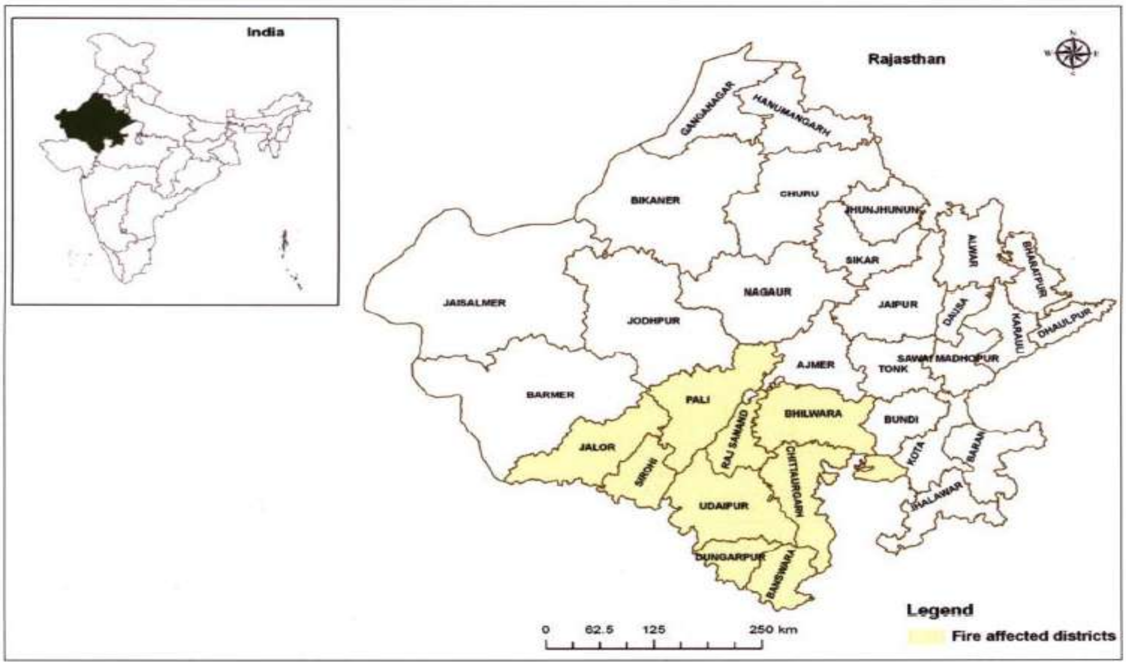

Figure 7.2. Rajasthan map showing the fire-affected districts during 2005-10.
Source: Peddi and Reddy, 2012

Udaipur, Chittorgarh, Rajsamand, Sirohi, and Pali are the major districts affected by forest fire. Since 2005, the number of districts affected by forest fire is increasing, as evidenced by total burnt area in each district (Fig. 7.3). The additional affected districts are Alwar, Banswara, Baran, Bharatpur, Bundi, Dholpur, Dungarpur, Jaipur, Kota and Sawaimadhopur. Likewise, fires in grasslands, which were very less in 2005, have been steadily increasing in subsequent years. From a vulnerability perspective, forest fires have adverse impacts on biodiversity, livelihoods, food, fodder and firewood. The extension of forest fires beyond the southern Aravalli range to urban settlements is especially a cause for worry.

Class	2005	2006	2007	2008	2009	2010
Forest						
Broadleaved	455.7	1259.4	46.5	896.3	3762.1	2,125.6
Dry deciduous	51,352.2	40,915.6	54,264.4	81,102.9	161,135.3	123,316.5
Thorn	435.2	940.2	1,514.9	2,488.4	9,399.6	7,857.4
Dry savannah	124.6	87.7	179.6	651.2	1,484.6	1,129.8
Sub total	52,367.7	43,202.9	56,005.4	85,138.7	175,781.7	134,429.2
Scrub	622.3	1,258.8	1,556.2	3,900.0	21,496.5	8,982.0
Grassland	33.5	219.7	127.5	616.5	2,559.1	1,404.7
Sub total	655.8	1478.6	1,683.7	4516.5	24,055.5	10,386.8
Grand total	53,023.5	44,681.5	57,689.1	89,655.2	199,837.3	144,816.0

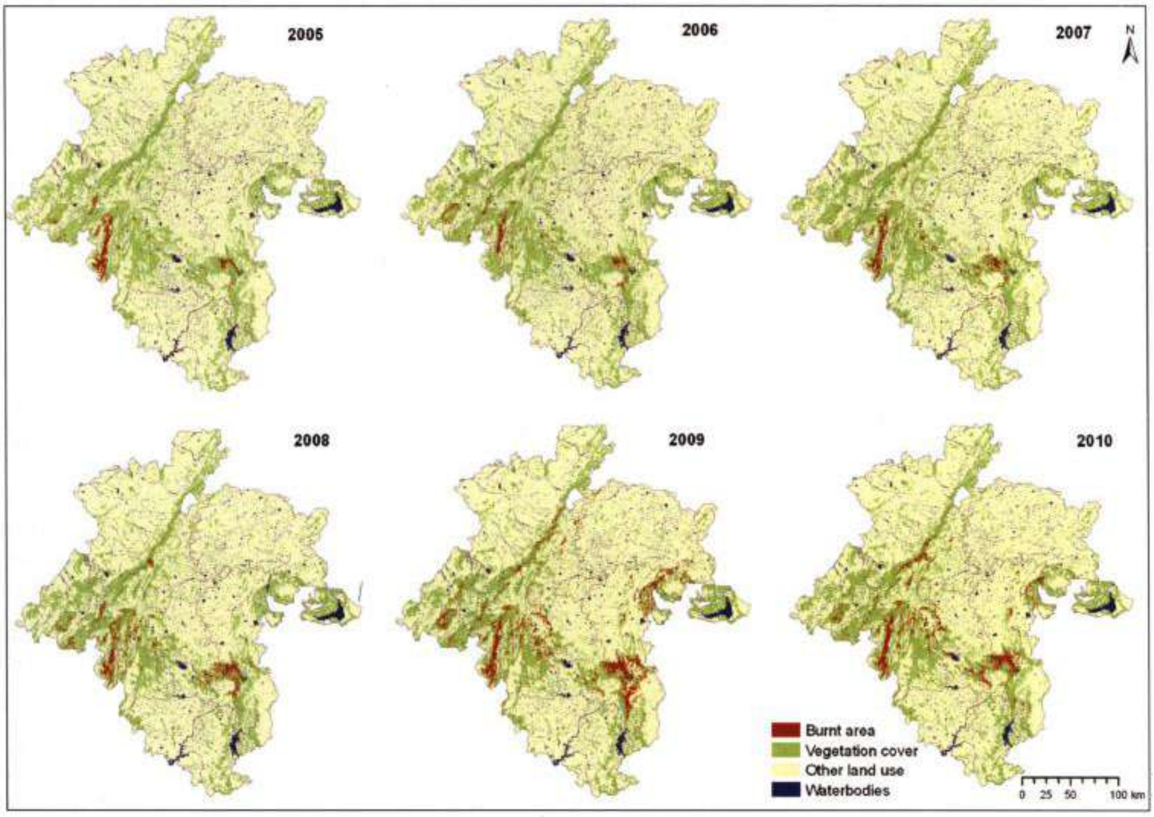

Figure 7.3. Aerial extent of burnt forests and map of burnt forest areas in Rajasthan: 2005-10. Source: Peddi and Reddy 2012

This brings us to total forest area and changes in forest area in Rajasthan. The data reveal an increase in some districts and a decrease in others. In general, it appears that forest area is decreasing in urbanising districts, indicating a clear anthropogenic cause. Rathore and Verma (2013) show that there has been an alarming decline in forest cover in the Aravalli hills in southern Rajasthan, which has historically been the major forest tract in the state (Fig.7.4). This has led to severe decrease in the availability of forest products such as fuelwood, fodder and timber; water in the springs, streams and rivers; and the forest habitat. They also report "increase in soil erosion, sediment transportation, siltation, drying-up of lakes, dams and surface water sources, lowering of water table from 5 to 10 m to 50 to 100 m" (Rathore & Verma, 2013). These changes are attributed to anthropogenic destruction – pressure of human and livestock population and rapid changes in precipitation patterns. The authors note that these have contributed to "depletion of environmental resources particularly, vegetation, soil resources and decline to water-table". River valleys in the Aravallis have also been affected by the loss of density in tree cover, apart from wildlife losing their habitats. Most forests in southern Rajasthan are now degraded. Remote sensing data also reveal a decline in well-stocked forest and pasture area from 1972 onwards. Whatever increase is seen is in social forestry. Decline in natural forest cover affects biomass availability considerably, leading to significant ecological and social vulnerability. Deforestation, removal of forest cover, soil erosion and land degradation in the Aravalli range have caused changes to the micro-climate. The number of rainy days has reduced by more than 50% from 101 in 1973 to 46 in 2010. Temperatures are rising, water tables are declining and water for drinking and irrigation faces severe shortages in the region.

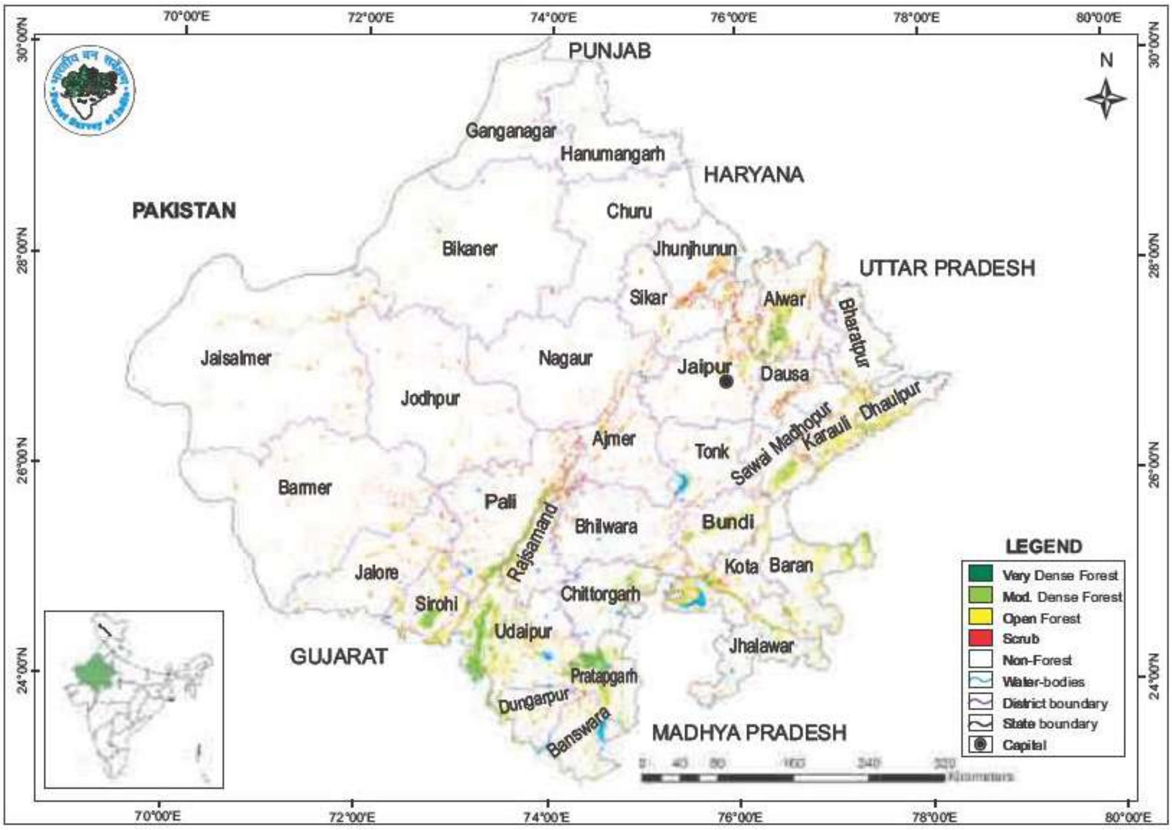

Figure 7.4. Forest cover map of Rajasthan.

Source: India State of Forests report 2019, Chapter on Rajasthan

Table 7.2 shows that very few districts currently have very dense forests. The majority of the districts have open forests with low tree canopy density, which indicates highly vulnerable natural systems.

Table 7.2. District-wise forest cover in Rajasthan

District	**Geographical Area**	**2019 Assessment**				**% of GA**	**Change wrt 2017 assessment**	**Scrub**
		Very Dense Forest	**Mod. Dense Forest**	**Open Forest**	**Total**			
Ajmer	8481	0.00	43.00	262.11	305.11	3.60	6.11	204.64
Alwar	8380	59.00	33.496	802.70	1196.66	14.28	-0.34	245.66
Banswara	4522	0.00	38.57	229.85	268.42	5.94	7.42	63.45

Baran	6992	0.00	154.89	856.10	1010.99	14.46	-2.01	106.56
Barmer	28387	0.00	3.85	285.94	289.79	1.02	16.79	234.23
Bharatpur	5066	0.00	22.00	208.27	230.27	4.55	1.27	77.93
Bhilwara	10455	0.00	31.00	193.19	224.19	2.14	3.19	176.39
Bikaner	30239	0.88	27.23	227.50	255.61	0.85	8.61	51.85
Bundi	5779	1.00	137.93	418.25	557 .18	9.65	-0.82	151.62
Chittaurgarh	7822	0.00	220.55	768.25	988.80	12.64	-0.20	100.09
Churu	13835	0.00	3.00	79.00	82.00	0.59	0.00	22.00
Dausa	3432	0.00	12.00	105.00	117.00	3.841	0.00	99.00
Dhaulpur	3033	0.00	80.00	339.00	419.00	13.81	0.00	75.40
Dungarpur	3770	0.00	42.71	259.59	302.30	8.02	11.30	75.35
Ganganagar	10978	0.00	10.00	102.92	112.92	1.03	-0.08	13.00
Hanumangarh	9656	1.00	7.00	81.96	89.96	0.93	-0.04	1.00
Jaipur	11143	12.00	97.11	443.65	552.76	4.96	0.76	285.39
Jaisalmer	38401	3.93	51.13	270.71	325.77	0.85	12.77	213.27
Jalor	10640	0.00	18.91	349.16	268.07	2.52	-6.93	250.89
Jhalawar	6219	0.00	83.02	352.56	435.58	7.00	-3.42	102.34
Jhunjhunun	5928	0.00	21.00	179.77	200.77	3.39	4.77	186.72
Jodhpur	22850	0.00	4.55	103.23	107.78	0.47	2.78	172.71
Karauli	5524	0.00	95.00	775.00	870.00	15.75	0.00	273.00
Kota	5217	0.00	153.62	393.11	546.73	10.48	-3.27	135.17
Nagaur	17718	0.00	15.00	132.04	147.04	0.83	4.04	102.32
Pali	12387	0.00	209.94	464.91	674.85	5.45	0.85	323.64
Pratapgarh	4449	0.00	562.54	475.37	1037.91	23.33	-6.09	58.73
Rajsamand	4655	0.00	134.91	386.88	521.79	11.21	10.79	123.23
Sawai Madhopur	4498	0.00	153.92	308.77	462.69	10.29	-3.31	116.67
Sikar	7738	0.00	31.00	162.06	193.06	2.50	1.06	202.34
Sirohi	5136	0.00	300.74	611.17	911.91	17.76	-2.09	229.36
Tonk	7194	0.00	26.94	138.12	165.06	2.29	0.06	57.73
Udaipur	11724	0.00	1213.88	1543.66	2757.54	23.51	-6.46	224.36

Grand Total	**342239**	**77.81**	**4341.90**	**12209.80**	**16629.51**	**4.86**	**57.51**	**4760.04**

Source: India State of Forests report 2019, Chapter on Rajasthan

7.5. Adaptation Potential (Including Co-Benefits)

In this section, we outline the adaptation potential for forestry and biodiversity in Rajasthan. Beyond reduced vulnerability, by combining with the co-benefits approach, the forestry sector has the potential to enhance livelihoods, meet SDG goals, reduce poverty and provide social safety nets for the poor. The following are the major adaptation strategies (current and future). Some of these are already being planned and implemented.

- Identification of wind and cyclone damage risk zones – forests as wind breaks (in recent years, cyclones and storms in the Arabian sea have tended to impact parts of southern Rajasthan through extreme precipitation events and cyclonic winds; this is likely to increase in the near future) (see Mohanty et al., 2014; Babar et al., 2018; Srivastava & Pradhan, 2018)
- Strategizing forest's role in arresting desertification
- Identifying and planning forest's role in arresting land degradation
- Reducing morbidities and mortalities during heat waves, through tree plantation for shade
- Livelihood enhancement through protecting and conserving grazing lands and common pool resources
- Providing control and governance over forest commons to communities to create social safety nets and sources of food, fuelwood and fodder during droughts
- Flood risk mitigation – forests, trees, and pasture have the capacity to reduce runoffs during extreme events
- Food, tourism, and medicinal benefits from forests and biodiversity, especially for the Adivasi population dependent on forests
- Promotion of biodiversity and increase in indigenous species implies better forest health, reduced vulnerability of forest ecosystems and better ecological adaptability
- Use forests to recharge groundwater, reduce runoffs and prevent soil erosion
- Enhance forest protection by highlighting their religious significance – *orans* (cultural and spiritual importance of forests, trees and other flora and fauna)

For more effective adaptation, land-use options outside forests that have the potential to increase resilience and reduce vulnerability of populations and are critical for livelihoods must be encouraged. Agroforestry has been a traditional land-use adaptation strategy in Rajasthan for a long time. It can support livelihoods through production of food, fodder and firewood along with mitigating the impact of climate change. As is well-recognized in the literature, the contributions of agroforestry systems are manifold: (i) biodiversity conservation; (ii) provision of goods and services to society, including ecosystem services; (iii) augmentation of the carbon storage in agroecosystems; (iv) fertility enhancement of the soils; and (v) safeguarding of social and economic well-being. Thus, as part of adaptation strategies, we need to strengthen and expand multifunctional traditional agroforestry systems in Rajasthan with a focus on indigenous useful species.

Significant opportunities exist for synergizing MGNREGA with the ongoing and newly planned agroforestry projects in Rajasthan (Singh, 2010; Pandey, 2002). Apart from contributing to mitigation and adaptation options, they can also provide co-benefits in the form of wages during the agricultural off-season. It is estimated that if an MGNREGS agroforestry programme covers $1/8^{th}$ of a hectare, it can sequester 1.6 million tonnes of carbon (as per methodology and calculation provided by Singh, 2010; Ravindranath & Murthy, 2021). This adaptation strategy can further be linked to sequential restoration of sand dunes by increasing green cover. Reactivated dunes can improve soil properties and moisture regimes. This will subsequently improve forest biodiversity in the areas where reactivation has taken place. By linking afforestation and agroforestry to sand dune reactivation, ecosystems services and livelihood-related activities can also be strengthened.

Urban forests as key urban ecological infrastructure can also be part of adaptation to climate change. Better governance of urban green spaces during the development of cities in Rajasthan can address vulnerabilities due to heat island effects and heat waves and enhance urban biodiversity. With the projected rapid urban growth in Rajasthan, designing multi-hazard adaptation strategies are a must for coping with risks due to climate change: temperature and precipitation variability, drought, flooding and extreme rainfall, cyclone and storm surge, sea-level rise and associated environmental health risks. Currently, the area under urban forests and green spaces are substantially below the WHO mandate figure of 9.0 m^2 green open space per city dweller. Increasing this will help address the above vulnerabilities and risks. Adaptation strategies suggested include creating multifunctional landscapes, protecting and developing adjoining forest lands and sequential restoration and enrichment of local biodiversity.

Urban and rural ecosystem restoration as part of climate change adaptation strategy can yield benefits for grasslands and forests; they can drought-proof at-risk regions, sectors and populations. Increasing vegetation cover can buffer the impacts of warming trends and increased rainfall variability; it will also support soil moisture retention, groundwater and aquifers recharge, restrict soil erosion, and increase overall productivity. If these are done in a participative manner using native species of value for local communities, the strategy can yield supplementary benefits of fodder availability, non-timber forest produce and ecosystem resilience.

For addressing biodiversity-related vulnerability due to climate change, the state needs to address the problem of habitat fragmentation and patch isolation, which affect species occupancy and mobility. By creating intervening corridors as part of conservation strategies and forest management, continued species survival and biodiversity restoration can be enabled. Biodiversity extinctions need to be explicitly incorporated into policy responses for effective management of protected areas.

Rajasthan has a successful record of creating a network of mega-shelterbelts. From the 1960s, the Rajasthan Forest Department has covered about 38,000 row km with plantations, especially under shelterbelt, roadside, railway lines and canal side. Incidentally, these plantations have improved agricultural returns in adjacent areas. These shelterbelts have been created to account for the predominant wind direction in the state and arrest the tendency for desertification. As a climate-proofing strategy, the Rajasthan Forest Department has over several decades created plantation strips and shelterbelts perpendicular to the predominant wind direction in areas spread from Ramgarh to the foothills of Mount Abu for climate change mitigation and livelihoods enhancement. This can be expanded to more locations and routes to strengthen the shelterbelt network as a part of the adaptation strategy. The mega-shelterbelts also provide other ancillary benefits:

1. Cost reduction in road maintenance due to reduced extremes of alternate heating and cooling of the road surface
2. Active pollutant removal
3. Interception of particulate matter and dust-storms

4. Networked-arrest of long-distance windblown sand as majority of wind flow is often likely to strike these mega green-avenues in near perpendicular direction
5. Enhanced resilience of road network
6. Moderation of local micro-climate
7. Climate change mitigation benefits (such as carbon sequestration) and adaptation benefits to neighbouring farmlands

Rajasthan has in place several policies for common pool resource management and village-specific laws and guidelines. Studies show that the restoration of CPRs through local governance and participatory initiatives can contribute to climate-resilient rural livelihoods. Studies in Udaipur and Bhilwara districts assessed the complex social interactions and ecological components of a system against climate change and variability. Coordinating governance of the commons with state agencies, private sector and NGOs will not only enhance local adaptive capacity they can also align livelihood security with sustainable management of natural resources.

7.6. Mitigation Potential of Forests

As is well known, forests and trees can substantially contribute to mitigation of emissions, in many different ways:

- Enhancing forest cover can increase the potential for carbon sinks/sequestration
- Using REDD+ framework for designing and implementing activities in the forestry sector can reduce emissions from deforestation and forest degradation; using REDD+ can also help enhance forest carbon stocks and reduce human pressure on forests that result in greenhouse gas emissions at national and subnational levels.
- New forest management plans can help in generating carbon stocks and wood products.
- Agroforestry and traditional tree-based systems also have significant mitigation and carbon sequestration potential through small-scale plantations that can be scaled up and out (Pandey, 2002).

Forests can contribute to mitigation using their capacity to remove carbon from the atmosphere and store it. It is estimated that deforestation and forest degradation contribute 15-20% of global GHG emissions. The IPCC LULUCF (Land Use, Land-Use Change and Forests) report distinguishes three main mitigation activities in the forestry sector:

- afforestation (converting long-time non-forested land to forest);
- reforestation (converting recently non-forested land to forest); and
- avoided deforestation (avoiding the conversion of forests to non-forested land) (Watson et al., 2000).

To encourage carbon sequestration and climate change mitigation, the state should design policy responses for tree planting and restoration of forests in Rajasthan on a large scale. Forest restoration is also consistent with the objectives of MGNREGA and employment generation. Management of multifunctional forests and employing tools of conservation biology and restoration ecology should be introduced for climate change mitigation.

Institutional mechanisms for afforestation and reforestation projects under the clean development mechanism (CDM) and reducing emissions from deforestation and forest degradation (REDD) should be financially incentivized to preserve forests and maintain or increase carbon stocks.

Chavan et al (2020) have estimated and calculated the potential of agroforestry in Rajasthan to reduce global warming and greenhouse gases. In Rajasthan's arid zones, tree-based systems have been an integral part of sustainable livelihoods options and food/nutrition/income security. They can become a key weapon in the fight against climate change by offsetting GHG emission through carbon sequestration, similar to forests. To quantify the offsetting potential of GHG emissions and area occupied by agroforestry, Chavan et al (2020) used dynamic CO2FIX version 3.1 for a 30-year simulation in five districts: Bikaner, Dausa, Jhunjhunu, Pali and Sikar. Given an estimated area under agroforestry of 1.49 million ha, the average estimated carbon sequestration and mitigation potential was 0.26 Mg CO_2 ha−1 year−1 and 0.95 Mg CO_2-eq. ha−1 year−1, respectively. This is to be highly encouraged since it does not involve bringing additional land into afforestation and can be carried out in farmers' fields.

The total potential reduction in GHG emissions as a result of agroforestry is estimated at 1.42 million tonnes annually, which would significantly cut the country's carbon footprint and contribute to India's targets as per the Paris Agreement.

7.7. Climate Action Plan for Forest and Biodiversity: Recommendations

1. Enhance the use of agroforestry and traditional tree-based systems for mitigation of heat wave impacts and temperature control in urban and rural areas; enhance the mitigation potential of forests; enhance urban and rural forest-based biodiversity, especially for food, fodder, and medicinal purposes; promote multifunctional agroforestry with a focus on indigenous species. The benefits of agroforestry systems are manifold: (i) biodiversity conservation; (ii) provision of goods and services to society, including ecosystem services; (iii) augmentation of carbon storage in agroecosystems; (iv) fertility enhancement of the soils; and (v) provision of social and economic well-being to people.
2. Implement national REDD+ strategy in Rajasthan as an additional mitigation option through improving green cover and afforestation. Targets for afforestation, agroforestry and green cover may be met by accessing funds under REDD+ and National Mission for a Green India/National Afforestation Programme. To address the Cancun safeguards for REDD+, state forest rules should align with local district (panchayat) and village rules for regulating land use and respect customary forest governance.
3. Promote afforestation/ reforestation for adaptation and carbon sequestration.
   - (i) Survey, demarcate and notify forest areas to assess potential for carbon sequestration and assess/estimate adaptation benefits for pastoralists, forest dependent communities, farmers and foragers.
   - (ii) Prepare a detailed land-use map of forested and non-forested areas of the state and impose a district wise-moratorium on deforestation.
   - (iii) Promote dry land agro/farm forestry, via economic incentives, on private and common lands through extension, distribution of improved seedlings, subsidies, market linkages and capacity building.
   - (iv) Integrate MGNREGA with afforestation and agroforestry projects.
4. Use agroforestry as a means for sequential restoration of sand dunes by increasing green cover. Reactivated dunes can improve soil properties and moisture regimes. This will subsequently improve forest biodiversity in the areas where reactivation has taken place. By linking afforestation and agroforestry to sand dune reactivation, ecosystems services and livelihood-related activities can also be strengthened.

5. Ensure proper implementation of Joint Forest Management (JFM) and rights-based and community-based forest management principles and policies; protect commons by enhancing support for *community-based natural resource management* (CBNRM).
6. Prevent and prohibit habitat fragmentation and patch isolation, which affect species occupancy and mobility. Create intervening corridors, as part of conservation strategies and forest management, for continued species survival and biodiversity restoration.
7. Conserve biodiversity and traditional knowledge:
   - (i) Introduce a satellite-based monitoring process and provide feedback on communication to policy makers for further actions, at all levels from state to village panchayat.
   - (ii) Encourage and support citizen science and community-based knowledge production to map and develop an atlas/database of biodiversity and local knowledge (Pareek & Trivedi, 2011).
8. Identify wind and cyclone damage risk zones across the state and design strategies to use forests as wind breaks through strategic management of species and plantations.
9. Strategize the forest's role in arresting desertification and land degradation especially in the border areas.
10. Integrate traditional knowledge into adaptation strategies.
    - (i) Assess the potential of traditional knowledge for local-level disaster management and decentralized and faster responses; design disaster risk reduction strategies based on co-production of hybrid knowledge.
11. Integrate forest and biodiversity-based livelihoods with climate adaptation and mitigation.
    - (i) Promote dairy, ayurveda/unani/allopathy, meat and poultry, minor forest produce, woodcrafts, ecotourism, especially for the Adivasi population dependent on forests.
12. Reduce morbidities and mortalities during heat waves through tree plantation for shade in heat wave hotspots.
13. Provide control and governance rights over forest commons to communities in order to create social safety nets and sources of food, fuelwood and fodder during droughts.
14. Plan for flood risk mitigation; forests, trees and pasture have the capacity to reduce runoffs during extreme events; implement plantations in flood-prone areas.
15. "Drought-proof" at-risk regions, sectors and populations. This can be facilitated by increasing vegetation cover to buffer the impacts of warming trends and increased

rainfall variability; this will also support soil moisture retention, recharge groundwater and aquifers, restrict soil erosion and increase overall productivity. If these are done in a participative manner using native species of value to local communities, the strategy can yield supplementary benefits for fodder, non-timber forest produce, and ecosystem resilience.

16. Specifically address the gendered nature of vulnerabilities of women, especially Adivasi women who are at risk due to loss of access to commons and forests and whose livelihoods, food and nutritional security, income and access to fodder and fuelwood are likely to be more affected by water scarcity, droughts, forest degradation and social inequalities.
17. Support and enhance ongoing policies, schemes and programmes for adaptation and mitigation.
    - (i) Drought-prone areas programme
    - (ii) Desert development programme
    - (iii) State Forest Policy – Conservation, protection, afforestation, plantations for forest produce, watersheds, land degradation, desertification, wildlife conservation, biodiversity
    - (iv) Protection and Conservation of *Orans* / *Dev van* (Sacred groves)
    - (v) Enforce Forest Rights Act in full and substantially
    - (vi) Implement Biodiversity Act based on fresh assessments and using evidence-based approaches by involving local communities.
    - (vii) Since deforestation has the potential to release new viruses, conduct economic assessments of potential health gains and losses due to pandemics; use the evidence for greater support of afforestation and conservation.
    - (viii) Ensure strict implementation of Panchayat Extension to Scheduled Areas (PESA) Act for forest governance in notified districts
    - (ix) Use modern scientific principles and inclusive approaches for protected area management
    - (x) Assign clear responsibilities and targets for implementation of State Biodiversity Strategy and Action Plan
    - (xi) Provide financial and administrative support and give teeth to the Eco Task Force.
    - (xii) Implement the plans for mega shelterbelts and intensive green belts along roads and canals (a) as a strategy for disaster risk reduction from cyclones and winds, (b) to prevent land degradation and desertification, (c) to improve climatic conditions by

enhancing ecosystem stability and increasing productivity, and (d) to increase carbon stock and livelihoods of the desert and arid region populations; (d) to reduce costs of road maintenance due to reduced extremes of alternate heating and cooling of the road surface; (e) to actively remove pollutants; (f) to intercept particulate matter and dust-storms; (g) to arrest long-distance windblown sand; (h) to moderate local micro-climate.

(xiii) Mapping plant, animal and insect genetic resources to better evaluate and assess the economic, food, fodder, and medicinal benefits of biodiversity protection.

(xiv) Use national programmes – MoEFCC, MoA, external projects, welfare and poverty alleviation programmes and schemes, tribal sub-plans, employment schemes (MGNREGA) – for adaptation strategies.

(xv) Prepare decentralized, block and panchayat-level action plans for forestry and biodiversity and link to SDG goals.

The new Draft Forest Policy for Rajasthan has been released and comments from diverse stakeholders were sought between Dec 2021 and Jan 2022. This policy needs to be urgently finalized and converted into an action strategy. The policy explicitly recognizes the forest-climate linkage by stating that forests play a significant role "in modulating climate, groundwater recharge and sequestering carbon thereby acting as a buffer between human vulnerability and climate distortion". The following points from the draft policy are especially of relevance to the Climate Action Plan for Rajasthan:

- Integration of climate change adaptation and mitigation measures through the forestry and biodiversity sectors
- Plantation of indigenous species and quality afforestation
- Reforestation of all the mined area
- Usage of desert grassland and its unique biodiversity for climate stabilization and carbon sequestration
- Management of grasslands and creation of new grasslands as drought-proofing strategies for agriculture and livestock
- Compensatory afforestation in lieu of land use for non-forestry purposes
- Integration of climate change with forest protection
- Increase of green space in urban areas

Chapter 8

Emission Profile and Mitigation Opportunities

8.1. Introduction

India's net greenhouse gas (GHG) emissions in 2007 were 1727.71 million tons of CO_2 equivalent (CO_2-eq), with emissions from the energy, industry, agriculture and waste sectors accounting for 58%, 22%, 17%, and 3%, respectively (INCCA Report, 2010). India's per capita CO_2-eq emissions were 1.5 tons per capita in 2007. Given the low per capita emissions, development pathways for any state should identify economic growth opportunities wherein mitigation is a significant co-benefit.

Being the largest Indian state, Rajasthan ranked 10th and 9th in 1990 and 1995 respectively for the aggregate GHG emissions from anthropogenic activities. The state accounted for 3.7% of Indian's CO_2-eq. emissions (38 million tons) in 1990 and in 1995, accounting for 4.2% (52.2 million tons) of India's emissions in that year.

This chapter introduces eight key sectors in terms of emissions in the state of Rajasthan. Historical emission trends are explored with 2018-19 serving as the base year, and the available information is used to develop an emission profile, which is presented in the second section of the chapter. Existing mitigation measures have been identified under the section titled *Mitigation Option*, and various policies are proposed for each sector. Lastly, future projections are up to 2030 considering three scenarios, which consist of one business as usual (BAU) scenario and two intervention-based scenarios. The emission profiles and mitigation scenarios, consider three pollutants: CO_2, CH_4 and N_2O.

8.1.1. Thermal Power Plants

Over the past decade, the gross state domestic product of Rajasthan has increased from 434837 crores INR in 2011-12 to 929124 crores INR (2019 prices). Further, the electricity demand of Rajasthan grew from 44109 MU in 2009-10 to 79815 MU in 2018-19 at a compound annual growth rate (CAGR) of 6.81% (MOP, 2021). In the same period, the electricity peak demand increased from 6859 MW in 2009-10 to 13276 MW in 2018-19 (MOP, 2021). Rajasthan accounted for 5.7% of India's total electricity demand as of 2018-19 (CEA, 2021). However, the electricity intensity of the GDP of Rajasthan was 0.0365 MJ/Rs. in 2019-20, which is higher than India's average electricity intensity at 0.0308 MJ/Rs. (CEA, 2021).

Electricity consumption in FY 2019-20 mainly stemmed from the agricultural sector, which accounted for 36% of total electricity, followed by industrial (34%) (comprising 30% industrial high tension and 4% industrial low tension), domestic (17%) commercial (7%) and others 6% (including traction, public lighting, public waterworks, sewage pumping, etc.) (CEA, 2021).

Rajasthan has a coal-dominated electricity mix: 56.5% of electricity is obtained from coal power plants, 1.3% from gas, 0.7% from hydro, and 17.6% from renewables (IEEFA, 2020). As of 2021, the allocated capacity of thermal plants in Rajasthan is 9.3 GW (coal and gas) (Merit, 2021), with emission factors ranging from 0.44 t CO_2/MWh (Dadri Gas) to 1.06 t CO_2/MWh (Kota thermal power plant). Currently, coal plants in the state yield 9.513 GW (CEA, 2020) of electricity, solar-based sources produce 4.997 GW (RRECL, 2020) and wind energy-based power plants generate 4.338 GW (RRECL, 2020).

Significant measures have been taken in the past to integrate renewables. However, rising electricity demands in the coming decades highlight the need to implement a state-level power supply strategy in line with India's climate change mitigation objectives. Hence, emission mitigation from electricity generation is vital to Rajasthan's climate action strategy.

8.1.1.1. The existing power supply situation

The per capita power consumption of Rajasthan in the year 2019-20 was 1317 kWh per capita, which was higher than the national average of 1181 kWh/capita (CEA, 2021). The state depends on power supply from allocated central generating stations to meet its demands. Rajasthan's total electricity demand in 2019 was 67805.34 GWh, with peak demand reaching 13.276 GW.

Earlier, the Rajasthan State Electricity Board (RSEB) was the main agency for the generation, transmission, and distribution of electricity in the state. But after 19 July 2000, RSEB was restructured into five different companies to strengthen infrastructure and separate the generation, transmission and distribution functions.

- **Generation company:** Rajasthan Rajya Vidyut Utpadan Nigam Ltd. (RVUNL)
- **Transmission company:** Rajasthan Rajya Vidyut Prasaran Nigam Ltd. (RVPN)
- **Distribution companies:** (a) Jaipur Vidyut Vitran Nigam Ltd. (JVVNL), (b) Ajmer Vidyut Vitran Nigam Ltd. (AVVNL), (c) Jodhpur Vidyut Vitran Nigam Ltd. (JdVVNL)

The power consumption status of various sectors is given in Table 8.1. The domestic, industrial and agriculture sectors consume 87% of the total power supplied.

Table 8.1. Power consumption by various sectors in Rajasthan

Sr. No.	Sectors	Consumption of electricity (MU)						
		2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
1	Domestic	9446	9786	10568	11497	11998	12506	12661
2	Commercial	3352	3610	4064	4273	4577	4863	4813
3	Industrial (LT + HT)	9981	14609	12864	11014	10901	23730	24490
4	Agriculture	17263	19089	19968	21361	22833	23300	25665
5	Others	3109	2868	2894	2882	3308	3406	4494
6	Total	43151	49920	50359	51027	53618	67805	72123

(Source: CEA, 2021)

About 34% of electricity consumption is by the industrial sector, 36% by agriculture, 17% by domestic, 7% by commercial and 6% by others. Table 8.1 depicts the pattern of electricity consumption in Rajasthan from 2013-14 to 2019-20. There are losses associated with the transmission and distribution electricity, these losses bifurcated based on the companies in Rajasthan are given in Table 8.2.

Table 8.2. Loss of electricity incurred by distribution companies

Year	JVVNL	AVVNL	JdVVNL	AT&C losses in (%) average
2014-15	30.46	26.08	24.29	26.94
2015-16	31.90	26.75	23.32	27.32

2016-17	25.48	22.10	21.69	23.09
2017-18	21.06	20.15	19.33	20.18
2018-19	20.54	18.03	23.12	20.56
2019-20	17.21	14.48	19.38	17.02
2020-21	19.44	15.15	22.46	19.02

(Source: ARR & Tariff Order- RERC, 2021)

8.1.1.2. Rajasthan power transmission system

Rajasthan Rajya Vidyut Prasaran Nigam Ltd., (RVPN) is engaged in transmitting bulk power from generating stations to inter-phase points of distribution company (Discoms). RVPN has decided to implement the smart transmission network and asset management system (STNAMS). The system is intended to achieve wide-area monitoring and control of the transmission grid in Rajasthan along with implementation of smart-grid initiatives for reactive power management and predictive assessment of grid stability/security and asset management. The total extra high voltage (EHV) transmission network of the state in 2012 was 28363.29 Ckt. Km (circuit km) (Table 8.3), which has increased to 41708.77 Ckt. km in 2020 (ARR & Tariff Order- RERC, 2020).

Further, the Green Energy Corridor project sanctioned in 2015-16 by the central government was aimed at strengthening interstate transmission capacity between renewable surplus states to renewable deficit states. The aim of the project was to build 9400 Ckt. km worth of transmission lines and sub stations with a capacity of 19000 MVA in seven renewable rich states (Rajasthan, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh, Madhya Pradesh) by March 2020. In addition, a new intrastate green energy corridor is currently being developed in Rajasthan to integrate 6311 MW of green energy infrastructure. This will involve connecting large renewable rich areas of Barmer, Jodhpur and Jaisalmer with load centres and the national transmission network.

Table 8.3. Transmission network in the state (in Ckt. km)

Year/ Voltage	765 kV	400 kV	220 kV	132 kV	Total
2011-12	0	2904.79	11143.09	14315.41	28363.29
2012-13	0	3019.00	11805.46	14781.00	29605.46
2013-14	425.50	3533.50	12315.83	15154.24	31429.07
2014-15	425.50	3633.50	13291.50	15599.17	32949.67
2015-16	425.50	3983.70	13804.23	16181.09	34394.52
2016-17	425.50	4292.30	14590.10	16771.10	36079.00
2017-18	425.50	5640.73	15130.05	17189.29	38385.57
2018-19	425.50	7317.00	15350.00	18012.00	41104.50
2019-20	425.50	7604.44	15442.93	18235.90	41708.77

(Source: ARR & Tariff Order- RERC, 2020)

8.1.2. Industry

The state of Rajasthan is home to several industries, and the major ones are cement, mineral-based industries, steel rerolling, textile dyeing and printing, brick and lime kilns, chemical(s), ceramics and marble and agro-based products (TERI and Govt. of Rajasthan, 2014; IBEF, 2021a; RSPCB and CII, 2021). Rajasthan also has a large number of micro, small and medium enterprises (MSMEs), which contribute a significant share to the state's industrial growth and economy.

Rajasthan is the largest cement producing state in the country. It was the leading producer of cement-grade limestone in India for the year 2019-20 (IBEF, 2021a), the second highest producer of minerals in India, accounting for 17% of the total production for the year 2019-20 (IBEF, 2021c), and the third largest producer of sodium chloride in the same year (RSPCB and CII, 2021). The state of Rajasthan presently houses three major automobile clusters of the country (RSPCB and CII, 2021). Overall, the industrial sector accounted for 21.2% of the state's GSDP in the year 2019-20 at current prices (IBEF, 2021b).

In the year 2013, Rajasthan was one of the top ten states (8th) in terms of emissions from the manufacturing sector; it accounted for the highest emissions from the mineral sector (mainly cement) among all the states (Gupta V. et al, 2017). The Bureau of Energy Efficiency (BEE) has identified four energy-intensive clusters in energy savings assessment, and these include rolling mills, bearing clusters, marble clusters and textile clusters (TERI and Govt. of Rajasthan, 2014).

The industrial energy use and related GHG emissions database offers energy consumption and CO_2 emissions data (with fuel-wise contribution) and gross value added (GVA) data for different industries across all states of India for the years 2005-06 to 2015-16 (Gupta V. et al, 2019). We used this database to estimate the energy consumption (in Petajoule (PJ)) and emissions (in MT CO_2 eq.) for different industries in Rajasthan and their fuel-wise distribution. We also estimated the GVA (in crores of INR) of various industries in Rajasthan. However, it is to be noted that complete data (energy consumption and/or CO_2 eq. emissions) are not available for many industries (especially MSMEs) and across many years for all the states, including Rajasthan.

The Annual Survey of Industries (ASI) datasets, obtained from the Ministry of Statistics and Programme Implementation (MOSPI), were the primary source of information for the GHG estimations. The GHG emissions have been estimated as per the IPCC classification for manufacturing industries. The greenhouse gasses covered are CO_2, CH_4, and N_2O.

8.1.2.1 Gross value added of various industries

Fig. 8.1 shows the GVA (in constant 2016 INR) for various industries in Rajasthan from the year 2005-06 to 2015-16. The top 4 four industries for the period 2005-06 to 2015-16 are non-metallic minerals (which include cement and other non-metallic minerals), others, textile and leather, and machinery. The year 2015-16 saw the highest overall GVA (Rs. 40937 crore). Overall, GVA has shown an increasing trend over the years. This could be due to increase in production and the associated increase in revenue generation from the different industries in Rajasthan.

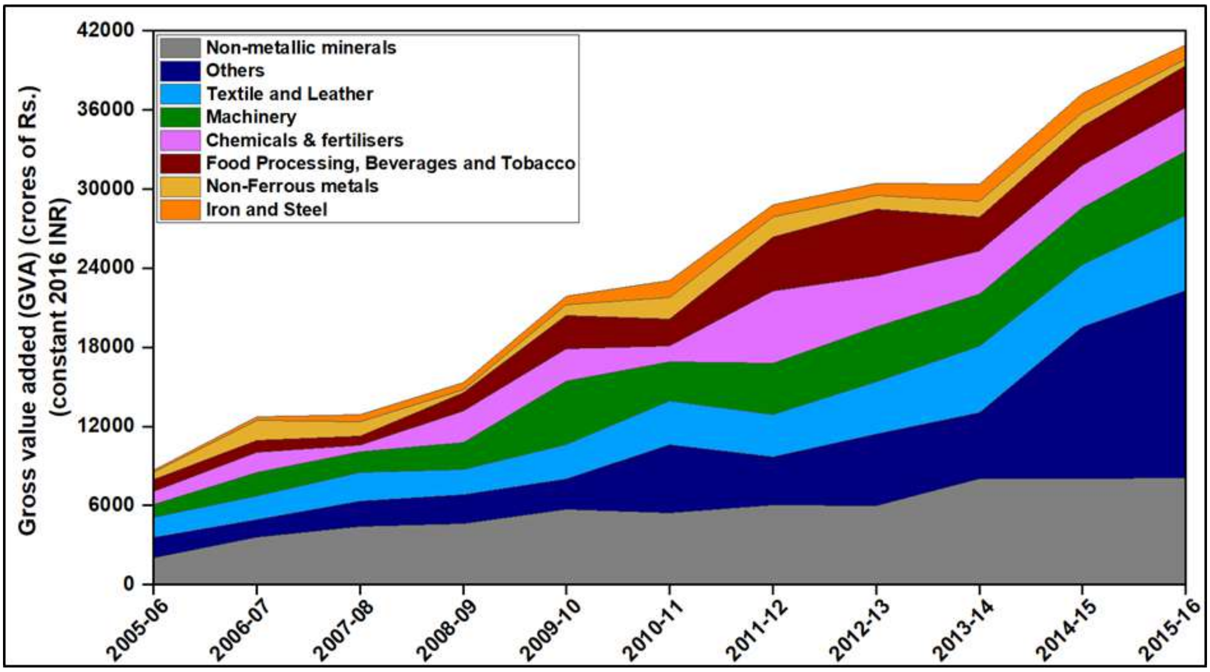

Figure 8.1. Gross value added (GVA) for various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.2 shows the GVA for different industries for the years 2005-06, 2011-12 and 2015-16. All the industries reported an increase in GVA in 2015-16 compared to the earlier years, except the non-ferrous metals, food processing, beverages and tobacco, and chemicals and fertilizers. These four industries reported a decrease in GVA in 2015-16 compared to 2011-12. For the year 2015-16, the top 4 industries with the highest GVA were others, non-metallic minerals, textile and leather, and machinery. The others accounted for around 35% of the total GVA for the year 2015-16 (this might be due to the increased contribution from the MSMEs) whereas the non-metallic minerals industry accounted for 20% of total GVA.

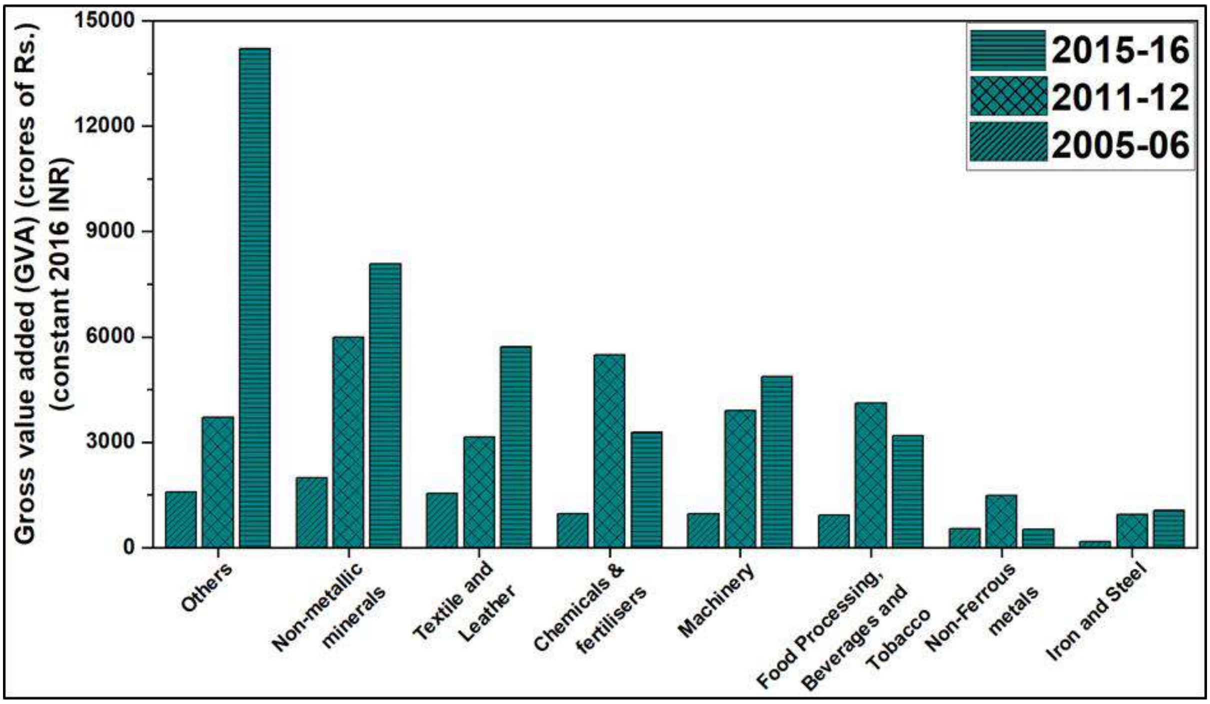

Figure 8.2. Gross value added for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16.

Table 8.4 shows the GVA for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16 and the CAGR of the GVA in the year 2015-16, as compared to the year 2005-06. A comparison of 2005-06 with 2015-16 showed that all the industries, except non-ferrous metals, reported a positive CAGR (increase in GVA). The overall GVA in the year 2015-16 was 42% more than that in 2011-12 and about 371% more than that in 2005-06.

Table 8.4. Gross value added and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	**Gross value added (crores of Rs) (2016 constant INR)**			**CAGR (%)**
	2005-06	**2011-12**	**2015-16**	**2015-16**[1]
Others[2]	1576.1	3721.8	14206.1	24.6
Non-metallic minerals[3]	1987.8	5999.1	8085.8	15.1
Textile and leather	1543.6	3141.3	5718.9	14.0
Chemicals & fertilizers	969.5	5498.2	3279.4	13.0
Machinery	968.7	3912.9	4873.2	17.5
Food processing, beverages and tobacco	924.7	4121.8	3193.9	13.2
Non-ferrous metals	545.6	1480.6	521.5	-0.5
Iron and steel	172.9	954.4	1058.1	19.9
Total	8688.9	28830.2	40936.8	16.8

[1]Base year for CAGR calculation is 2005-06.

[2]"Others" include construction, manufacture of solid fuels, mining and quarrying, pulp, paper and print, transport equipment, wood and wood products and some non-specified industries (which may include various MSMEs).

[3]Non-metallic minerals include cement and other non-metallic minerals.

8.1.2.2 Energy consumption of various industries

Fig 8.3 shows the energy consumption of various industries in the state of Rajasthan from the year 2005-06 to 2015-16. The top 3 industries with highest cumulative energy consumption from 2005-06 to 2015-16 are cement, chemicals and fertilizers, and textile and leather. The year 2014-15 saw the highest overall energy consumption (272.9 PJ) mainly due to increase in energy consumption in the following industries: food processing, beverages and tobacco; cement; and other non-metallic minerals. Overall, energy consumption by industries has shown an increasing trend over the years. This could be due to the increase in production rates across different industries in Rajasthan.

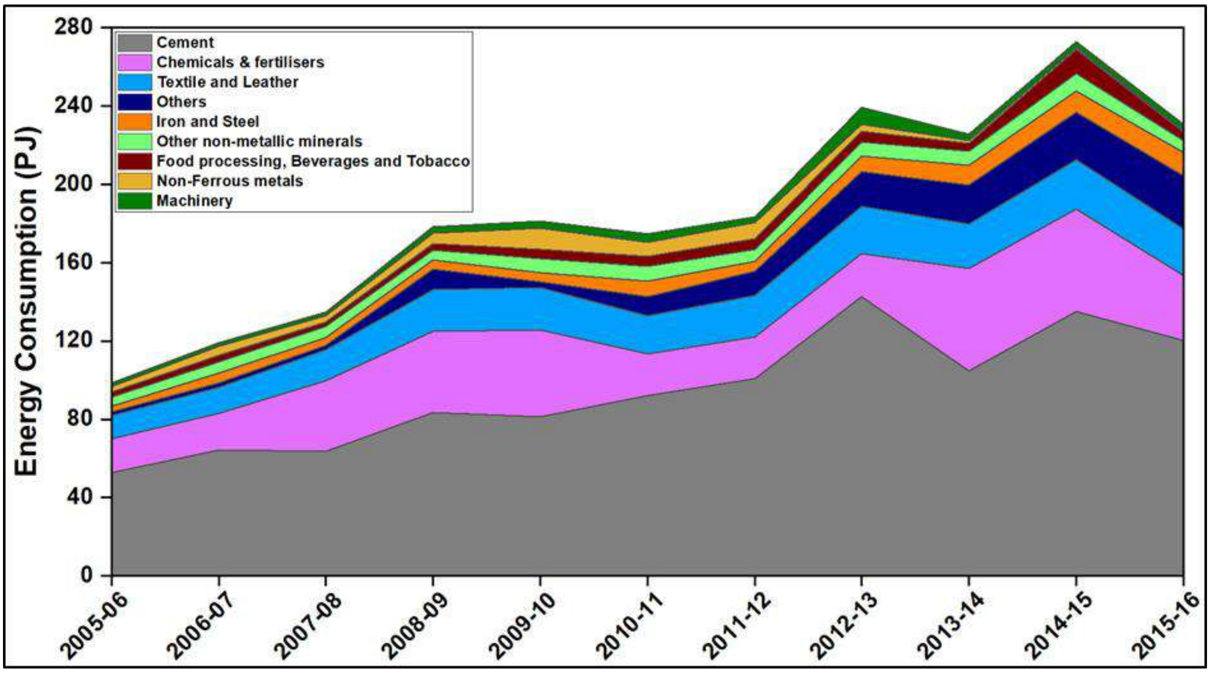

Figure 8.3. Energy consumption across various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.4 shows the energy consumption and the fuel-wise distribution across different industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16 respectively. It can be clearly seen coal and lignite are the dominant fuel/energy source across different industries. The use of natural gas and its derivatives increased in some industries in the year 2015-16 compared to the years 2005-06 and 2011-12. Compared to the years 2005-06 and 2011-12, all the industries reported an increase in energy consumption in the year 2015-16, except non-ferrous metals and food processing, beverages and tobacco, both of which reported a decrease in energy consumption in 2015-16 compared to 2011-12.

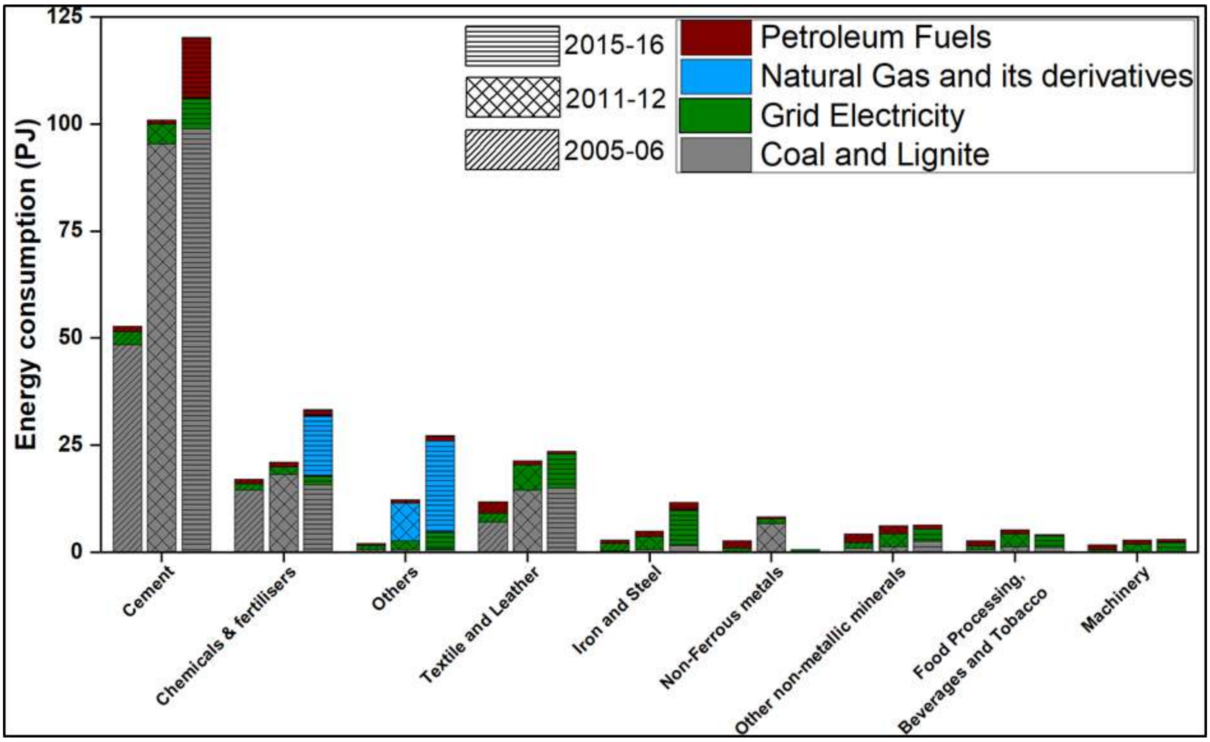

Figure 8.4. Energy consumption and fuel-wise distribution of various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16.

Table 8.5 shows the energy consumption of various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16 as well as the CAGR of the energy consumption between the year 2015-16 and the year 2005-06. All the industries, except non-ferrous metals, reported a positive CAGR (increase in energy consumption) in 2015-16 compared to 2005-06. The overall energy consumption in the year 2015-16 increased by about 26% compared to the year 2011-12 and by about 134% compared to the year 2005-06.

Table 8.5. Energy consumption and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	**Total energy consumption (PJ)**			**CAGR (%)**
	2005-06	**2011-12**	**2015-16**	**2015-16**[1]
Cement	52.9	100.9	120.2	8.6
Chemicals & fertilizers	17.1	21.1	33.3	6.9
Others	2.1	12.3	27.3	29.3
Textile and leather	11.9	21.4	23.7	7.1
Iron and steel	2.8	4.9	11.7	15.2
Non-ferrous metals	2.8	8.4	0.7	-12.7
Other non-metallic minerals	4.4	6.3	6.5	3.9
Food processing, beverages and tobacco	2.7	5.2	4.2	4.4
Machinery	1.8	2.9	3.1	5.6
Total energy consumption (PJ)	98.5	183.4	230.6	8.9

[1]Base year for CAGR calculation is 2005-06.

Fig. 8.5 shows the industry-wise distribution of energy consumption in Rajasthan for the year 2015-16. The top 4 industries with the highest energy consumption in the year 2015-16 were cement (52%), followed by chemicals and fertilizers (14%), others (12%), and textile and leather (10%).

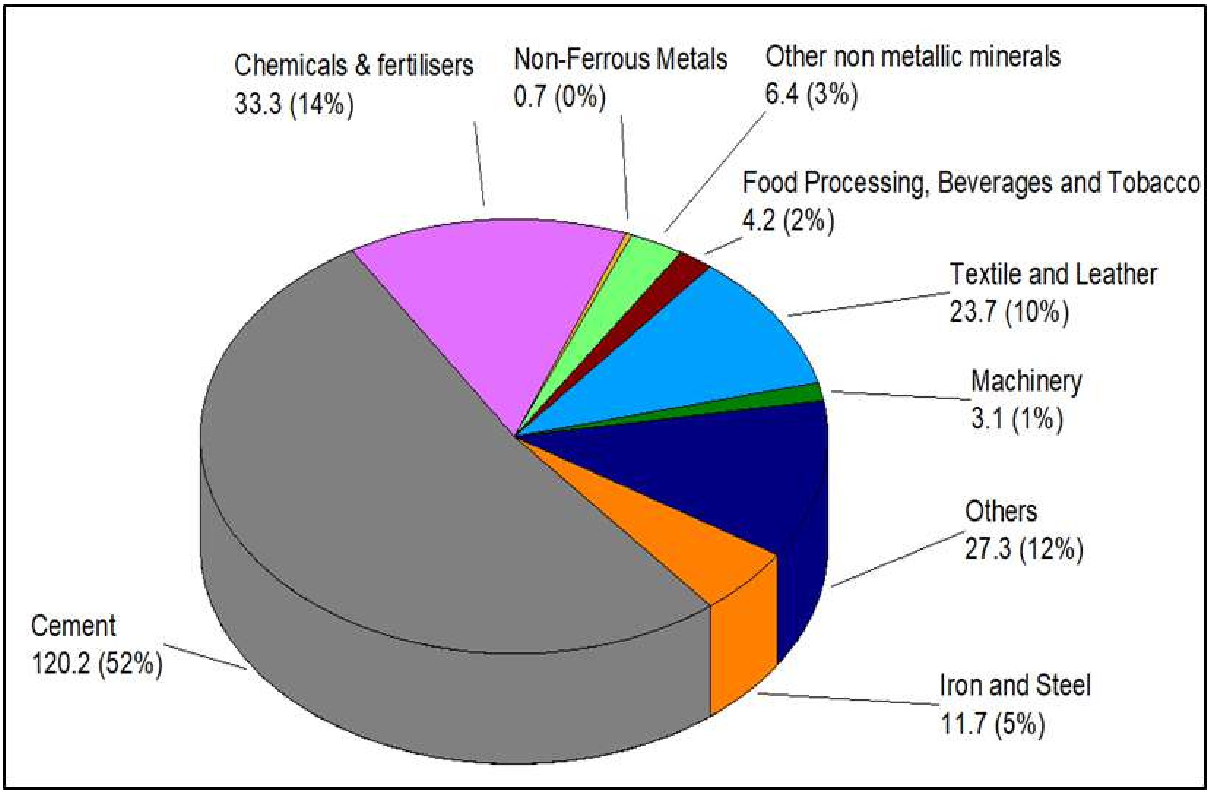

Figure 8.5. Industry-wise distribution of energy consumption (PJ) in Rajasthan for the year 2015-16.

Fig. 8.6 shows the fuel-wise distribution of energy consumption in Rajasthan for the year 2015-16. Coal and lignite (59%) constituted the most used fuel/energy source in various industries for the year 2015-16, followed by grid electricity (16%), natural gas and its derivatives (15%) and petroleum fuels (9%).

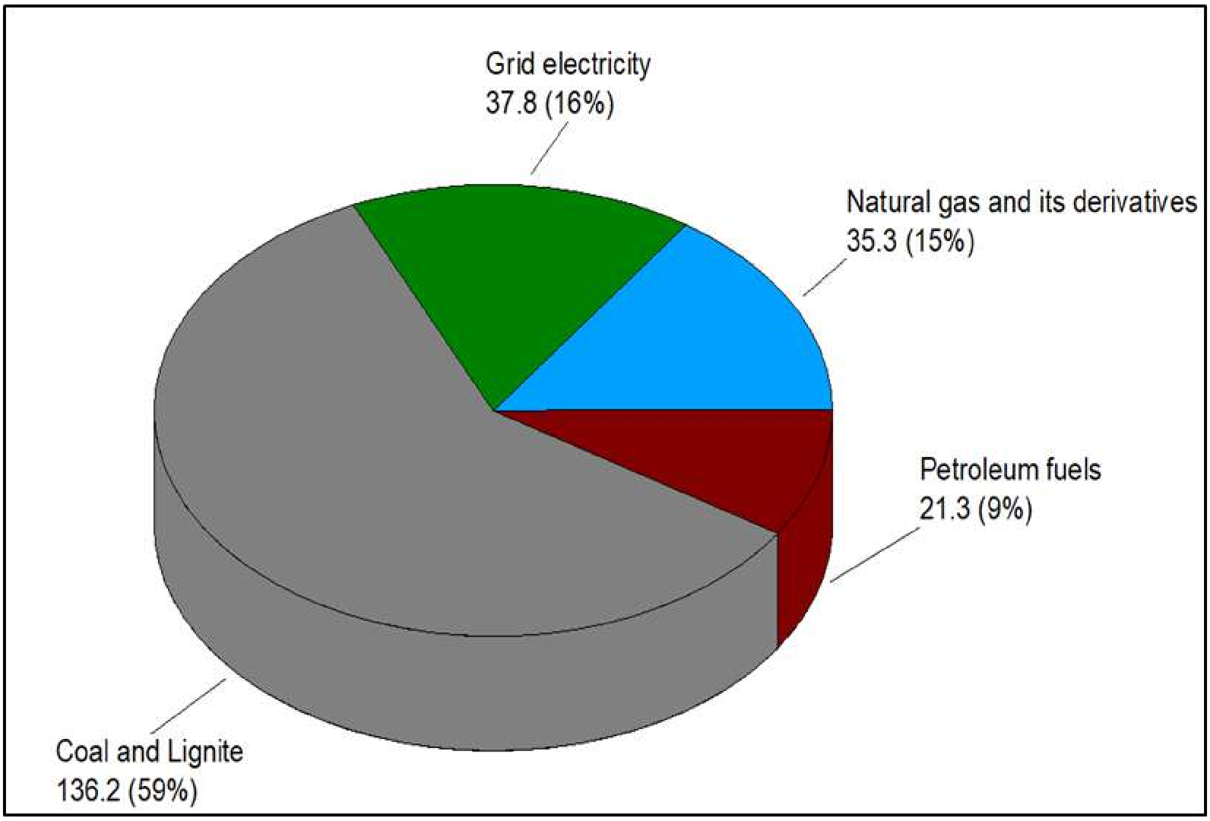

Figure 8.6. Fuel-wise distribution of energy consumption (PJ) in Rajasthan for the year 2015-16.

8.1.3. Brick Production

India is the second largest producer of bricks globally with an annual production of approximately 290 billion bricks in 2019. Among the different types of walling materials used for construction, fired-clay bricks are the most dominant (Maithel et al., 2017). These are manufactured by baking moulded clay under high temperatures, which makes it an energy-intensive sector. While the energy demand is primarily met through coal, other fuels such as fuelwood, saw dust, crop residue, oil and rubber tyres are also used (Maithel et al., 2012). Such heavy consumption of coal makes this sector an important contributor to GHGs. Moreover, the industry is still reliant on traditional and inefficient technologies, which emit particulate matter along with CO and SO_2 and thereby degrade the air quality around major urban centres of India (Guttikunda & Calori, 2013; Kumbhar et al., 2014). Brick production in India largely employs four major technologies: clamps, fixed chimney Bull's trench kilns (FCBTKs), zigzag-fired kilns and vertical shaft brick kilns (VSBKs).

According to the 2011 census, Rajasthan had nearly 5 million houses made up of burnt-clay bricks, accounting for nearly 3% of the total houses in the country. Compared to 1991, the number of such houses is increasing at a CAGR of 5%. At this rate, Rajasthan potentially accounts for nearly 5% of the country's current annual brick demand. With government policies such as PM Gramin Awas Yojana gaining importance, this demand is only likely to accelerate. Given that a majority of the kilns are yet to shift to cleaner manufacturing practices, the emission mitigation potential of the brick industry is significant.

8.1.4. Transportation

The demand for transportation services has increased in Rajasthan due to the state's economic growth, rise in tourism and infrastructure development (RAPCC, 2014). Private vehicles have seen a rapid growth. The increase in vehicle numbers is around 125% within a period of 10 years (from 2010 to 2020), with two-wheelers accounting for 75.86% of the total vehicles registered in Rajasthan. The share of four-wheelers (cars, jeeps and taxis) is around 10.9%, buses is 0.61%, and goods vehicles is 3.68%. The percentages of buses and goods vehicles have decreased in the past 10 years (Rajasthan Transport department statistical report 2020-21). Emission analysis in the transport sector considers freight vehicles – heavy diesel vehicles (HDV) and light diesel vehicles (LDV) – that mainly consist of trucks and other goods vehicles. Buses, taxis and passenger three-wheelers constitute public and intermediate transport systems, and motorized two-wheelers and cars are private vehicles as per GHG emission estimations from the road transport sector in Rajasthan.

Road transport vehicles majorly run on petrol and diesel. Over 10 years (2010-11 to 2019-20), alternative fuel vehicles consisting of CNG, LPG and battery-operated electric vehicles have increased with a CAGR of 1.3% in Rajasthan. Petrol and diesel vehicles contribute significantly to air pollution (CO, PM, and NOx) and GHGs (CO_2, N_2O, and CH_4). Significant transport policies have been implemented in Indian states to control vehicle emissions. These policies target air pollution mainly; however, as a co-benefit, they also impact GHG emissions from the vehicles. The growing private vehicles, increase in freight transport and lack of good public transport have rescinded the effect of emission control policies. Therefore, suitable mitigation measures are required in future to control vehicle emissions.

8.1.5. Residential

The residential sector consists of energy-intensive activities such as cooking, lighting, water heating and space heating. Access to clean energy or electricity in India remains a challenge with a large population still dependent on traditional cooking devices that use fuelwood, crop residue, cow-dung, charcoal and coal (Census of India, 2011). Clean energy sources include electricity, natural gas, biogas, solar power and liquified petroleum gas (LPG). Rajasthan's daily energy demand is approximately 16 MJ per household for cooking and water heating, which is ~5% more than the national average (Pandey et al., 2014). With nearly 75% of the population residing in rural areas, the majority still uses biomass fuel for cooking. Such traditional cooking practices are a major source of indoor air pollution in rural areas and pose a significant threat to human health. Besides cooking, use of kerosene lamps for lighting, due to unavailability of reliable power supply, and wood burning for space heating also contribute to air pollution. Globally, air pollution is ranked as the third highest contributor to premature mortality, and it accounts for nearly 1 million deaths in India (GBD MAPS Working Group, 2018). The residential sector with its current technology mix is the largest contributor to premature mortality (~25%). With the population of Rajasthan expected to increase by 30% by 2030 with only a marginal shift towards urbanisation, ensuring access to clean energy in the rural areas is a serious concern.

8.1.6. Agricultural

Agriculture is the mainstay of the Rajasthan economy, accounting for ~25% of the state's GDP. The largest state in the country in terms of area – of which 61% is arid – has four agro-climatic zones. About half the land in the state is used for cultivation, of which 75% is rain-fed. The state receives most of its rainfall during the summer monsoon, kharif-growing season (JJAS months). Wheat (rabi) is the most produced crop in the state, followed by oilseeds (kharif and rabi) and millets (kharif). The crop productivity in the state is low because of factors such as poor soil quality and low water availability. Emissions from this sector can be attributed to the following sub-sectors: residue burning, tractor use on fields, diesel irrigation pumps, cattle, and soils (fertilizers). Globally, the agricultural sector contributes ~10% to total GHG emissions as per IPCC AR5 estimates (Smith et al. 2014).

Burning of agricultural residue is CO_2 neutral, as all the emitted carbon is considered to be sequestered by the plants in the first place. Nevertheless, it accounts for about 7% of total N_2O, 11% of total CH_4 and 17% of total CO emissions (Pandey et al., 2014; Sadavarte & Venkataraman, 2014) in the country. The emissions from crop stubble have attracted attention in the recent years because large-scale burning of crop residue in the adjoining states of Punjab and Haryana has led to poor air quality in the Indo-Gangetic plains during the winter months. This has been mainly triggered by combine harvesters that leave behind difficult-to-remove stubble on the farmlands, and the farmers find burning them on field as the easiest option.

Rajasthan has the second highest population of livestock after Maharashtra, accounting for ~10% of the total population of the country (DHAD, 2019). Enteric fermentation in the digestive systems of livestock leads to large emissions of CH_4, which amounts to ~37% of the total agricultural sector emissions globally (Tuboello et al. 2013). Other emissions from livestock include N_2O from manure management. N_2O is also emitted from agricultural soils, because of the application of fertilizers and animal manure, which increase the nitrogen content. Standing water in agricultural fields for rice cultivation also leads to CH_4 emissions, but since rice production is very low in Rajasthan, this source has not been included in the present report. This source may become important if rice cultivation increases in the future.

8.1.7. Waste Management

With growing urbanization, changing lifestyles and the increasing amount of waste generated, appropriate treatment and disposal has become a challenge for the state of Rajasthan. Sustainable and robust waste management practices are therefore the need of the hour. Management of waste is important because of environmental and health-related concerns as well as for the mitigation of emissions and resource recovery, which have larger implications for climate change.

Of the total emissions from various sectors, the waste sector accounts for 4%. These emissions are local but have global implications. Domestic wastewater is the largest emitter of GHGs in the waste emissions. Projections indicate that the total emissions from waste are expected to grow by 40% by 2040 from the 2015 levels.

Waste management can play a role in climate change mitigation, mainly by emission-reduction interventions such as expanding the current waste treatment facilities and utilizing waste for energy generation. However, it also relevant to climate adaptation and resilience building, which are brought about by activities such as collaboration with stakeholders and building an overall sustainable infrastructure for waste management.

8.1.8. Tourism

Home to both a desert and mountain ranges, the state offers diverse tourism activities (Tourism Department annual report). Tourism destinations include Mount Abu and Udaipur in the mountains, the historical destinations of Chittorgarh and Kumbhalgarh, and the desert in Jaisalmer. In Jaipur (pink city) and Jodhpur (blue city), the outer walls of many houses are painted in the same shade to highlight their belongingness. Rajasthan also has destinations of religious importance, which are of special significance to one and all.

Tourism in India accounted for around 2.8% of the GDP in 2009-10, which increased to 5.2% of the GDP in 2015-16 (Ministry of Tourism, 2009; NCAER, 2016). Employment opportunities generated by the tourism industry increased from 4.6% to 12.4% in the same period. Similarly, Rajasthan has also seen an increase in the footfall of domestic and international tourists (Annual report of Rajasthan Tourism Department, 2018-19; and earlier). Around 430 lakh domestic tourists visited Rajasthan in 2018, which is an increase of 44% from that in 2008 (SAPCC, 2009). The state attracts 16 lakh international tourists, which is nearly 50% of total international tourists arriving in India. Moreover, the growth rates of international and domestic tourism in Rajasthan have been increasing at 3% and 7% per annum, respectively (from 1990 to 2018).

8.2. Emissions Profile

8.2.1. Thermal Power Plants

Within the existing installed capacity, coal-based thermal power plants are the primary source of electricity generation. The total capacity of coal thermal power plants in the state over the years has increased from 2968 MW in 2005-06 to 9400 MW in 2015-16. In the same period, the total emissions have increased from 20.51 MT CO_2 in 2005-06 to 40.22 MT CO_2 in 2015-16. As of December 2020, Rajasthan has 8 coal (9160 MW) and 3 gas thermal power plants (1019.8 MW) (Table 8.7). Further, the emission factor of coal thermal power plants ranges from 0.97 to 1.06 t CO_2/MWh. However, in the recent years, the coal thermal plants have faced price competition from competitive renewable energy sources. The prices achieved through transparent reverse auctions have been in the range of 2.36–2.92 Rs/kWh (IEEFA, 2020).

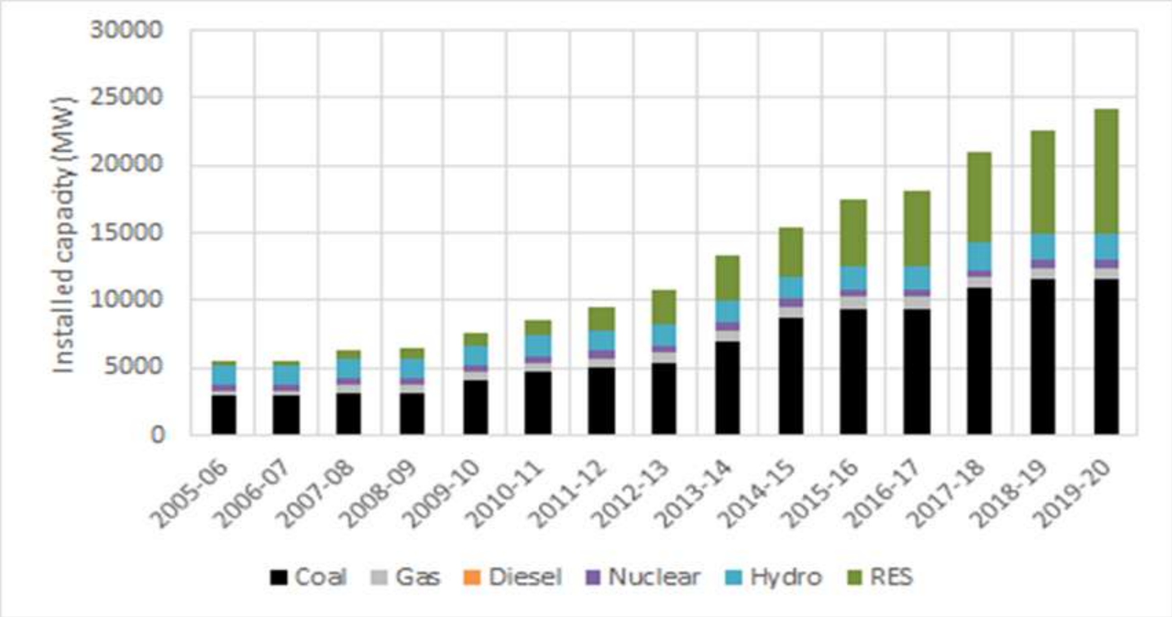

Figure 8.7. Installed power generation capacity of Rajasthan (CEA, 2021).

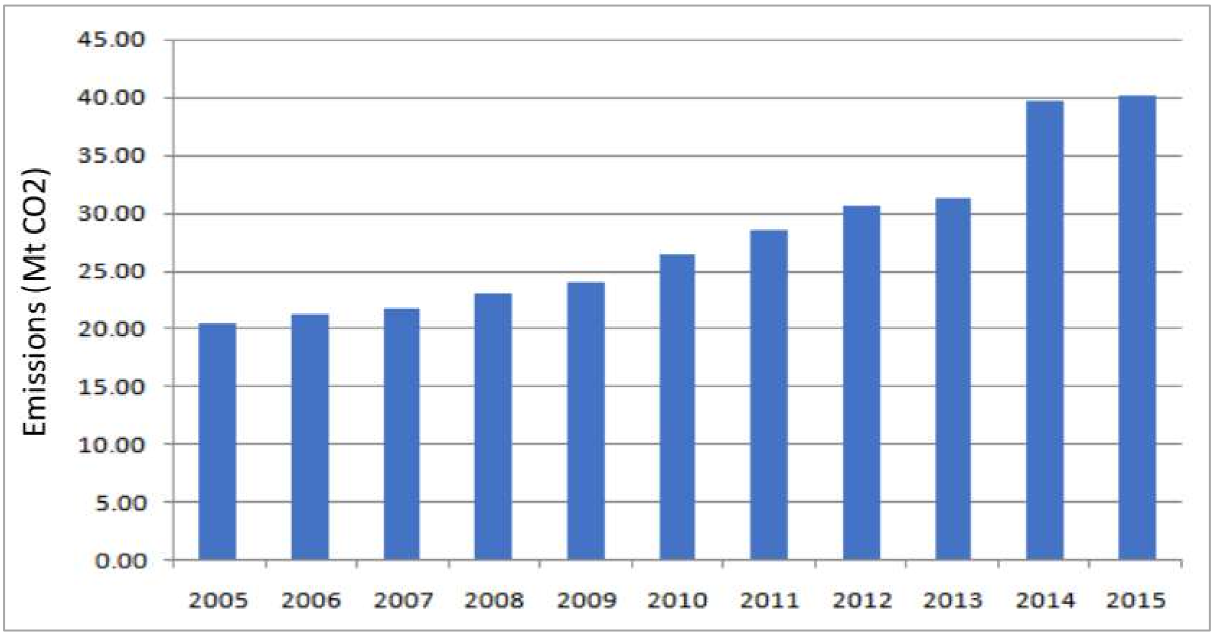

Figure 8.8. Emissions from electricity generation (MT CO_2) (Mohan et al. 2019).

Table 8.6. Thermal power stations and their installed capacities (CEA, 2019; Merit, 2020)

Name of plant	Capacity (MW) as on 31/03/2019	Sector	System	Cost of electricity (Rs/kWh) (Dec 2020)	Year
Anta GT	419.3	Central	NTPC	2.75	1989 (86.7MW X 3), 1990 (153.2MW)
Barsingsar Lignite	250.0	Central	NLC	3.40	2010 (125MW), 2010 (125MW)
Chhabra TPS (Coal)	2,320.0	State	RRVUNL	4.06	2009 (250MW), 2010 (250MW), 2013 (250MW), 2014 (250MW), 2017 (660MW), 2019 (660MW)
Dholpur (Gas)	330.0	State	RRVUNL	7.16	2007
Giral LTPS	250.0	State	RRVUNL	3.20	2007 (125MW), 2008 (125MW)
Jallippa Kapurdi TPP (Lignite)	1,080.0	Private	RAJ WEST POWER LTD (jsw)	-	2009 (135MW), 2010 (135MW), 2011(135MW X 2), 2013 (135MW X 4)
Kalisindh (Coal)	1,200.0	State	RRVUNL	4.65	2014 (600MW), 2015 (600MW)
Kawai TPP (Coal)	1,320.0	Private	ADANI POWER LTD	3.92	2013
Kota (Coal)	1,240.0	State	RRVUNL	3.96	1983 (110MW X 2), 1988 (210MW), 1989 (210MW), 1994 (210MW), 2003 (195MW), 2009 (195MW)

Ramgarh GT	270.5	State	RRVUNL	3.51	1996 (35.5MW), 2002 (37.5MW), 2003 (37.5MW), 2013(110MW), 2014 (50MW)
Suratgarh (Coal)	1,500.0	State	RRVUNL	4.57	1998 (250MW), 2000 (250MW), 2001 (250MW), 2002 (250MW), 2003 (250MW), 2009 (250MW)

8.2.2. Industry

Fig. 8.9 shows the CO_2-eq. emissions (in million tonnes (MT)) for various industries in the state of Rajasthan from 2005-06 to 2015-16. The trend in emissions is similar to that of energy consumption. The top three industries with highest cumulative CO_2-eq. emissions from 2005-06 to 2015-16 are cement, chemicals and fertilizers, and textile and leather. The year 2014-15 saw the highest overall CO_2-eq. emissions (30.1 MT) mainly due to an increase in emissions in the following industries: cement; other non-metallic minerals; food processing, beverages and tobacco; others; and textile and leather. Overall, the CO_2-eq. emissions have shown an increasing trend over the years, proportional to the increase in energy consumption. This could be mainly due to the increase in production rates across different industries in Rajasthan.

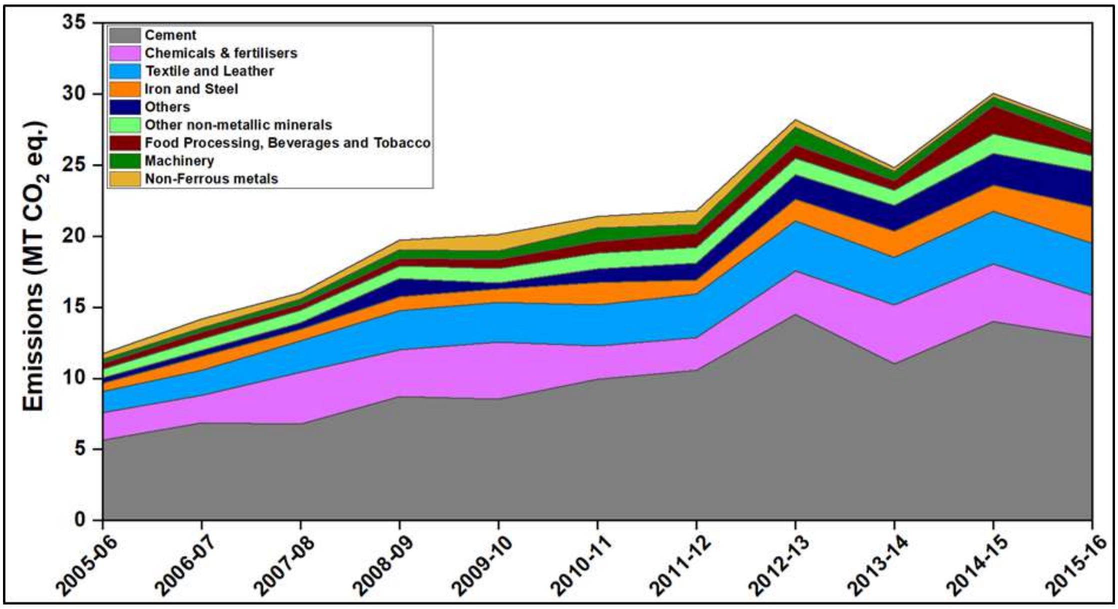

Figure 8.9. CO_2-eq. emissions across various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.10 shows the CO_2-eq emissions and the fuel-wise breakup of different industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16. It can be clearly seen that the use of coal and lignite is responsible for the bulk of CO_2-eq emissions. Further, compared to the years 2005-06 and 2011-12, the contribution of natural gas and its derivatives to CO_2-eq emissions has increased in some industries in 2015-16.

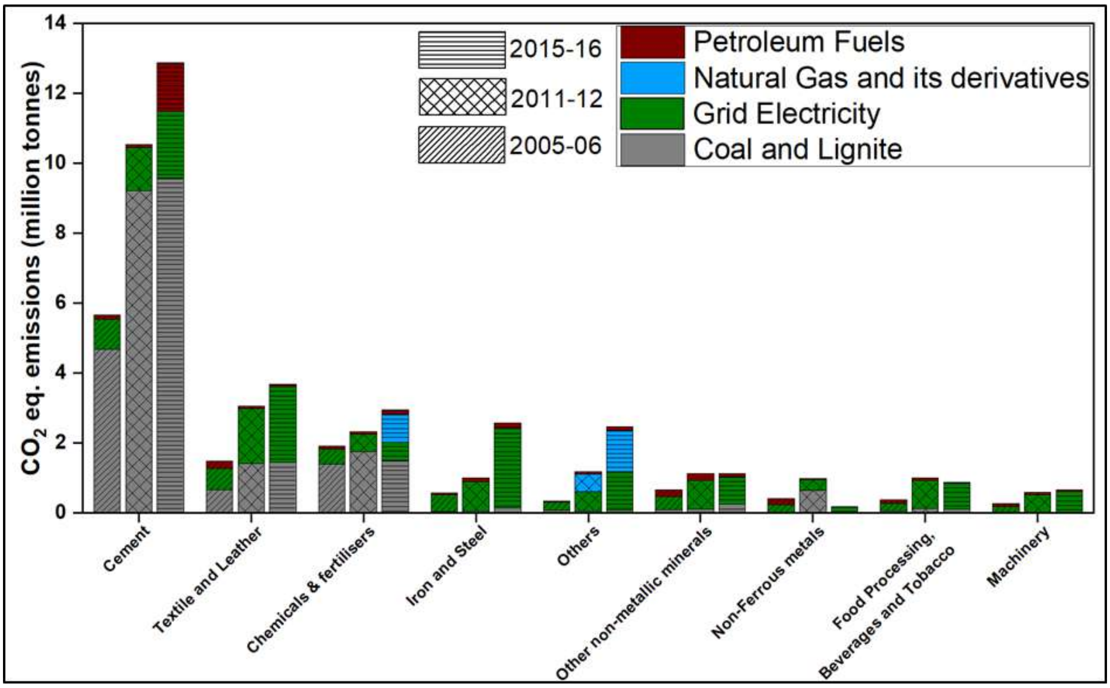

Figure 8.10. CO_2-eq. emissions for various industries in Rajasthan for the years 2005-06, 2011-12, 2015-16.

All the industries reported an increase in CO_2-eq. emissions in the year 2015-16 as against the emissions in 2005-06 and 2011-12, except the non-ferrous metal industry and the food processing, beverages and tobacco industry. These two reported a decrease in CO_2-eq. emissions in 2015-16 compared to 2011-12.

Table 8.7 shows the CO_2-eq. emissions for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16 as well as the CAGR of the CO_2-eq. emissions in the year 2015-16 compared to the year 2005-06. All the industries, except the non-ferrous metals reported a positive CAGR (increase in CO_2-eq. emissions) in 2015-16 compared to 2005-06. The overall CO_2-eq. emissions in 2015-16 were about 26% higher than in 2011-12 and about 133% higher than in 2005-06.

Table 8.7. CO_2-eq. emissions and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	**Total emissions (MT CO_2 eq.)**			**CAGR (%)**
	2005-06	2011-12	2015-16	2015-16[1]
Cement	5.7	10.5	12.9	8.6
Textile and leather	1.5	3.1	3.7	9.5
Chemicals & fertilizers	1.9	2.3	2.9	4.4
Iron and steel	0.6	1.0	2.6	16.1
Others	0.4	1.2	2.5	21.6
Other non-metallic minerals	0.7	1.1	1.1	5.4
Non-ferrous metals	0.4	1.0	0.2	-7.6
Food processing, beverages and tobacco	0.4	1.0	0.9	8.8
Machinery	0.3	0.6	0.7	9.5
Total emissions (MT CO_2 eq.)	11.8	21.8	27.4	8.8

[1]Base year for CAGR calculation is 2005-06

Fig. 8.11 shows the industry-wise contribution to CO_2-eq. emissions in Rajasthan in the year 2015-16. The top 5 industries are cement (47%), followed textile and leather (13%), chemicals and fertilizers (11%), others (9%), and iron and steel (9%).

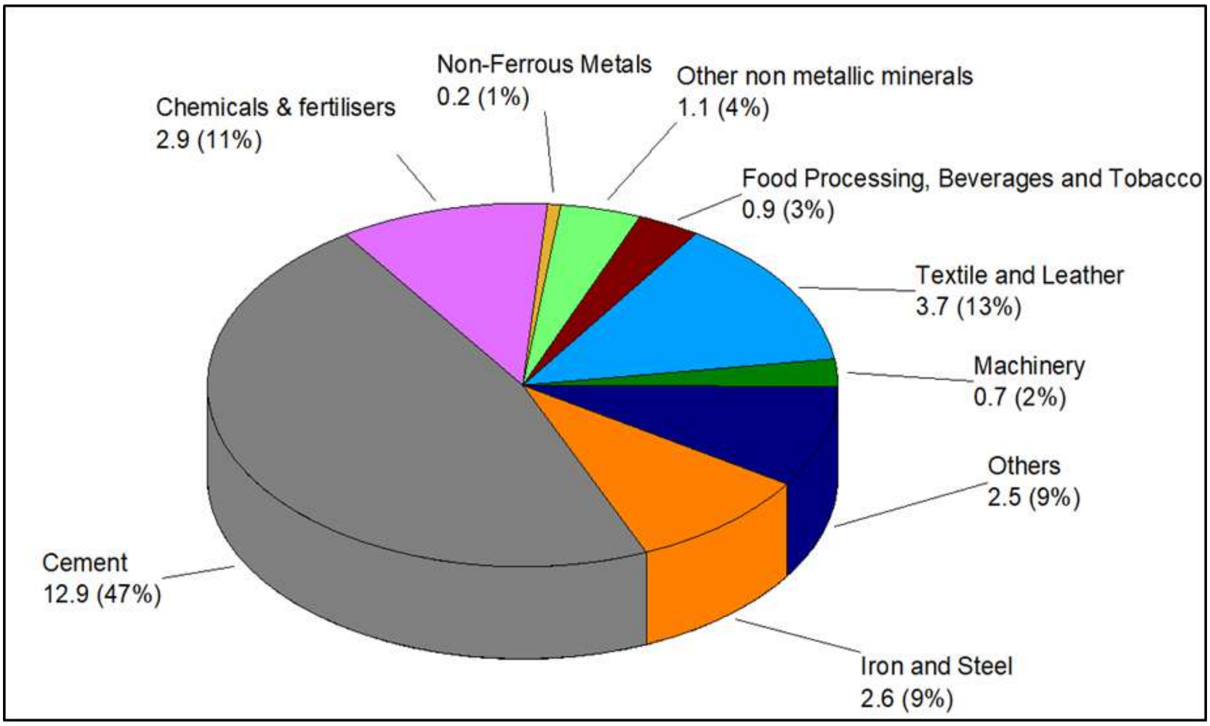

Figure 8.11. Industry-wise contribution to CO_2-eq. emissions (MT) in Rajasthan in the year 2015-16.

Fig. 8.12 shows the fuel distribution of CO_2-eq. emissions in Rajasthan for the year 2015-16. Coal and lignite (48%) accounted for the maximum CO_2-eq. emissions across various industries in 2015-16, followed by grid electricity (37%), natural gas and its derivatives (7%) and petroleum fuels (7%).

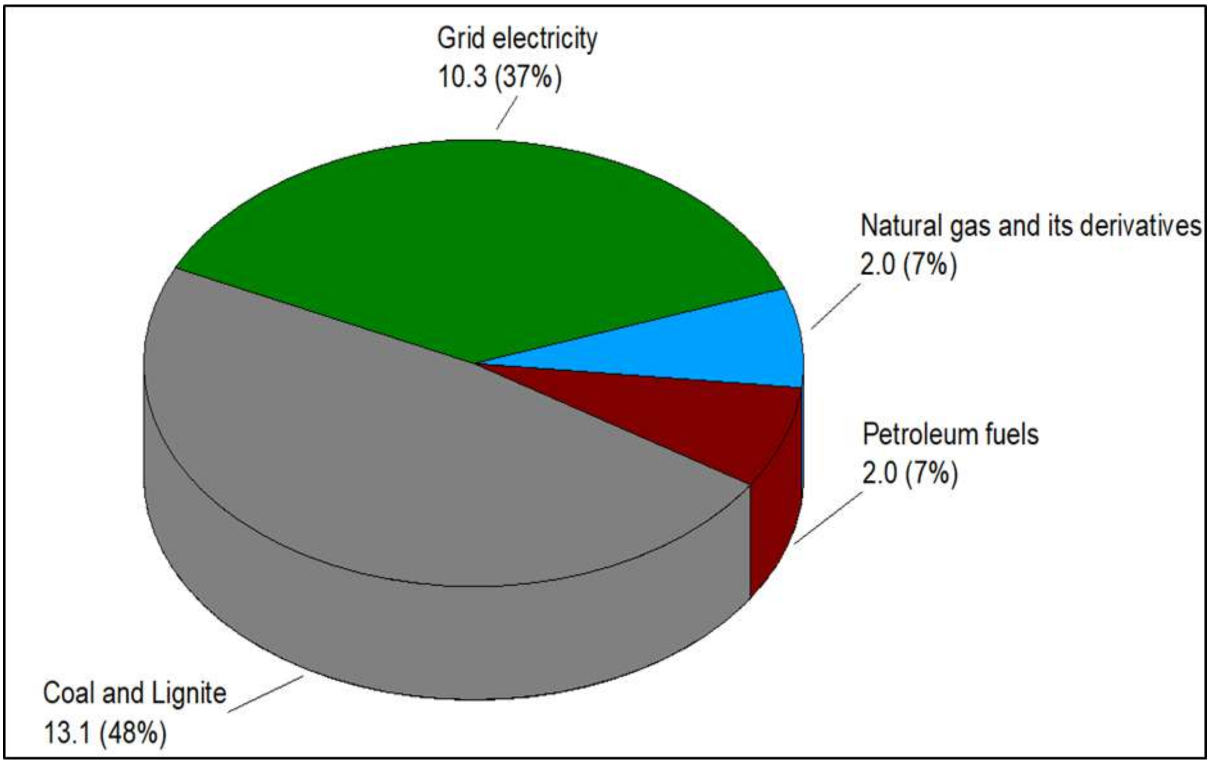

Figure 8.12. Fuel-wise distribution of CO_2-eq. emissions (MT) in Rajasthan for the year 2015-16.

8.2.2.1 Relative performance metrics

a. Energy consumption/GVA

Fig. 8.13 shows the energy consumption/GVA (GJ/crores of INR) for various industries in Rajasthan from the year 2005-06 to 2015-16. The energy consumption/GVA shows an alternate decreasing and increasing trend for different industries from the year 2005-06 to 2015-16. Fig. 8.14 shows overall energy consumption/overall GVA for different industries in Rajasthan. The top four industries with the lowest overall energy consumption/overall GVA from the year 2005-06 to 2015-16 are machinery; food processing, beverages and tobacco; others; and non-ferrous metals, whereas the industries with the highest overall energy consumption/overall gross value added are non-metallic minerals and chemicals and fertilizers.

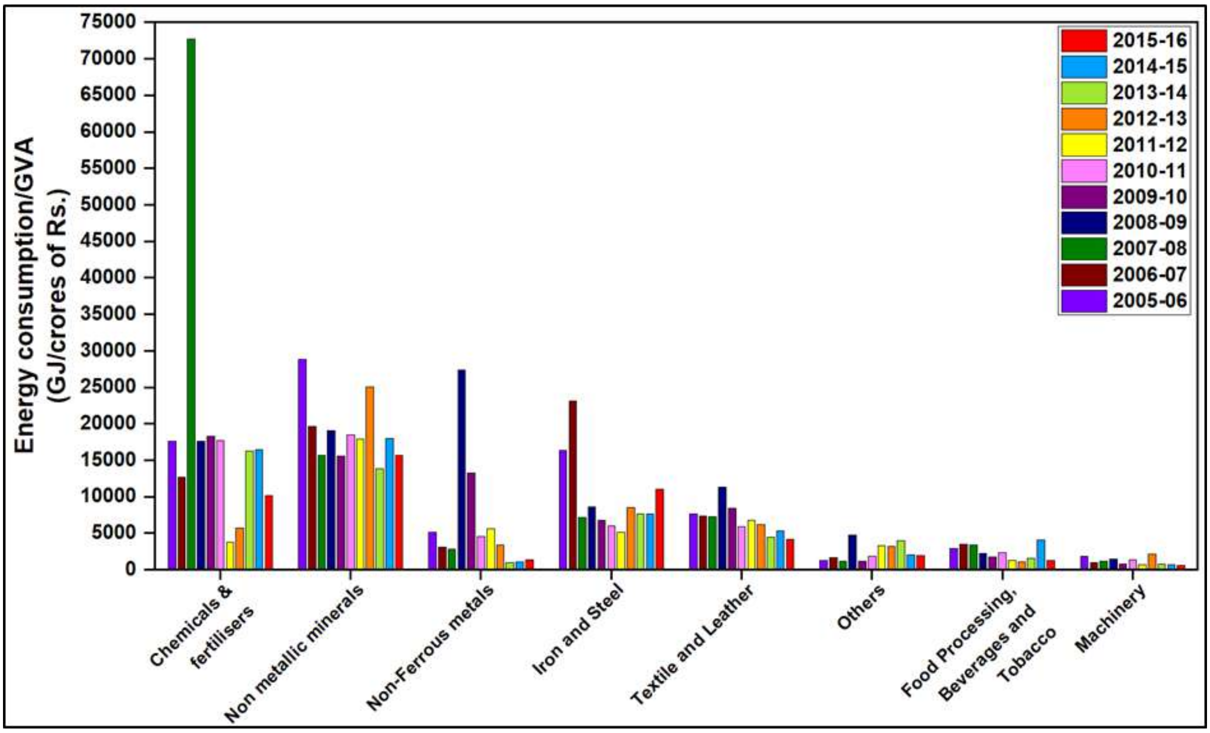

Figure 8.13. Energy consumption/GVA for various industries in Rajasthan from 2005-06 to 2015-16.

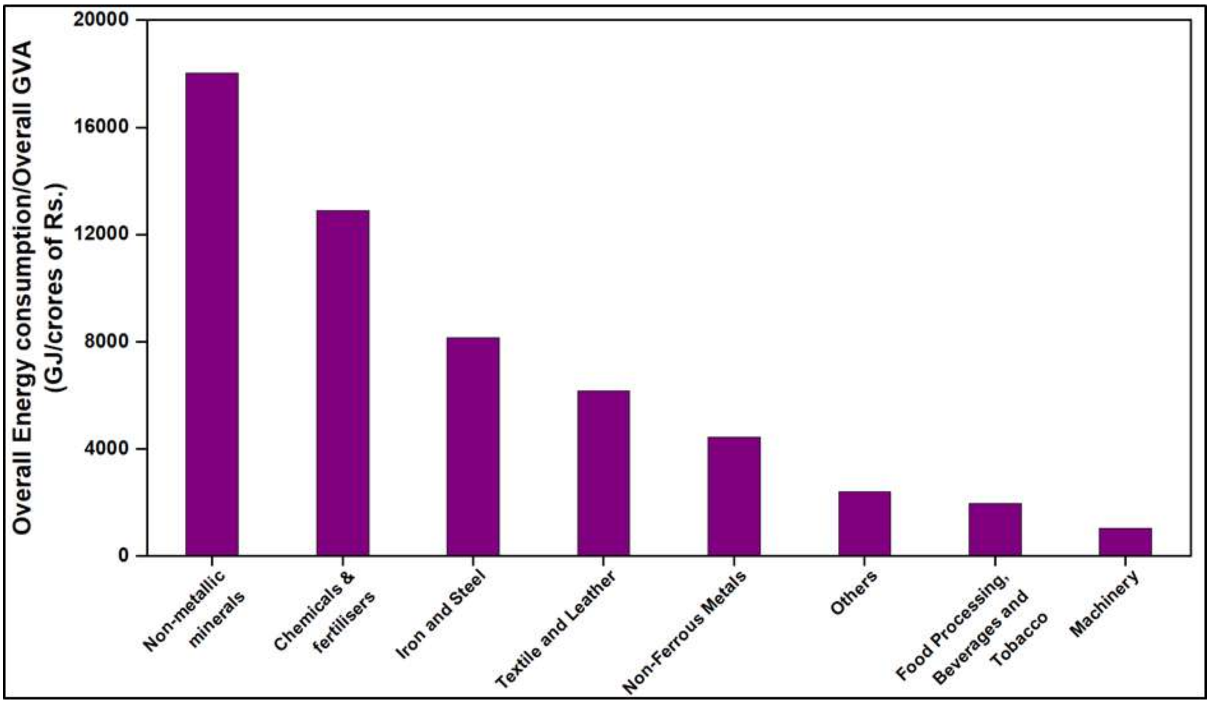

Figure 8.14. Overall energy consumption/overall GVA for various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.15 shows the energy consumption/GVA for different industries in the years 2005-06, 2011-12 and 2015-16. Compared to 2005-06, the energy consumption/GVA ratios in the year 2015-16 decreased for all industries, except others, which reported a 45% increase in the energy consumption/GVA value. This could be mainly due to a higher increase in GVA than in energy consumption. The non-ferrous metals industry reported a 72% decrease in the energy consumption/GVA value in the year 2015-16 as against 2005-06, whereas the corresponding decrease in machinery, textile and leather, non-metallic minerals and chemicals and fertilizers was 66%, 46%, 46% and 42% respectively.

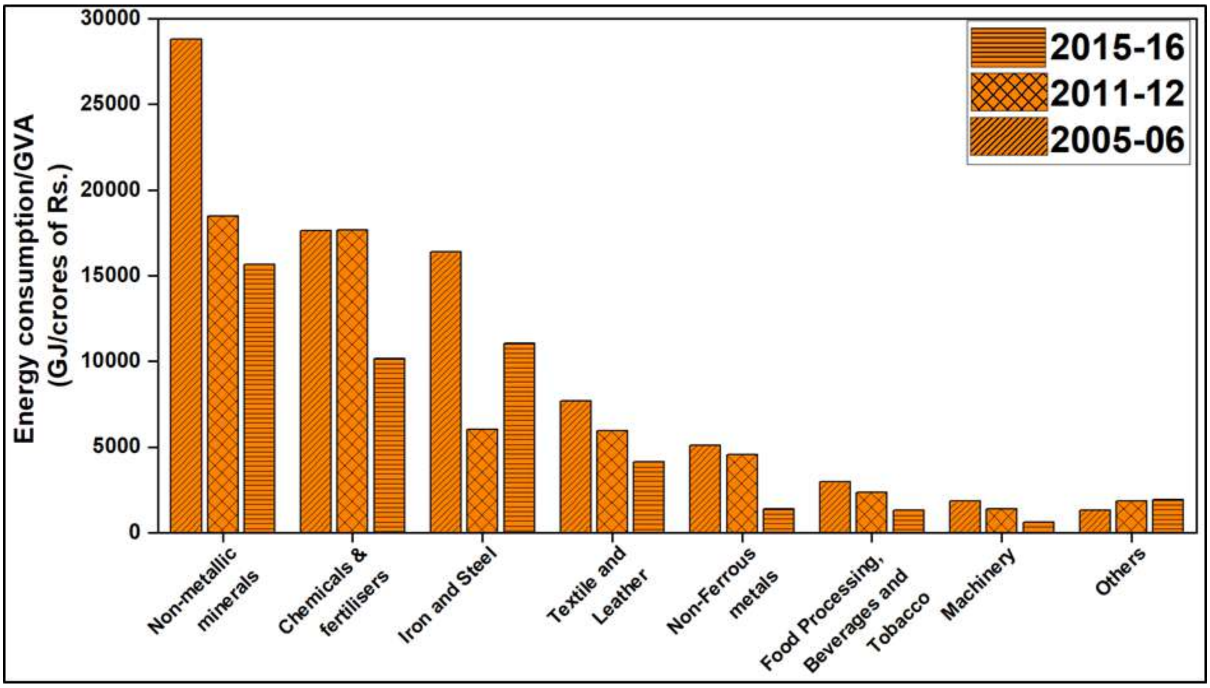

Figure 8.15. Energy consumption/GVA for various industries in Rajasthan in the years 2005-06, 2011-12 and 2015-16.

Table 8.8 shows the energy consumption/GVA (crores of INR) for various industries in Rajasthan in the years 2005-06, 2011-12 and 2015-16 as well as the CAGR of energy consumption/GVA in the year 2015-16 compared to the year 2005-06. All the industries, except others reported a negative CAGR (reduction in the ratio of energy consumption to GVA) in 2015-16. Measures should be taken to further reduce the ratio of energy consumption to GVA in all the industries; in other words, the industries should reduce their energy consumption and/or increase their GVA.

Table 8.8. Energy consumption/gross value added (GVA) and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	**Energy consumption/GVA (GJ/crores of INR)**			**CAGR (%)**
	2005-06	2010-11	2015-16	2015-16[1]
Non-metallic minerals	28807.1	18494.1	15657.8	-5.9
Chemicals & fertilizers	17640.8	17662.6	10162.1	-5.4
Iron and Steel	16386.8	6041.6	11052.1	-3.9
Textile and Leather	7708.6	5938.5	4139.2	-6.0
Non-Ferrous Metals	5105.6	4559.0	1384.0	-12.2
Food Processing, Beverages and Tobacco	2966.0	2346.1	1319.0	-7.8
Machinery	1838.4	1391.4	631.4	-10.1
Others	1319.4	1850.2	1918.7	3.8

[1]Base year for CAGR calculation is 2005-06

b. CO_2-eq. emissions/GVA

Fig. 8.16 shows CO_2-eq. emissions/GVA (tonnes/crores of INR) for various industries in Rajasthan from the year 2005-06 to 2015-16. The CO_2-eq. emissions/GVA trend is similar to that of energy consumption/GVA, i.e., an alternate decreasing and increasing trend for different industries from the year 2005-06 to 2015-16. Fig. 8.17 shows overall CO_2-eq. emissions/overall GVA for different industries in Rajasthan. The top four industries with the least overall CO_2-eq. emissions/overall GVA from 2005-06 to 2015-16 are machinery; others; food processing, beverages and tobacco; and non-ferrous metals. On the other hand, the industries with the highest overall CO_2-eq. emissions/overall GVA are non-metallic minerals and iron and steel.

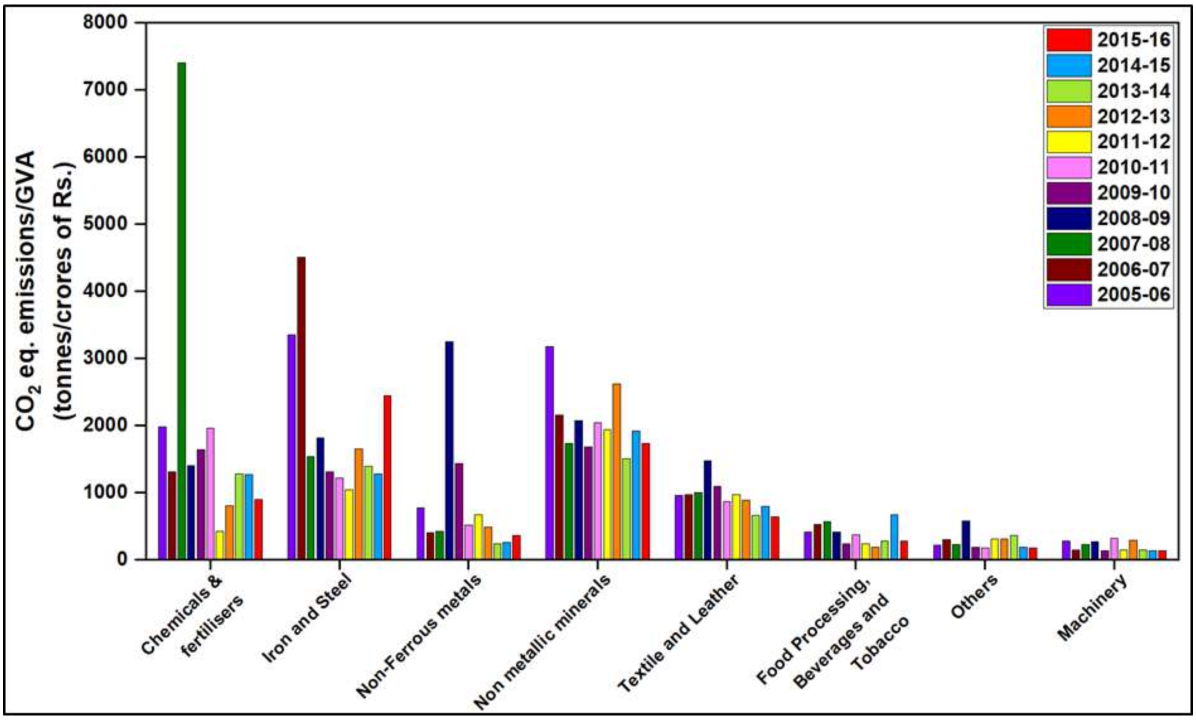

Figure 8.16. CO_2-eq. emissions/GVA for various industries in Rajasthan from 2005-06 to 2015-16.

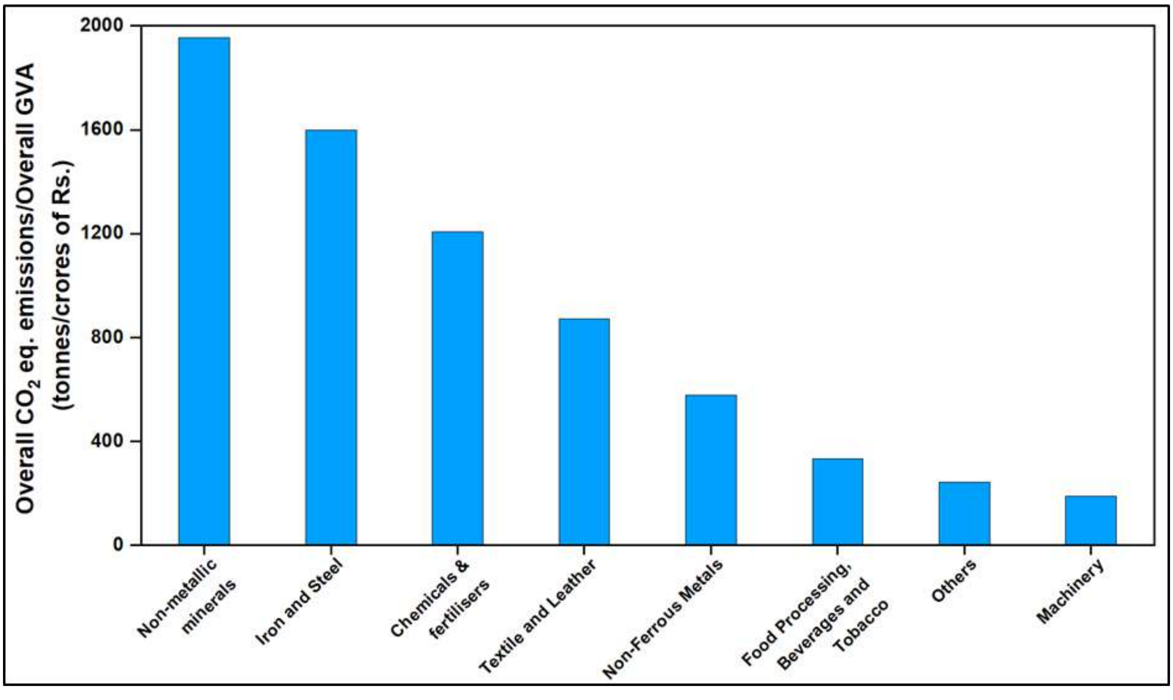

Figure 8.17. Overall CO_2-eq. emissions/overall GVA for various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.18 shows the CO_2-eq. emissions/GVA ratios for different industries for the years 2005-06, 2011-12 and 2015-16. The ratios in the year 2015-16 were lower than those in 2005-06 for all industries. This could be mainly due to a higher increase in GVA compared to the increase in CO_2-eq. emissions. The chemicals and fertilizers industry reported a 55% decrease in the CO_2-eq. emissions/GVA value in 2015-16 compared to the value in 2005-06. Non-ferrous metals, machinery and non-metallic minerals reported a 54%, 52%, and 46% decrease respectively.

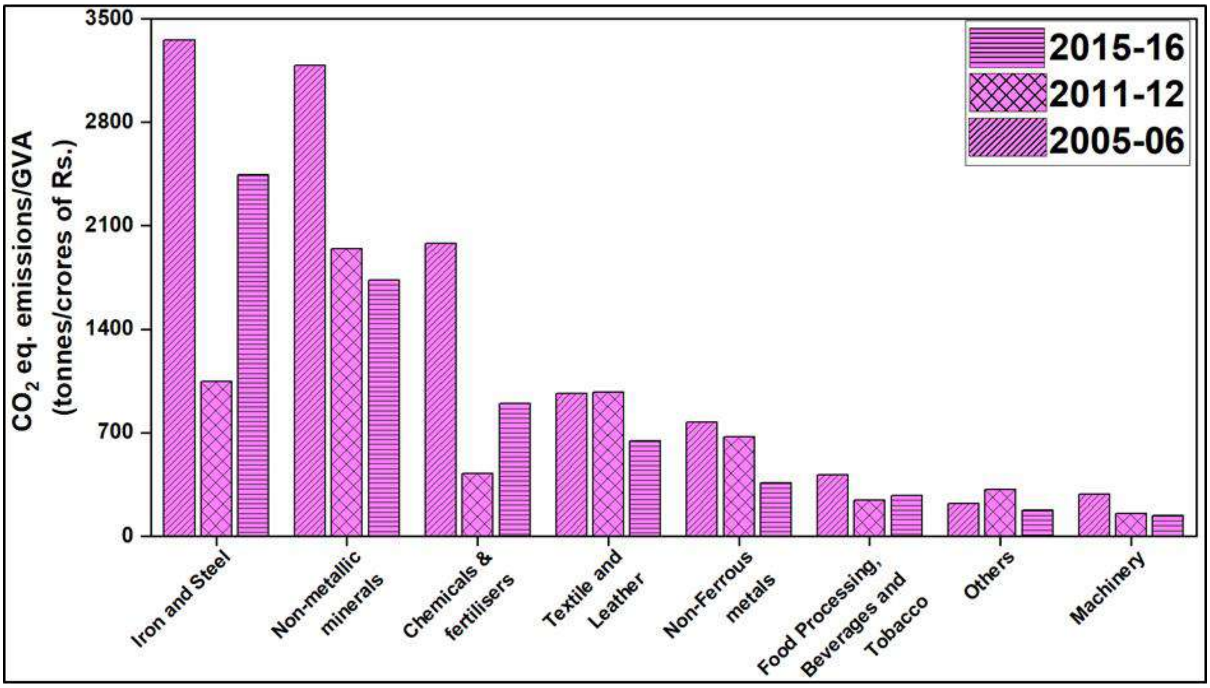

Figure 8.18. CO_2-eq. emissions/GVA for various industries in Rajasthan for the years 2005-06, 2011-12, 2015-16.

Table 8.9 shows the CO_2-eq. emissions/GVA ratios for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16 and also the CAGR of the CO_2-eq. emissions/GVA in the year 2015-16 compared to the year 2005-06. All the industries reported a negative CAGR (reduction in the ratio of CO_2-eq. emissions to GVA) in 2005-06. Measures must be taken to further reduce the ratio of CO_2-eq. emissions to GVA at all the industries, i.e., they should reduce their CO_2-eq. emissions and/or increase their GVA.

Table 8.9. CO_2-eq. emissions/GVA and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	CO2-eq. emissions/GVA (tonnes/crores of INR)			CAGR (%)
	2005-06	**2011-12**	**2015-16**	**2015-16[1]**
Iron and steel	3358.1	1045.0	2444.2	-3.1
Non-metallic minerals	3183.7	1944.6	1733.1	-5.9
Chemicals & fertilizers	1982.2	424.7	898.1	-7.6
Textile and leather	965.2	975.7	643.3	-4.0
Non-ferrous metals	771.7	669.7	359.2	-7.4
Food processing, beverages and tobacco	416.3	242.8	276.6	-4.0
Others	220.3	314.0	174.0	-2.3
Machinery	283.6	151.2	137.5	-7.0

[1]Base year for CAGR calculation is 2005-06

c. CO_2-eq. emissions/energy consumption

Fig. 8.19 shows the CO_2-eq. emissions/energy consumption (tonnes/GJ) for various industries in Rajasthan from 2005-06 to 2015-16. The values show an alternate increasing and decreasing trend for different industries from 2005-06 to 2015-16, finally reaching the highest peak in 2015-16 for all industries, except others and chemicals and fertilizers. Fig. 8.20 shows the overall CO_2-eq. emissions/overall energy consumption ratio for different industries in Rajasthan. The top four industries with the lowest values from 2005-06 to 2015-16 are chemicals and fertilizers, others, cement and textile and leather, whereas the industries with highest values are iron and steel and machinery.

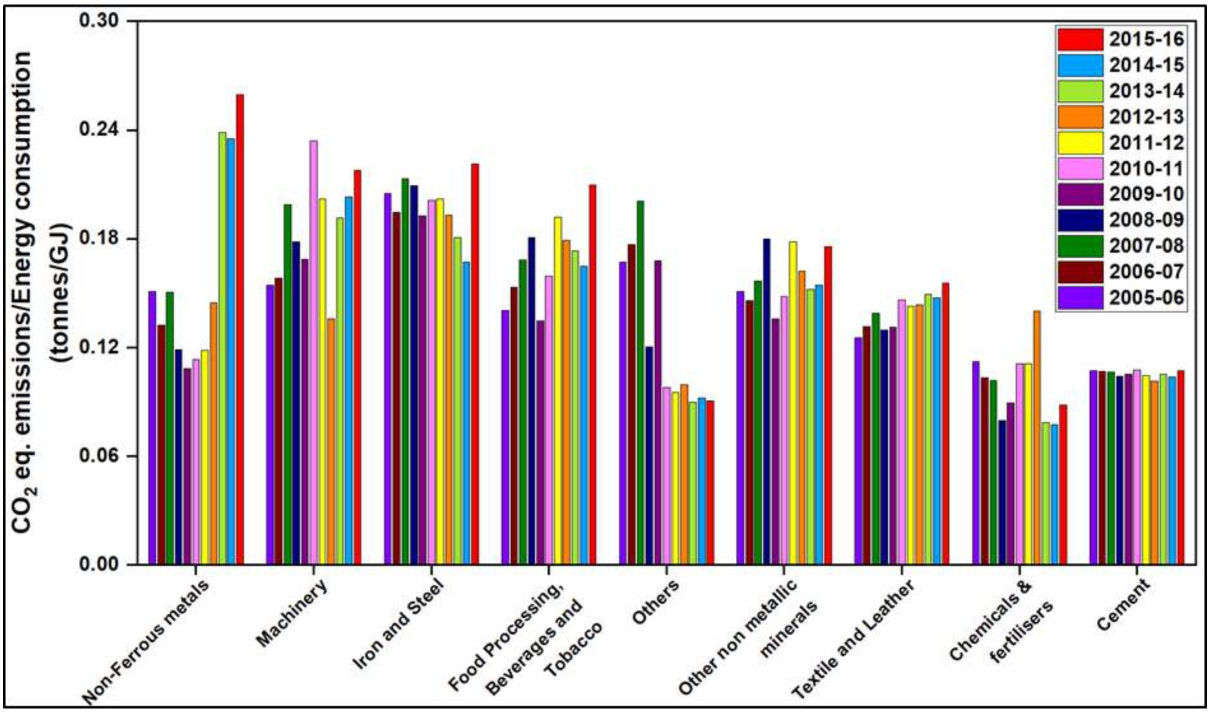

Figure 8.19. CO_2-eq. emissions/energy consumption for various industries in Rajasthan from 2005-06 to 2015-16.

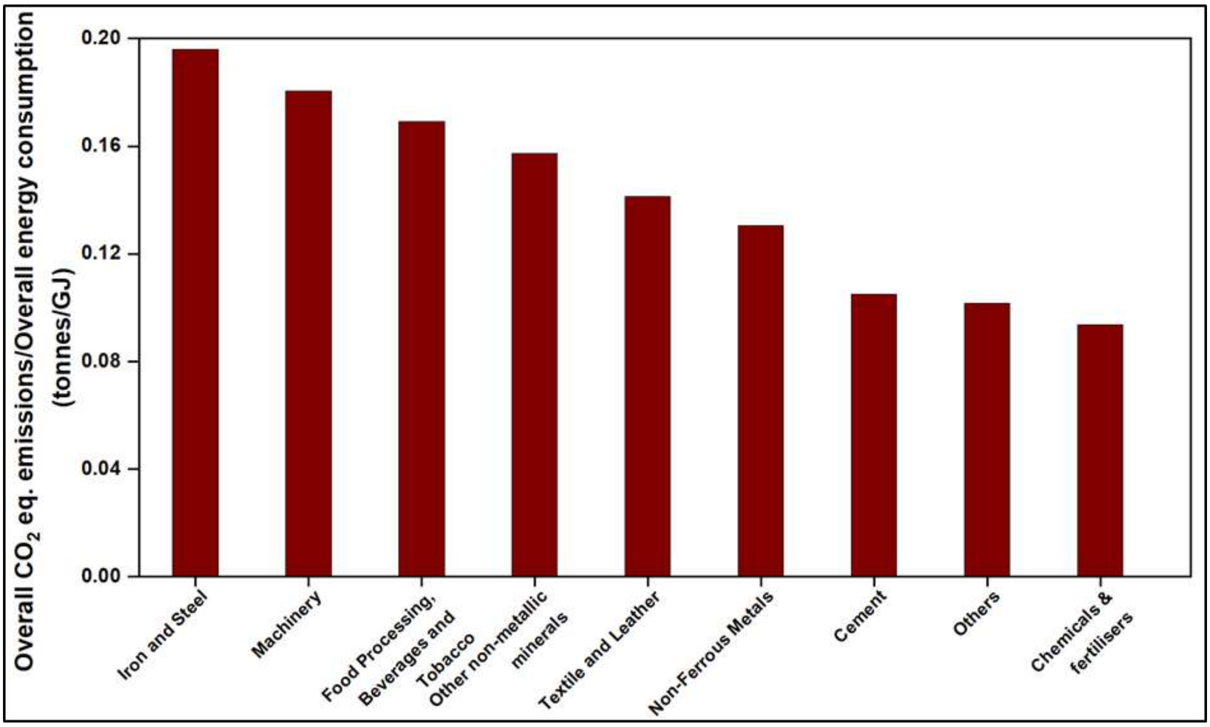

Figure 8.20. Overall CO_2-eq. emissions/overall energy consumption for various industries in Rajasthan from 2005-06 to 2015-16.

Fig. 8.21 shows the CO_2-eq. emissions/energy consumption for different industries for the years 2005-06, 2011-12, and 2015-16. The ratio of CO_2-eq. emissions to energy consumption was higher for all industries in 2015-16 than in 2005-06, except for others and chemicals and fertilizers. This could be mainly due to the greater increase in CO_2-eq. emissions compared to the increase in energy consumption. The CO_2-eq. emissions/energy consumption value of the non-ferrous metals industry was 72% higher in 2015-16 than in 2005-06. During the same comparative period, the corresponding increase in the industries of food processing, beverages and tobacco; machinery; and textile and leather were 49%, 41%, and 24% respectively.

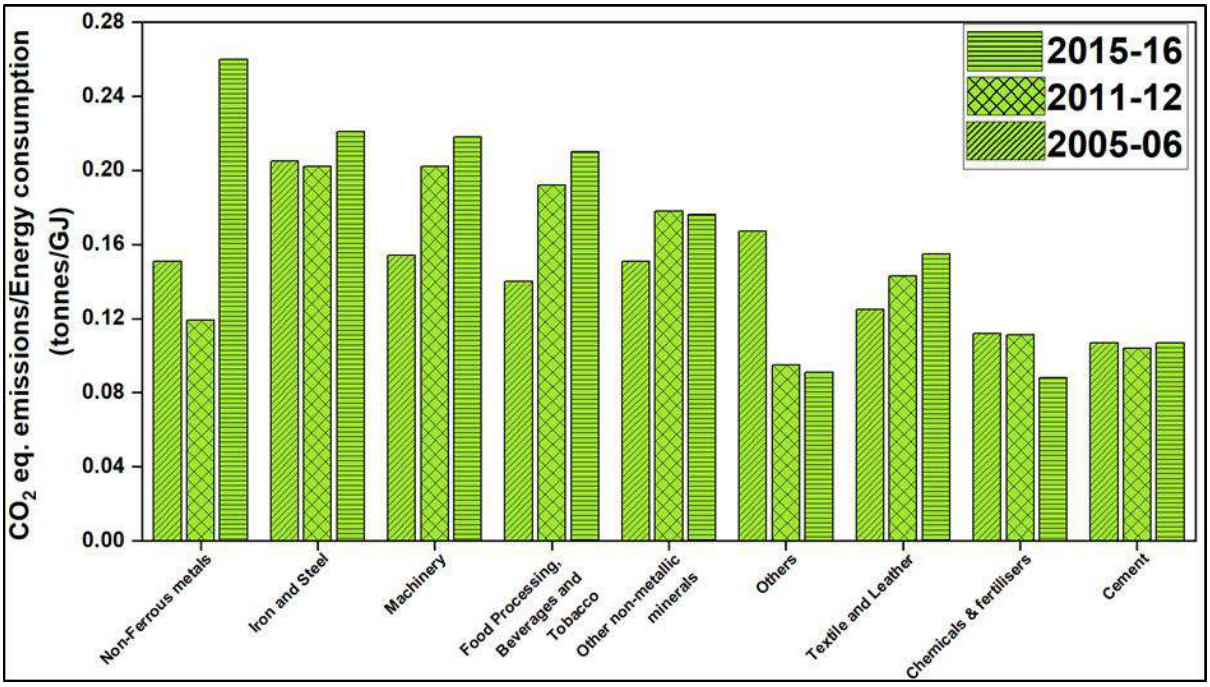

Figure 8.21. CO_2-eq. emissions/energy consumption for various industries in Rajasthan for the years 2005-06, 2011-12, 2015-16.

Table 8.10 shows the CO_2-eq. emissions/energy consumption ratios for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16, along with CAGR comparison between 2005-06 and 2015-16. All the industries, except others and chemicals and fertilizers, reported a positive CAGR (increase in the ratio of CO_2-eq. emissions to energy consumption) between 2005-06 and 2015-16. Measures must be taken to reduce this ratio across all the industries. One of them could be improving energy efficiency, which will result in lower energy consumption and consequently lower CO_2-eq. emissions. Another measure could be the capture of CO_2 emissions by employing carbon capture and storage (CCS) technologies at various industries.

Table 8.10. CO_2-eq. emissions/energy consumption and CAGR for various industries in Rajasthan for the years 2005-06, 2011-12 and 2015-16

Industry	**CO_2 eq. emissions/Energy consumption (tonnes/GJ)**			**CAGR (%)**
	2005-06	**2011-12**	**2015-16**	**2015-16[1]**
Non-ferrous metals	0.151	0.119	0.260	5.6
Iron and steel	0.205	0.202	0.221	0.8
Machinery	0.154	0.202	0.218	3.5
Food processing, beverages and tobacco	0.140	0.192	0.210	4.1
Other non-metallic minerals	0.151	0.178	0.176	1.5
Others	0.167	0.095	0.091	-5.9
Textile and leather	0.125	0.143	0.155	2.2
Chemicals & fertilizers	0.112	0.111	0.088	-2.4
Cement	0.107	0.104	0.107	0.0

[1]Base year for CAGR calculation is 2005-06

8.2.3. Brick Production

Although there is no official record of the number of kilns or their production capacities, a modelled estimation (Tibrewal, Maithel, & Venkataraman, 2018) suggests that the annual production in the state in 2019-20 was nearly 15 billion bricks. The production number is assumed to be met largely by FCBTKs, with small contributions from zigzag kilns (15%) and clamps (7%). FCBTKs are continuous kilns with capacity to produce nearly 15-30 thousand bricks daily, unlike clamps that produce a stack of bricks at a time. The size of a stack can vary from as low as 15 thousand bricks to up to a lakh. Depending on the size, the production cycle can vary from 15 days to a month; and as a result, the production rate is slower than that of FCBTKs. Moreover, clamps are more energy intensive than FCBTKs, consuming nearly 2 times more energy. On the other hand, zigzag kilns are more energy efficient than BTKs. Thus, there is a push from central government for a shift from FCBTKs to zigzag and a complete phase out of clamps. Unlike the national picture, where coal is the major source of energy, a significant share of Rajasthan's fuel needs is met by biomass. Overall, it is estimated that brick production in the state emitted 5.4 MT CO_2-e in the year in 2019-20, which is approximately 4% of the total national emissions from the sector. Of this, 5.3 MT/year is CO_2 emissions while 0.1 MT/year is from CH_4.

Table 8.11. Assumptions to estimate emissions from the brick industry in Rajasthan in 2019-20

Parameter	**FCBTKs**	**Clamps**
Production capacity (million bricks per year)	3 - 8	0.01 - 0.2
Specific energy consumption (MJ/kg of brick)	1.3	2.9
Emissions factor - CO_2 (g/kg of fuel)	2228	1858
Emissions factor - CH_4 (g/kg of fuel)	0.9	11
Total Emissions (CO_2 + N_2O + CH_4)	5.4 MT CO_2-e/year	

MT – Million tonnes

8.2.4. Transportation

Road transport emissions in the state have been analysed using an IPCC Tier III activity approach bottom-up model (Pachauri et al. 2014). The registered vehicle stock from 2010-11 to 2019-20 was obtained from the Rajasthan Statistical Report 2020-21 and Vahan database (CMIE, 2020). The vehicles were categorised based on fuel and technology. Registered vehicles are further classified based on their age-wise distribution in the fleet. Survival fraction of on-road vehicles was estimated using the method employed by Pandey and Venkataraman

(2014). For analysis of emissions in the reference year 2019-20, annually registered vehicles from 2010-11 to 2019-20 were taken into account.

Emissions from road transport are quantified from a total stock of vehicles registered under different categories, distance travelled annually and emission factors for CO_2, N_2O, and CH_4 from vehicle types (IPCC, 2013). The fuel share of the registered vehicle stock was obtained from the Centre for Monitoring Indian Economy (CMIE). Data showed that petrol, diesel and CNG are the main road transport fuels. The share of other fuels (electric and hybrid vehicles and liquified natural gas) is negligible (<1%). Average distance travelled (ADT) and vehicles' fuel efficiency based on their age, technology, and fuel type were assumed from the study by Goel & Guttikunda (2015). Emission factors for CO_2 were assumed from WRI (2015) for different vehicle categories while those for N_2O and CH_4 were assumed from Ramachandra and Shwetmala's (2009) study for India and its states.

According to estimates, total CO_2-e emissions in the reference year (2019-20) were around 10.34 MT. N_2O emissions totalled to 0.07 MT, and CH_4 totalled to 0.02 MT. Of the total CO_2-e emissions, a significant proportion came from heavy diesel vehicles (freight vehicles), followed by motorized two-wheelers and private cars on-road in Rajasthan.

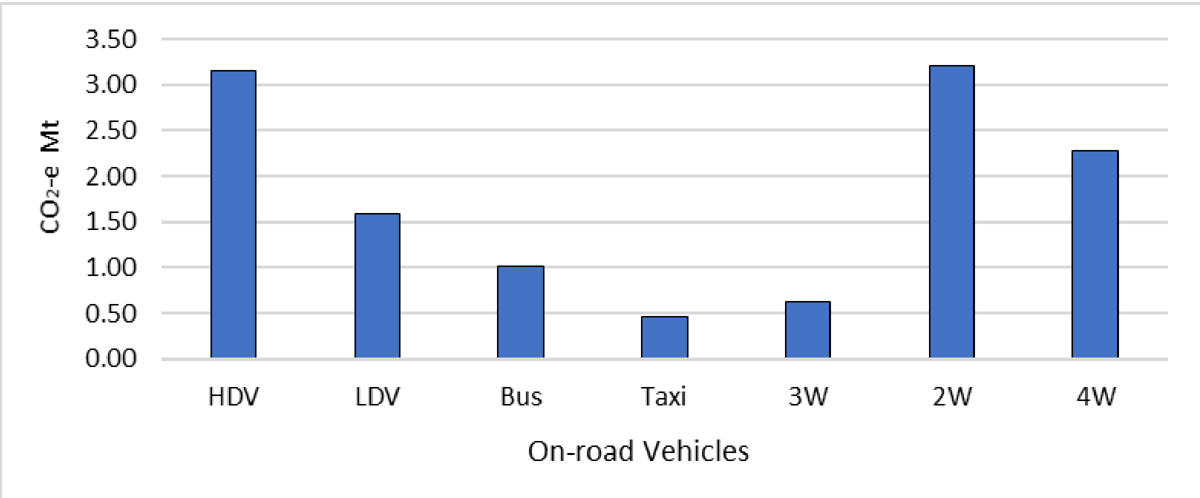

Figure 8.22. Emissions of GHGs (CO_2, N_2O and CH_4) from the road transport sector in Rajasthan in 2019-20.

8.2.5. Residential

Using state-specific per capita daily food consumption and regional mean temperature, specific energy demand for cooking and heating activity was estimated for rural and urban Rajasthan (Pandey, Sadavarte, Rao, & Venkataraman, 2014). The fuel fraction used to meet the energy demand, as reported by the NFHS 2019, revealed that nearly 73% of rural households depend on biomass, while it is the reverse with urban households where 87% use LPG. According to data from the 2011census, 40% households in rural Rajasthan are deprived of electricity, while ~95% of urban households have access. Thus, in terms of emissions from this sector, nearly 70% (combined emissions of CO_2, CH_4 and N_2O) of the emissions in 2019-20 (i.e., ~10 MT CO_2-e/yr) are from rural households. Residential cooking is the highest source, accounting for nearly 80% of the total emissions.

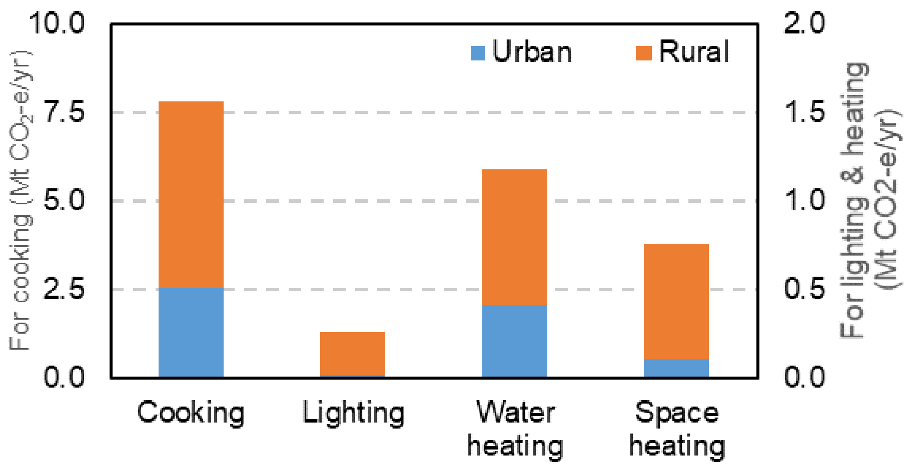

Figure 8.23. Emissions of GHGs (CO_2, CH_4 and N_2O) from residential cooking, lighting and heating in Rajasthan in 2019-20.

8.2.6. Agricultural

Emissions from burning of crop residue were calculated using the commonly used bottom-up approach. The most crucial input, the fraction of residue subjected to on-field burning, was calculated by subtracting the different uses of crop residue from the total generated residue (Venkataraman et al., 2006). The different uses of crop residue include its use as rural household fuel, cattle fodder, industrial fuel and thatching material. Our calculations showed that the majority of crop residue being burned on-field (total of 9.4 GT) is wheat stalk (59%), followed by millets (32%) and maize (6%) (Fig. 8.24). The large share of wheat emissions may be due to the use of combine harvesters that leave behind difficult-to-manage stubble on the field. The estimated emissions are primarily from the northern and eastern districts of the state. The dryer parts (southern and western districts), where crop production is low, contribute little to the emissions. Overall, stubble burning in Rajasthan emits 25.4 Gg/y CH_4, 0.7 Gg/y N_2O and 865 Gg/y CO. Since stubble burning is considered CO_2 neutral, it has not been reported. The three GHGs amount to total CO_2 equivalent emissions of 2.7 Gg/y (using GWP100), of individual contributions from each species are as follows: 0.8 Gg/y CO_2-eq. from CH_4, 0.2 Gg/y CO_2-eq. from N_2O and 1.7 Gg/y CO_2-eq. from CO.

Livestock emissions from enteric fermentation and manure management were calculated using the IPCC good practice guidelines (IPCC, 2006) and the recommended Tier 2 coefficients for large ruminants and Tier 1 coefficients for small ruminants (MoEF, 2012). Livestock population for the year 2019 was obtained from the 20th livestock census (DAHD, 2019). Emissions from the following livestock species were considered: cattle (dairy and non-dairy), buffalo, sheep, goats, camels, horses, mules, pigs and poultry. A total of 30.8 MT of CO_2-eq/year is emitted from livestock, with enteric fermentation accounting for the majority of emissions (28.02 MT CO_2-eq/year) and manure management for the rest (2.8 MT CO_2-eq/year). Buffalos constitute the largest source of emissions (47%), followed by cattle (37%), goats (11%) and sheep (4%); the remaining livestock contributes relatively negligible amounts. N_2O emissions from animal manure and synthetic fertilizers are directly from the soil and from indirect volatilization. The total fertilizer consumption was obtained from the annual Agricultural Statistics Report (DES-GOI, 2020). Synthetic fertilizers emit up to 3.15 MT CO_2-eq/year and animal manure releases 2.9 MT CO_2-eq/year in Rajasthan.

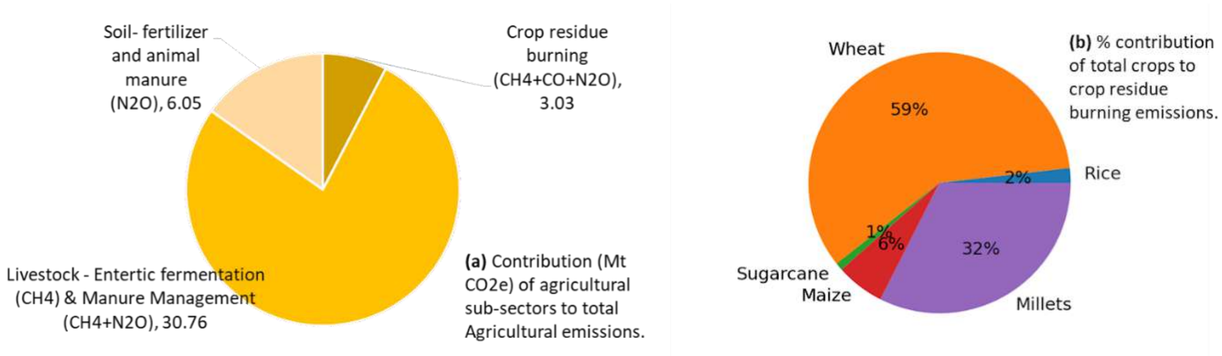

Figure 8.24. (a) Contribution of agricultural sub-sectors to total agricultural emissions. (b) Contribution (%) of various crop residues to total emissions from burning agricultural residue.

8.2.7. Waste Management

In 2015, emissions from the waste sector accounted for less than 4% of the total emissions in Rajasthan. However, with growing population and rapid urbanization, emissions from this sector are on the rise. The key contributors are solid municipal waste, domestic wastewater and industrial wastewater.

CH_4 and N_2O are the major GHGs emitted from the waste sector. Methane (CH_4) is produced and released into the atmosphere as a by-product of the anaerobic decomposition of solid waste and the anaerobic treatment of domestic and industrial wastewater. Nitrous oxide (N_2O) emissions occur due to the protein content in domestic wastewater.

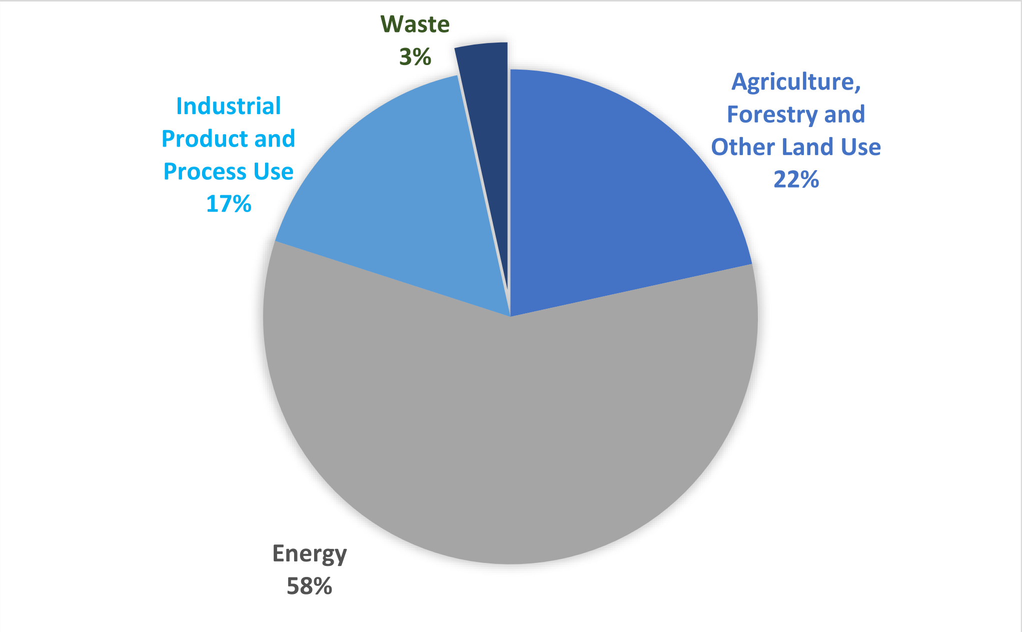

Figure 8.25. Contribution of waste sector emissions to the total emissions in Rajasthan.
Source: GHG platform India 2005-2015 Sub-National Estimates: 2005-2015 Series

Emission estimates from the waste sector have been taken from Kolsepatil et al. (2019), GHG Platform India. Of the total emissions from the waste sector in 2015, domestic wastewater accounted for almost 80 %, followed by solid municipal waste (11.48 %) and industrial wastewater (8.55%).

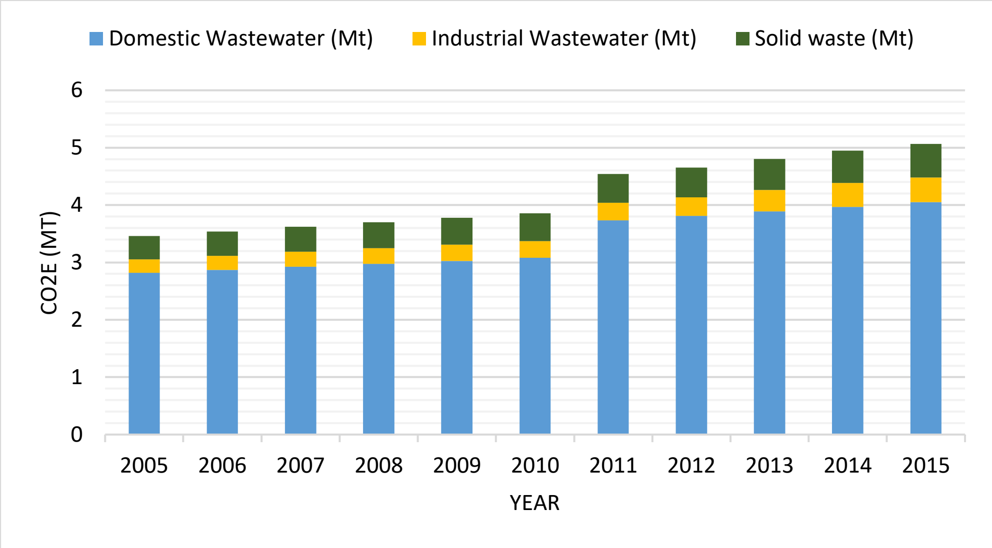

Figure 8.26. Annual emissions from the waste sector

Source: Kolsepatil et al. (2019).

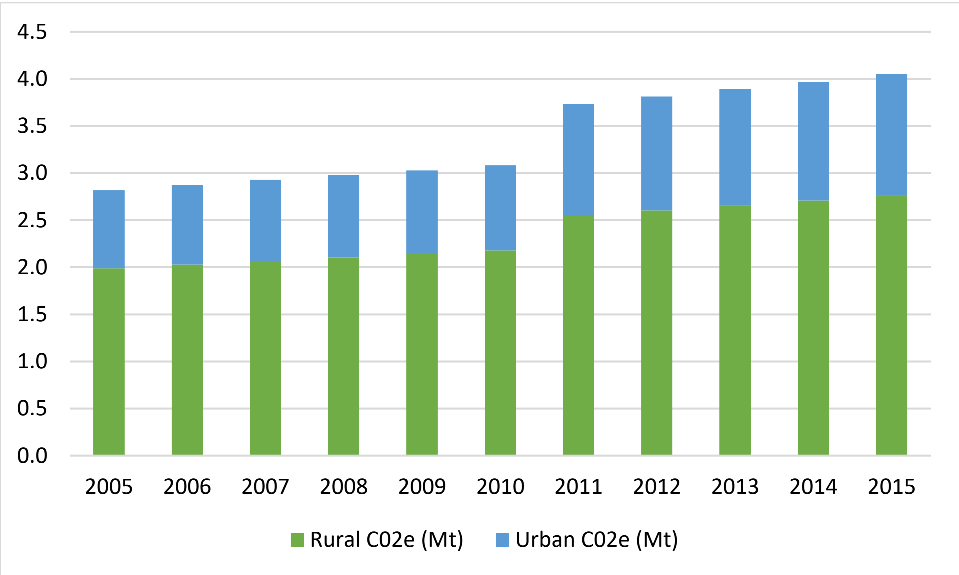

Figure 8.27. Rural and urban share of domestic wastewater emissions

Source: Kolsepatil et al. (2019)

Domestic wastewater contributes more to total emissions in rural areas than in urban areas. This can be attributed to agricultural practices and the presence of livestock in rural areas. The population in the rural areas is also higher. As per the 2011 census, 75% of the population in Rajasthan resides in rural areas.

8.2.8. Tourism

The tourism industry involves many emission-contributing activities, including transport (road, rail and air), stay in hotels and lodges, food consumption (mostly outside at restaurants) and other local recreational activities and experiences. All these activities contribute to emissions, especially transportation to and from the point of origin. International tourism accounts for the highest transport-related emissions as it involves air travel; it contributes 72% to the total CO_2 emissions from the tourism sector (Peeters and Dubois, 2010). Next, accommodation contributes around 24% and local activities are responsible for 4% of CO_2 emissions.

In this study, the transport to and from Rajasthan has been closely evaluated, along with various modes of transport. Similarly, hotels and lodges are part of the residential sector (indirectly). Evaluating emissions from the transport and accommodation sectors again may lead to double accounting. However, it must be mentioned that in Rajasthan, tourism is a major contributor to the state GDP and state employment.

8.2.9. Rajasthan's Emission Profile

Economically important sectors also contribute towards emissions in Rajasthan. Carbon emissions from Rajasthan have tripled as per our estimates from 41 MT of CO_2 in 2005-06 to 137 MT of CO_2 in 2019-20. The highest emissions are from power generation and distribution (40.2 MT CO_2-eq) and the agricultural sector (39.8 MT CO_2-eq), each contributing approximately 29%. In fact, emissions from power generation have doubled from 2005-06 (20.5 MT CO_2-eq). Industrial emissions (27.4 MT CO_2-eq) contribute 20% to Rajasthan's total emissions, and they, too, have risen 2.3 fold since 2005-06 (11.8 MT CO_2-eq). Transport emissions (10.34 MT CO_2-eq) have grown at 2% per annum, contributing 8% to the total emissions. The residential sector (10 MT CO_2-eq), brick manufacturing (5.4 MT CO_2-eq) and waste management (4 MT CO_2-eq) contribute, 7%, 4% and 3% respectively to the total emissions in the state.

8.3. Mitigation Options

In this section, various mitigation policies, linked to the existing policies, are addressed.

8.3.1. Existing Policies Pertaining to the Power Sector, Brick Industry, Residential Sector, Transport Sector and Burning of Agriculture Residue

Table 8.12. Mitigation measures enlisted for power, brick, transport and residential sectors and burning of agricultural residue

Intervention/Action	Existing policy	Description	Associated Ministry/ Govt. Body
		Power Sector	
1. 100% electrification of households	Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY)	Implemented to strengthen the rural electricity distribution network and to electrify rural households in populated areas.	Ministry of Power (2015)
	Saubhagya Yojana	Launched in 2017, Pradhan Mantri Sahaj Bijli Har Ghar Yojana provides electricity to all willing households in the country in rural as well as urban areas.	Ministry of Power (2017)
2. To reduce electricity distribution losses and to improve the operational and financial efficiency of state discoms	Ujwal Discom Assurance Yojana (UDAY)	Launched by the Indian government in 2016 with the objective of improving the operational and financial efficiency of state discoms.	Ministry of Power (2015)

	Mukhya Mantri Vidhyut Sudhar Abhiyan (MMVSA)	The scheme has multi-fold objectives: providing 24*7 uninterrupted and quality power supply, improving consumer services, enhancing electrical safety, and reducing AT&C losses.	Rajasthan Energy Department (2016)
3. Utilization of energy-efficient equipment	Unnat Jyoti by Affordable LEDs for All (UJALA)	The objective is to promote efficient lighting and enhance awareness about efficient equipment like LED bulbs, tube lights and fans that will reduce electricity bills and preserve the environment.	Ministry of Power (2015)
4. Shifts to renewable energy sources	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM)	Scheme provides financial assistance for installing solar pumps and solarizing existing grid-connected solar pumps.	Ministry of New and Renewable Energy (2019)
	Development of solar parks and ultra-mega solar power projects	The Ministry of New and Renewable Energy has approved the development of 6 solar parks in Rajasthan with a total capacity of 5,410 MW under the "Scheme for development of solar parks and ultra-mega solar power projects"	Ministry of New and Renewable Energy (2014)

	Solar rooftop power generation scheme/ Solar rooftop under net metering	To promote the generation of solar energy on rooftops, net metering regulation was issued by the Rajasthan Electricity Regulatory Commission (RERC) in February 2015. RREC has also undertaken an initiative to install solar photovoltaic (SPV) grids connected power plants to promote rooftop solar power generation in the state with Central Financial Assistance (CFA) from the Ministry of New and Renewable Energy (MNRE).	Ministry of New and Renewable Energy & Rajasthan Electricity Regulatory Commission (2015)
	Solar energy electrification in rural areas	The programme provides financial assistance to electrify un-electrified villages and *dhanies* of Rajasthan through off-grid solar photovoltaic (SPV) home lighting systems (HLSs).	Rajasthan Renewable Energy Corporation Ltd. (2016)
	SPV water pumping programme	The SPV Water Pump Programme is being implemented by Rajasthan Horticulture Development Society (RHDS) with technical support from RREC.	Rajasthan Renewable Energy Corporation Ltd. (2019)
	National Solar Mission	The project aims to promote both grid and off-grid solar power in India	Ministry of New and Renewable Energy (2010)
	Rajasthan Wind & Hybrid Energy Policy, 2019	The policy aims to build 2000 MW wind power capacity by up to 2024-25. The policy also targets production of 3.5 GW through various projects by 2024-25.	Rajasthan Renewable Energy Corporation Ltd. (2019)

	Hybridization of existing wind or solar projects will account for 200 MW, new wind-solar hybrid projects will account for 2 GW, wind-solar hybrid with storage systems will account for 500 MW, and hybridization of existing conventional projects will account for 800 MW.	
Rajasthan Solar Energy Policy, 2019	The policy aims to achieve a target of generating 30,000 MW through solar power projects by 2024-25. Individual capacity targets include installing utility/grid scale solar parks of 24,000 MW, distributed generation of 4000 MW, solar rooftops of 1000 MW and solar pumps of 1000 MW.	Rajasthan Renewable Energy Corporation Ltd. (2019)
Policy for promoting the generation of electricity from biomass, 2010	This policy promotes the setting up of biomass power projects with a capacity of up to 20 MW, where biomass like forestry-based & agro-based industrial residues, energy plantations, and forestry and agro-residues can be used as fuel.	Rajasthan Renewable Energy Corporation Ltd. (2010)
New National Biogas and Organic Manure Programme (NNBOMP)	This supersedes the National Biogas and Manure Management Programme (NBMMP) 2019, which was implemented for the dissemination of small biogas plants for cooking and lighting.	Ministry of New and Renewable Energy (2019)

	Biogas-based power generation (off grid) and thermal application programme (BPGPT)	This programme was launched in order to promote decentralized renewable energy sources (DRES) of power generation, specifically in the small capacity range (3 kW to 250 kW) and to promote the use of thermal energy for heating/cooling from biogas plants sized 30 m^3 to 2500 m^3 size. The programme provides central financial assistance from MNRE for the setting up of biogfas plants.	Ministry of New and Renewable Energy (2017)
Brick Production			
1. Transitions from traditional brick-making practices	Emission standard	Notice was issued in 2018 that new kilns should be of zigzag/ vertical shaft while existing ones must convert themselves into these.	Ministry of Environment, Forest and Climate Change (2018) / State pollution control board
2. Manufacturing of perforated / hollow bricks (resource-efficient bricks)	NA	NA	NA
3. Use of fly-ash mixed clay bricks	NA	NA	NA
4. Use of non-fired bricks such as fly-ash bricks and autoclaved aerated concrete blocks	NA	NA	NA
Transport Sector			

1. Improvement in emission norms	BS-IV emission norms present in vehicles	Auto fuel norms implemented to control tail-pipe emissions of air pollutants from vehicles. In 2020, the government of India leapfrogged from BS-IV to BS-VI emission norms	Ministry of Road Transport and Highways (MoRTH)
2. Vehicle fuel efficiency program	Fuel consumption standards for cars (effective from 2017-18)	Fuel efficiency norms were finalized for commercial vehicles (HDVs) in 2017. Fuel consumption standards for cars control for CO_2 emissions: 130 g CO_2/km in 2016-17 and 113 g CO_2/km in 2022	Ministry of Power (MoP) and Ministry of Road Transport and Highways (MoRTH)
3. Alternate fuel and vehicles	FAME and NEMMP, 20% blending target for bioethanol and biodiesel by 2017, Natural gas Programme in India	Electric, hybrid, CNG, LPG, and biofuels are alternative transport fuels in Rajasthan	Ministry of Power and Rajasthan Electricity Regulatory Commission; Ministry of Petroleum and Natural Gas (MOPNG)
4. Metro system	Jaipur Metro Phase 1A, comprising 9.63 kilometres (5.98 mi) of route from Mansarovar to Chandpole Bazar	Jaipur Metro Rail Corporation (JMRC) provides public transportation through metro rail lines along the city’s main arterial corridors. Line 1 has a running length of 12 km on the east–west corridor.	Urban Development & Housing Department, Government of Rajasthan
5. Green tax	In 2016-17, 62% green tax was collected from new vehicles and 38% from old vehicles	Tax collected at the time of registration of new vehicles and at the time of renewal of fitness certificate of old vehicles in Rajasthan	Rajasthan Regional Transport Department

Residential Sector			
1. Transition to cleaner cooking fuels – LPG cookstoves	Direct Benefit Transfer of LPG (DBTL) scheme	Launched in 2014-15, the scheme transfers the applicable subsidy amount on a domestic LPG cylinder directly into the consumer's bank account.	Ministry of Petroleum and Natural Gas (2014)
	Give-It-Up campaign	Launched in 2015, it aims to encourage well-to-do LPG customers to voluntarily surrender their LPG subsidy	Ministry of Petroleum and Natural Gas (2015)
	Pradhan Mantri Ujjwala Yojana	Launched in 2016, it aims to provide LPG connections to around 8 crore households belonging to the below-poverty-line segment.	Ministry of Petroleum and Natural Gas (2016)
2. Transition to cleaner fuels for cooking and lighting – biogas	New National Biogas and Organic Manure Programme (NNBOMP).	Superseded by the National Biogas and Manure Management Programme (NBMMP) in 2019, for dissemination of small biogas plants for cooking and lighting.	Ministry of New and Renewable Energy (2019)
3. Transition to solar-powered devices for cooking, lighting and heating	National Solar Mission	Launched in 2010, it aims to promote both grid and off-grid solar power in India	Ministry of New and Renewable Energy (2010)
	Rajasthan Solar Energy Policy	Policy was updated in 2019 and it aims to promote both grid and off-grid solar power in Rajasthan	Rajasthan Renewable Energy Corporation Ltd. (2019)
	Rooftop solar power generation scheme for 45 MW - Rajasthan	Recently announced, it aims to promote solar power by providing subsidies for the installation of solar	Rajasthan Renewable Energy Corporation Ltd. (2019)

		rooftop power in Rajasthan.	
4. Shifts to electric powered devices for cooking, lighting and heating	Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY)	Launched in 2015, this programme aims to improve the electricity distribution infrastructure in rural areas.	Ministry of Power (2015)
	Saubhagya Scheme	Launched in 2017, this scheme aims to provide free electricity connections to all households in rural areas and poor households in urban areas.	Ministry of Power (2017)
		Agricultural Residue Burning	
1. Satellite-based monitoring of burning activities 2. Appropriate machineries for farming practices	National Policy for Management of Crop Residue (NPMCR)	Launched in 2014, this policy prevents the burning of crop residues through technological intervention, diversified use of crop residues and providing financial support for implementation	Ministry of Agriculture (2014)
3. Optimum utilization and in-situ management of crop residues 4. Penalizing open burning	Central Sector Scheme	Announced during the fiscal budget 2018, as part this scheme, approximately Rs.1700 crores have been allocated to promote in-situ management of crop residue by retention and incorporation into the soil through the use of appropriate mechanization inputs and creating awareness / capacity building activities for effective utilization and	Central government (2018)

		management of crop residue.	
	Directives to ban burning	Since 2015, the National Green Tribunal (NGT) has been issuing directives to ban open burning of crop residues by imposing fines between INR 2500 and 15000 on farmers.	National Green Tribunal (2015)
5. Incentivizing adoption of alternatives	--	Example: The Punjab government disbursed Rs. 19 crores to small farmers for not burning residues.	
6. Use of residues as an energy source – Biomass-based power generation, biogas, biofuel	State renewable energy policies	Punjab and Haryana governments launched renewable policies promoting the generation of biomass power and bio-CNG/ bio-manure/biofuel	
	Policy for biomass utilization for power generation through co-firing in pulverized coal-fired boilers	This was issued in November 2017 to encourage coal-fired power plants to use 5-10% blend of biomass pellets (made of crop residue)	Ministry of Power (2017)
	Programme on Energy from urban, industrial and agricultural wastes/ residues	The programme was launched to promote the setting up of waste-to-energy plants to recover energy in the form of biogas or bioCNG	Ministry of New and Renewable Energy
	The National Policy on Biofuels	Launched in June 2018, the policy targeted 20% blending of ethanol in gasoline by 2030. This will promote the use of agricultural waste in	Ministry of Petroleum and Natural Gas (2018)

refineries to generate
biofuel.

8.4. Industry

8.4.1. Existing Policy Schemes for Large-Scale Industries

8.4.1.1. PAT scheme

The perform, achieve and trade (PAT) scheme is the flagship programme of the Bureau of Energy Efficiency (BEE), government of India, under the National Mission for Enhanced Energy Efficiency (NMEEE) (BEE, 2020a). It is a regulatory mechanism for reducing specific energy consumption by large-scale energy intensive industries.

Selected energy-intensive industries across multiple sectors identified as “designated consumers” (DCs) are given targets for reducing their specific energy consumption for a period of 3 years. If these DCs overachieve their targets, they are entitled to receive energy savings certificates (ESCerts), which can be traded on energy exchanges (such as Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL)). DCs who do not meet their targets have to purchase ESCerts or pay a penalty (BEE, 2020a, 2020b, 2020c; PWC and SSEF, 2014).

Until 31st March 2020, six PAT cycles had been rolled out by BEE, which covered a total of 1073 DCs from 13 sectors. Total energy savings of 26 MTOE (million tonnes of oil equivalent), which translates into avoiding around 70 million tonnes of CO_2 emissions, are projected to be achieved by March 2023 (BEE, 2020c).

In Rajasthan, around 58 DCs participated in PAT cycle-I (PWC and SSEF, 2014) and 71% of them met their targets (SEEI, 2018). In PAT cycle-II, a total of 66 DCs participated from Rajasthan and their sector-wise breakup is given in Table 8.13 (BEE, 2020d). The majority of DCs in PAT cycle-II from Rajasthan belonged to the textile industry (29), followed by the cement industry (19) (BEE, 2020d).

Table 8.13. Break-up of DCs from Rajasthan for PAT cycle-II

Industry	No. of DCs in Rajasthan for PAT Cycle-II
Textile	29
Cement	19
Thermal Power Plants	10
DISCOM's	3
Fertilizers	3
Chlor-alkali (Chemicals)	1
Indian railways	1
Total	66

The total energy savings achieved by Rajasthan in PAT cycle-II was 0.66 MTOE (million tonnes of oil equivalent) (BEE, 2020e), and 68% of the DCs met their PAT cycle-II targets (AEEE, 2019).

8.4.1.2. Green rating of industries in Rajasthan

Rajasthan State Pollution Control Board (RSPCB) and Confederation of Indian Industry (CII), together, have launched a scheme called the "GreenCo rating" for enhancing the environmental performance of various industries in the state. The GreenCo rating is a comprehensive and a first-of-its-kind scheme in the world that evaluates the environmental performance of the companies using a life-cycle approach.

The developed rating system assigns points on various parameters. Details about the parameters and the rating system are given in Table 8.14 and Table 8.15 respectively. The GreenCo rating scheme was launched in July 2021, and many industries are being encouraged to come forward and participate on a voluntary basis (RSPCB and CII, 2021).

Table 8.14. Rating parameters and maximum points under the GreenCo rating system

Sr. no	**Parameters**	**Maximum points**
1	Energy efficiency	150
2	Water conservation	100
3	Renewable energy	100
4	Greenhouse gas mitigation	100
5	Waste management	100
6	Material conservation, recycling and recyclability	100
7.	Green supply chain	100
8	Product stewardship and life cycle aspects	125
9	Innovation for environment	50
10	Green infrastructure and ecology	75
	Total	1000

Table 8.15. Rating levels for the GreenCo rating system

Sr. no	Points	Rating level
1.	750-849	Platinum
2.	650-749	Gold
3.	550-649	Silver
4.	450-549	Bronze
5.	350-449	Certified

The GreenCo rating system is an initial step towards industry compliance with future strict environmental regulations. Implementation of the GreenCo rating system will help industries reduce their resource and energy consumption as well as their emissions and provide them with new opportunities for cost reduction. It will pave the way for industries to achieve world-class green standards. The ratings can be used as a tool to showcase the green friendliness of industries and thus improve their brand value.

In addition to the above benefits, RSPCB plans to provide incentives such as reduction in consent fee and extension in consent period for the units that successfully implement the GreenCo rating system, apart from annual recognition of the three best units and exclusive mention of the GreenCo-rated companies on the websites of RSPCB and CII. Thus, the large-scale implementation of the GreenCo rating scheme by industries in Rajasthan will help the state march towards a green and low carbon economy.

8.4.1.3. State energy efficiency index

The State Energy Efficiency Index (SEEI) has been jointly developed by the Bureau of Energy Efficiency (BEE) and Alliance for an Energy Efficient Economy (AEEE). For the year 2020, the State Energy Efficiency Index 2020 assessed the performance of 36 states and UTs using 68 qualitative, quantitative, and outcome-based indicators, across six sectors, namely, buildings, industry, municipalities, transport, agriculture & DISCOMs and cross sector for calculating the state energy efficiency index (SEEI). The maximum score for the State Energy Efficiency Index 2020 was 100. The industry sector had the maximum weightage of 25%. The indicators for calculating the energy efficiency index stressed on the following aspects: a) policy and regulation, b) financing mechanisms, c) institutional capacity, d) adoption of energy efficiency measures, and e) energy savings (SEEI, 2020a). Based on the scores achieved by the states, they were classified as Front runner, Achiever, Contender and Aspirant (SEEI, 2020b).

Overall, the state of Rajasthan achieved the second highest SEEI score (61 out of 100) in 2020 and was placed in the *Front Runner* category. Rajasthan also achieved the highest improvement in SEEI from 2019 to 2020 (SEEI, 2020b; SEEI 2020c). In the industry sector, Rajasthan showed the highest improvement in terms of SEEI indicators from 2019 to 2020; it was ranked 4th among all the states (with a score 13 out of 25) (SEEI, 2020c).

The State Energy Efficiency Index report for 2020 (SEEI, 2020c) indicates that Rajasthan is one of the states that has at least one mandate on energy efficient equipment standards or energy efficiency programmes in the industrial sector. The state is also reported to offer financial rewards for energy efficiency implementation in industries in the form of either incentives for conducting energy audits and implementing the recommendations or low-interest loans and subsidies for the adoption of energy-saving equipment and facilities. Rajasthan is one of the states to have designated an entity to support the industries in energy efficiency implementation, e.g., through technical advisory support or enforcement of energy audits. The State Development Authority (SDA) of Rajasthan has conducted awareness workshops and training programmes for the designated consumers (DCs) in the state. The SDA also organizes the Rajasthan Energy Conservation Awards (RECA) every year, which covers five sectors and fifty sub-sectors (SEEI, 2020c; SEEI, 2020d).

8.4.1.4.. Existing policy schemes for MSMEs

a) BEE-SME programme

For the MSMEs (micro, small and medium enterprises), BEE has launched the Bureau of Energy Efficiency-Small and Medium enterprises (BEE-SME) programme, which aims to identify energy-intensive SME clusters in each state, undertake energy-mapping of these clusters on a pan India basis, provide technical assistance and promote energy efficiency and technology upgradation within the SMEs (BEE, 2020f).

For the state of Rajasthan, three energy-intensive clusters have been identified at Pali (textile), Alwar (oil milling) and Jodhpur (limestone). For the textile cluster at Pali, a demonstration project has been implemented under the National Programme on Energy Efficiency and Technology Upgradation of MSMEs. Also, three clusters have been identified at Jaipur for energy mapping: foundry, glass and paper (BEE, 2020f).

During the financial year (FY) 2018-19, the state of Rajasthan achieved an energy saving of 309 toe (tonnes of oil equivalent) and an emission reduction of 1528 tonnes of CO_2 through the BEE-SME programme (BEE, 2020e; BEE 2020f).

b) GEF-UNIDO-BEE programme

The Global Environmental Facility-United Nations Industrial Development Organization-Bureau of Energy Efficiency (GEF-UNIDO-BEE) programme aims to develop and encourage the market towards introducing energy-efficient technologies and enhancing the use of renewable energy technologies in five energy-intensive MSME sectors: brass, ceramics, dairy, foundry, and hand tools (BEE, 2020f).

In Rajasthan, an energy-intensive cluster has been identified at Nagaur (hand tools) and during FY 2018-19, an energy saving of 23 toe (tonnes of oil equivalent) and an emission reduction of 223 tonnes of CO_2 was achieved (BEE, 2020e; BEE, 2020f).

c) BEE-WB-GEF-SIDBI programme

The Bureau of Energy Efficiency-World Bank-Global Environmental Facility-Small Industries Development Bank of India (BEE-WB-GEF-SIDBI) programme aims to promote financing of energy efficiency at MSMEs by increasing demand for energy efficiency investments at selected energy intensive MSME clusters. The programme has successfully completed 3 phases till the year 2019 (BEE, 2020f).

For the state of Rajasthan, during the FY (financial year) 2018-19, an energy saving of 300 tonnes of oil equivalent was obtained from the implementation of the BEE-WB-GEF-SIDBI programme (BEE, 2020e).

8.4.2. Technology and Policy Recommendations

As mentioned in the earlier section, the state of Rajasthan already has quite a few policies in place for reducing both energy consumption and CO_2 emissions from the industry sector. Below are a few policy and technology recommendations that could be implemented in conjunction with the existing measures for further decarbonization of the industry sector.

8.4.2.1. Energy audit and CO_2 emission measurement scheme for MSMEs and large-scale industries

- Voluntary energy audits and CO_2 emission measurements should be carried out at MSMEs and large-scale industries in Rajasthan with the help of certified personnel such as energy auditors/energy managers and/or third-party agencies.
- As part of the energy audit and CO_2 emission measurements (to be carried out every three years), the following should be measured: a) total production output, b) total yearly energy consumption, c) total yearly fuel/electricity consumption and d) total CO_2 emissions. For measurement of CO_2 emission from a particular industry, different sources of CO_2 emissions should be identified and measured.
- For successful implementation of the energy audit and CO_2 emission measurements, capacity-building activities need to be carried out at the industry level. These activities should not only emphasize the significance of the energy audit and the harmful effects of CO_2 emissions on the atmosphere (i.e., global warming and climate change) but also train industry personnel so that they may assist energy auditors/energy managers and/or third-party agencies in successfully carrying out measurements. This calls for coordination between Rajasthan's energy department, its environment department, the RSPCB, RIICO and BEE.
- The energy audit scheme can help quantify the energy currently being consumed by various large-scale and MSME industries and can eventually help in achieving energy savings through the identification of maximum energy consumption areas.
- The CO_2 emission measurement scheme can help in the quantification of CO_2 emissions from a particular industry and help them define targets for reduction through various technology/policy interventions.
- Industries successfully completing the energy audit can be awarded an "energy audit compliance certificate" and/or "CO_2 emission measurement compliance certificate," and their names should be highlighted on the website of RIICO and RSPCB.

- The implementation of this policy will help in building an actual energy consumption/GHG emission inventory for the industry sector in Rajasthan.

8.4.2.2. Small scale CO_2 emission reduction scheme through various technology interventions

- Voluntary efforts should be undertaken at large-scale industries and especially in MSMEs in Rajasthan to reduce CO_2 emissions directly or indirectly through the use of any of the following techniques:
    a) Reduction in fuel/material consumption by achieving a high degree of material circularity
    b) Use of lower embodied carbon materials wherever possible (e.g., use of timber-based products and partial replacement of cement with supplementary cementitious materials as an alternative to steel and concrete, which are two of the most carbon-intensive products)
    c) Improvement in process efficiency through optimization
    d) Use of advanced machinery/equipment
    e) Utilization of low/medium/high temperature waste heat within the process or for some other processes (waste heat recovery)
    f) Replacement of fossil fuels as heat source by electrification of various low-temperature processes, especially in various MSME sector industries
    g) Achieving low/zero carbon heat/electricity by partially/completely switching over to renewables-based energy and electricity generation
    h) Use of low/zero carbon fuel sources such as biomass, blue or green hydrogen, green ammonia, etc. as feedstock for various processes.
    i) Adoption of the principles of circular economy such as reduce, reuse and recycle.
- As part of the small-scale CO_2 emission reduction scheme, reduction in direct or indirect CO_2 emissions should be measured on a yearly basis by a third-party agency in order to assess the percentage reduction compared to the base value. Various CO_2 emission sources should be considered and quantified from a life-cycle perspective.
- For successful implementation of this scheme, capacity-building activities need to be conducted at industry level. These activities should emphasize the significance of reduction in CO_2 emissions for the state and the country as well as its impact on global

warming and/or climate change. They should also clarify the various techniques listed above and the requirements for their successful implementation. This calls for coordination between Rajasthan's energy department, environment department, RSPCB and RIICO.

- As part of this scheme, industries are required to commit to a target percentage reduction in their CO_2 emissions. Industries that overachieve their targets for CO_2 emission reduction through any of the techniques will be eligible for financial support through soft loans.

8.4.2.3. Industry-specific low carbon technology alternatives

For industries that struggle with reducing emissions and are responsible for a large share of CO_2 emissions such as cement, iron and steel, chemicals etc., some industry-specific technology alternatives for decarbonization are given below (Rissman J. et al (2020); Nurdiawati, A. and Urban, F. (2021))

- Cement industry
  - i. Use of mineral and chemical admixtures (substitution of clinker with other materials)
  - ii. Use of alternative fuels such as biomass, hydrogen etc.
  - iii. Electrification of cement kilns
  - iv. Waste heat recovery and
  - v. Improving process efficiency by optimization

- Iron and steel industry
  - i. Use of decarbonized electricity for the electric arc furnace (EAF) process for steelmaking
  - ii. Use of hydrogen as a fuel and reducing agent in the DRI-EAF (Direct Reduced Iron-Electric Arc Furnace) (HYBRIT) process
  - iii. Aqueous electrolysis (electrowinning) of iron ore
  - iv. Use of biochar as a fuel and reducing agent in the BF/BOF process
  - v. Increased use of scrap

- Chemical industry
    i. Use of decarbonized electricity in place of steam for the cracking process (breaking down of large hydrocarbons into smaller molecules)
    ii. Use of new and improved catalysts which could result in the reduction of input energy requirements for various chemical processes
    iii. Use of biomass instead of fossil fuels
    iv. Use of recycled materials such as plastics for production of various chemicals
    v. Use of less energy-intensive chemical separation processes such as membrane separation, sorbent separation, solvent extraction and crystallization in place of the traditional separation processes such as distillation, drying and evaporation.

Successful development and deployment of the above industry-specific technology measures require suitable policy and/or regulatory support, such as funding in the form of research grants or financial incentives or the possible introduction of emission standards. If these technology measures are developed and implemented in the existing industries, it would result in the decarbonization of the industry sector in the state of Rajasthan.

8.4.2.4. Large scale CO_2 emission reduction through carbon capture and utilization (CCU) scheme

- Considering the regulations likely to be introduced in the future to reduce CO_2 emissions, Rajasthan has the potential to become a leader in the development of carbon capture and utilization (CCU) technologies, especially for hard-to-abate industries such as cement, iron and steel and chemicals. There are various technology pathways for CO_2 capture such as post combustion and oxycombustion. CO_2 that is separated and captured can be utilized as feedstock to produce urea and other chemicals such as synthetic fuels.
- Voluntary and preliminary efforts should undertaken at large-scale industries to reduce CO_2 emissions, especially at cement industries, which are responsible for the largest share of CO_2 emissions in Rajasthan.
- Support from the government in the form of funding for academic, public, or private research; or for a public-private joint initiative; or for entrepreneurial development of innovative technologies is needed. Research, development and demonstration (RD&D)

of CCU technologies at a pilot scale initially will be followed by the development of large-scale demonstration units.

- In order to encourage industries to implement CCU technologies, financial incentives, such as capital subsidy equivalent to 25% of investment made on the plant for purchase of new equipment/machinery, could be made available. These industries should also be eligible for a 5% interest subsidy on term loans taken from financial institutions or banks recognized by the Reserve Bank of India for a period of five years. Industries can use this capital for making an investment in plant & machinery.
- To fast track the development of CCU technologies for the industry sector, regulatory measures such as carbon pricing could be introduced. This would support and motivate companies/industries that are coming forward to develop CCU technologies.
- Capacity building/awareness activities should be conducted to make the industry personnel and government officials understand the significance of technologies associated with CCU and the steps required for their implementation.
- Absolute CO_2 emissions before and after the implementation of CCU technologies should be measured and verified by a third-party agency every year, and the percentage reduction in CO_2 emissions should be quantified.
- Large-scale CO_2 emission reduction will help the state of Rajasthan accelerate its transition to a low carbon economy. In fact, the development and implementation of CCU technologies will also help India to achieve/overachieve its NDC targets.
- Industries that successfully implement CCU technologies to reduce CO_2 emissions should be awarded a "CO_2 emission reduction champion" certificate, and their names should be featured on the websites of RIICO and RSPCB. Companies with this certificate should be eligible to use it to market their products as green or as low carbon/zero carbon products, which in turn would help improve their brand image. These companies should also be recommended to the central government for official recognition.
- These industries should be invited to share their expertise with other industries in India and across the world through various conferences/workshops that can be organized by the Rajasthan state government. Doing so will help attract local and foreign investment to the state.

8.4.2.5. Large-scale CO_2 emission reduction through integrated CO_2 absorption mineralization-cum-regeneration of absorbent (IAMR) process

- In the integrated CO_2 absorption-waste mineralization-cum-regeneration of absorbent (IAMR) process, CO_2 from heavy industries like iron and steel, cement, coal power plants, etc., is captured using different solvents and the CO_2-rich solvent solution can be used to mineralize alkaline waste(s) (such as steel slag, cement kiln dust, fly ash, etc.), which are also generated from these industries (M Liu et al (2021)).

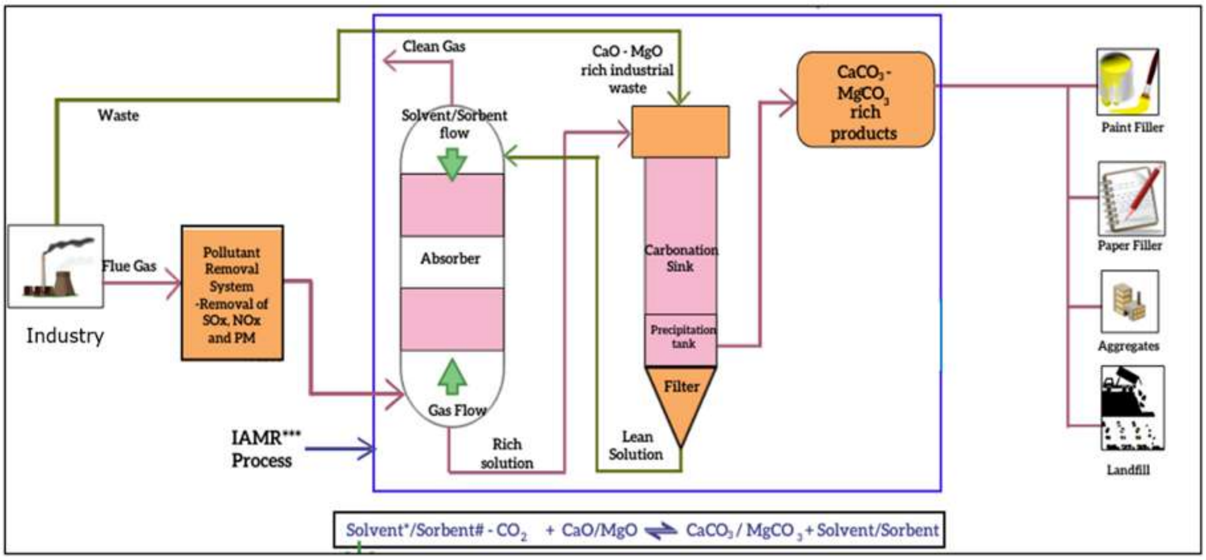

Figure 8.28. Schematic of the IAMR process.

- The IAMR process would ensure that the captured CO_2 is permanently sequestered in the form of stable mineral carbonates and hence areas with low/no CO_2 storage potential can also implement this process. The mineral carbonates produced can be used in multiple industries as alternative materials and thus would also help in indirect saving of CO_2 emissions.
- By employing the IAMR process, the twin issues of CO_2 emission reduction and waste management from industries (iron and steel, cement, etc.), which are major sources of CO_2 and alkaline wastes (steel slag, fly ash, etc.), can be addressed in an energy-efficient and cost-effective manner.
- The use of CO_2 capture solvents for mineralizing the alkaline waste(s) accelerates the process of carbon mineralization by increasing the concentration of dissolved carbonate species.
- Combining the carbon mineralization process with the regeneration of the solvent is also exothermically favorable and thus eliminates the need for high temperatures that are conventionally required for solvent regeneration.

8.4.3. Agricultural

To reduce present and future emissions from agricultural residue burning, several technological and non-technological options are available. Technological options include the use of crop residue as a biomass energy source to directly produce electricity or to convert to biogas, biochar or other biofuels. After harvesting, the crop residue can be immediately incorporated back into the soil, used for mulching and even used for composting. While farm machinery such as combine harvesters have not helped the stubble burning situation, other options such as seeders, shredders and balers may be more effective in handling crop residue. Hybrid seeds that produce little residue for the same amount of crop produce can also be used to mitigate the problem. Non-technological options include raising awareness about the ill-effects of burning residue, (e.g., they cause the soil to lose useful microorganisms and nutrients and contribute negatively to atmospheric warming and human health). Another solution could be to encourage mixed crop production that incentivizes farmers to switch to different crops that not only have more nutritional value but also result in monetary gains. Disincentives may also be levied by frequent monitoring (physically or via satellites) and imposing of fines on farmers that burn their residues on the field.

The reduction of emissions from enteric fermentation calls for improvements to the diet of the livestock (i.e., increasing the digestibility of forage and increasing digestible forage intake). These can be achieved by feeding livestock green fodder, adding feed concentrates, adding molasses urea product, etc. These methods may not be economically feasible to the herders – and consequently difficult to adopt – although they do increase productivity and hence abate additional costs. Improved feed – especially the addition of rumen-degradable protein – can also decrease emissions from manure management. Other techniques for emission reduction in manure management include optimizing fertilizer application, achieving more uniform distribution of urine in soil, and feeding forage harvested in the afternoon (with higher sugar content). Manure, when stored, should be aerated, stacked and preferably stored for shorter periods. Attempts should be made to use any excess dung in anaerobic digesters to produce renewable energy.

8.4.4. Waste Management

Mitigation of GHG emissions from waste management often comes with co-benefits in terms of pollution reduction, preservation of open spaces and maintenance of soil and water quality.

Waste management needs to be supported by policies, collaboration across departments and stakeholder engagement. Options for reducing the emissions from the waster sector are as follows:

1. Development and expansion of treatment facilities for domestic and industrial wastewater

   The emission profile of the waste sector as given in section 8.2.7 clearly shows that domestic wastewater is the main source of waste-related emissions in Rajasthan. Treatment of wastewater is an easy-to-achieve target for reducing emissions from waste. In fact, apart from reduction in emissions, treatment of wastewater can avoid serious health problems. Sewage treatment facilities should be capable of dealing with the generated sewage. As of June 2020, only 15% of the total sewage generated in Rajasthan was treated. The state has 114 sewage treatment plants (STPs) as of 2021 and is capable of treating only 25% of the total generation during rated conditions. Although 26 more STPs have been proposed, the number is still significantly lower than what is required.

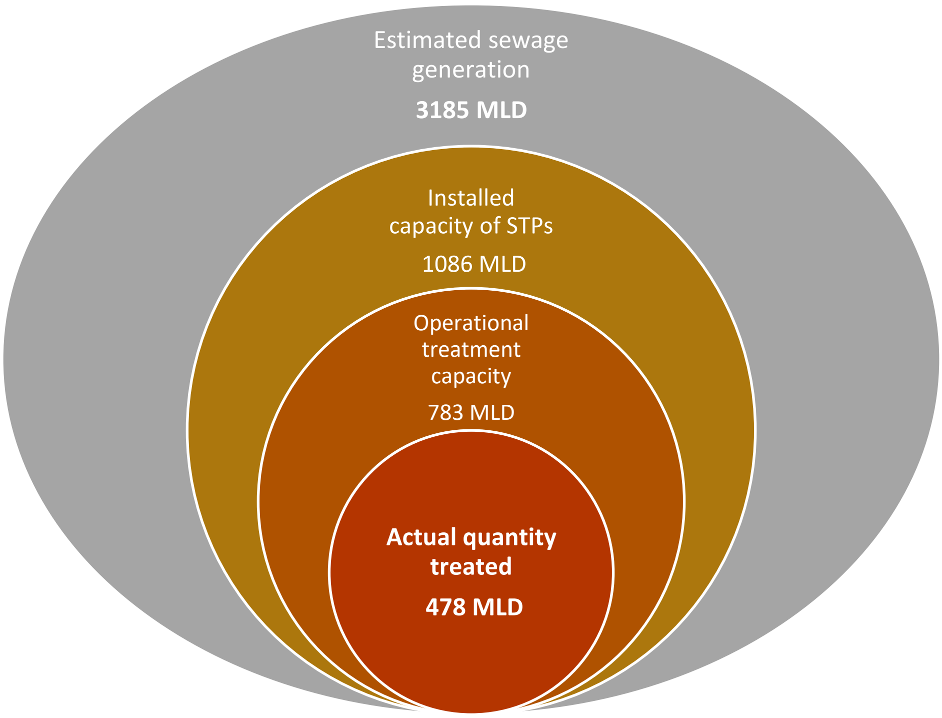

Figure 8.29. Stacked Venn diagram illustrating sewage generation, installed treatment capacity and actual sewage treatment for Rajasthan, as on 30.06.2020

Source: National Inventory of STPs (CPCB, 2021).

2. Development and expansion of treatment facilities for municipal solid waste

   Biodegradable waste fractions from homes, restaurants, garden waste, and sewage sludge can be used for anaerobic digestion and composting. Anaerobic digestion produces biogas, which is a form of secondary energy. Compost has several applications in horticulture, agriculture and in soil stabilization and improvement.

3. Utilization of waste to exploit its energy content.

   This can be done through waste-to-energy incinerators and gasifiers.

4. Reducing methane emissions from landfills

   Methane is one the major GHG released from waste, particularly from landfills. Reduction in methane emission can be achieved in two ways:

   i. Landfill gas recovery systems. The technology is already in place, and many cities in various countries have already adopted the technology.

   ii. Reduction in the quantity of biodegradable waste to be landfilled.

5. Waste prevention, reduction, re-use and recovery

   Recycling reduces GHG emissions by lowering the demand for energy production (avoided fossil fuel) and by substituting virgin materials with recycled feedstocks. (AR4, IPCC). Waste can also be reduced through material efficiency.

   - Through landfill taxes and extended producer responsibility (EPR), producers should be held accountable for the waste they create and have opportunities to minimize unwanted plastic waste.
   - Reuse and recovery of waste can be easier when the waste is segregated at source. Segregation of waste especially from domestic, commercial and industrial sectors needs to be mandated. This can be supported through subsidies and awareness programmes.
   - Financial incentives can be used to encourage private players in the waste recycling market.
   - Remediation of legacy waste and economic management of recyclables to promote circular economy

6. Regulations against open burning of municipal waste

Open burning of waste is a source of GHG emissions and extremely harmful pollutants. The management strategies for solid waste are detailed in the Rajasthan State Solid Waste Management Policy and Strategy, 2019 and SWM Rules, 2016. (CPHEEO, 2015). They include

- Stringent regulations and penalties and facilitating easy door-to-door collection of waste.
- Regular check and control of burning of municipal solid waste

7. Control of air pollution from construction and demolition activities
    - Construction and demolition waste rules should be enforced.
    - Control measures should be implemented for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and dust suppression units.
    - Transportation of construction material and debris should be in covered vessels.
    - Construction sites should be covered, and restrictions should be imposed on storage of construction materials along the road.

8. Re-suspension of road dust and other fugitive emission control
    - A plan for green buffers along the traffic corridors should be prepared.
    - Roads should be free of potholes in order to allow free flow of traffic.
    - Efforts should be made towards greening of open areas, gardens, community places, schools and housing societies

9. Decentralization of waste management
    - Empowering local governments, municipal corporations and residential communities at the ward or village level to manage their waste at a local level is a step in this direction.

10. Creating an infrastructure for sustainable waste management

    While certain interventions can bring results in the short term, sustainable waste management for the future demands systemic changes such as

    - Inclusion of waste management as part of the school curriculum

- Organizing public awareness programmes related to waste segregation and promoting behaviour change for strengthening waste management
- Stakeholder engagement with local bodies, civil society organisations, non-government organisations (NGOs), self-help groups (SHGs), panchayats, etc.
- Clear definition of roles and responsibilities of various stakeholders in an operating framework
- Recognizing the informal players in the sector, formalizing their positions where needed and engaging in fair-wage practices.
- Encouraging CSR initiatives in waste management in the state.

8.4.5. Green Tourism

Sustainable tourism is defined as "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities" (UN WTO). Sustainable tourism should meet the requirements of the present tourists as well as preserve the integrity of the site for future tourists in terms of heritage, ecology, biology and life-support. Issues associated with tourism include GHG emissions (especially from transport), excessive water consumption, inappropriate waste management, loss of biodiversity, impact to local heritage and lack of awareness (Pan et al. 2018).

Green Tourism can translate into various sectoral implementations, especially for the reduction of emissions. Energy consumption and transport requirements of tourists can be addressed by employing renewables, like solar power, at tourist attractions and at various hotels and restaurants. Similarly, an integrated public transport network with metros, railways, bus and other modes for various destinations could provide tourists with green options for commuting. Integrated transport networks have been demonstrated to reduce CO_2 emissions (Manan et al. 2017). These alternatives call for top-down implementation from the government.

Management information systems can be used to promote eco-tourism, eco-branding, environmental-friendly local products, local foods, agri-based products and training programmes for new strategies to be implemented. Surveys and feedback can be gathered at notable tourist spots about the newly introduced products and tourism experiences for further evaluations. Such an intervention requires a mixed approach, with inclusive participation from the government and local authorities. The framework has been presented in the Fig. 8.30 below.

It is important to mention that in the current pandemic situation, the most environmentally friendly option will be virtual tourism. Committed efforts are needed from the tourism department of Rajasthan to offer such experiences to tourists.

8.4.6. Renewable Energy Initiatives

To harness renewable energy sources, the Rajasthan government is encouraging generation from non-conventional sources like solar, wind, and biomass. Rajasthan is among the states with high renewable energy potential – an estimated 142 GW from solar and 18.7 GW from wind. In view of this high potential, MNRE has assigned a combined target of 14.3 GW for solar and wind capacity for the state by 2022. Under the Rajasthan Solar Energy Policy 2019, the state envisions the development of a 30 GW solar project by 2024-25. The Wind and Hybrid Energy Policy, 2019, aims to achieve 2000 MW capacity by 2024-25.

As of September 2020, solar power plants with a capacity of 4996.96 MW had been commissioned in the state. By the same period, the installed wind power capacity in Rajasthan was 4,337.64 MW. The total potential of wind power in the state is about 18,770 MW (at 100 M hub height). By September 2020, Rajasthan also had 13 biomass power generation plants with a total capacity of 120.45 MW. Three power plants with a total capacity of 18.8 MW capacity are currently being installed. The main source for biomass energy in Rajasthan is mustard husk and *Prosopis Juliflora*.

Table 8.16. Total installed capacity of renewable energy power stations in Rajasthan

Sr. No.	Source of energy	Total installed capacity (MW)
1.	Solar energy (ground mounted)	4996.96
2.	Wind energy	4337.64

3.	Biomass energy	120.45
4.	Solar rooftop under net metering scheme	356.80
	Total	9811.85

(Source: RRECL (up to Sept. 2020))

Rajasthan has an installed renewable energy capacity of 9811.85 MW. DISCOMs are making considerable efforts to meet their renewable purchase obligations (RPO) targets. Over the years, the RPO targets have grown from 6% to 17.5%, as shown in Table 8.17.

Table 8.17. Defined minimum quantum of purchase (in %) from renewable energy source (in terms of energy equivalent in KWh) of total consumption

Year	Solar	Wind	Biomass	Total RPO
2011-12	0.5	4.5	1.0	6
2012-13	0.75	5.1	1.25	7.1
2013-14	1.0	5.7	1.5	8.2
2014-15	1.5	6.8	0.7	9
2015-16	2.0	7.3	0.9	10.2
2016-17	2.5	7.8	1.1	11.4
2017-18	4.75	8.2	1.3	14.25
2018-19	6.75	8.75	1.5	17
2019-20	7.0	9.0	1.5	17.5

(Source: RRECL)

The MNRE has also approved 6 solar parks with a total capacity of 5410 MW for Rajasthan under the “Scheme for development of solar parks and ultra-mega solar power projects”. Rajasthan Solarpark Development Company Limited (RSDCL) has been established as a special purpose vehicle (SPV) in the form of a subsidiary company of RRECL for the development of infrastructure and management of solar park. RSDCL formulates guidelines for the allotment of land and sharing of development cost by solar power producers.

Table 8.18. Installation capacity and implementing agencies of solar parks

Solar park	**Capacity (MW)**	**Implementing agencies**
Bhadla Solar Park Phase-II, Jodhpur	680	Rajasthan Solar Park Development Company Limited (A subsidiary of RRECL)
Bhadla Phase-III, Jodhpur	1000	GOR JVC M/s Saurya Urja Company of Rajasthan Limited
Bhadla Phase-IV, Jodhpur	500	GOR JVC M/s Adani Renewable Energy Park Rajasthan Limited
Phalodi, Jodhpur & Pokhran, Jaisalmer	750	GOR JVC M/s Essel Saurya Urja Company of Rajasthan Limited
Dawada and Rasla, Fatehgarh, Phase-IB, Jaisalmer	1500	GOR JVC M/s Adani Renewable Energy Park Rajasthan Limited
Nokh Solar Park, Bikaner	980	Rajasthan Solar Park Development Company Limited (RSDCL)
Total Capacity	5410	

(Source: RRECL)

8.5. Future Scenarios

The section will focus on emission projections and the mitigation potential in the future, taking into account the policies suggested for each sector above.

8.5.1. Thermal Power Plants

The total power demand from Rajasthan stood at 67805 GWh in 2019. The electricity demand is projected to grow to 125 TWh by 2030 with a CAGR of 4.5%. Further, the state has a renewable energy target of 30 GW from solar projects and 2 GW from new wind hybrid projects by 2025 in line with state renewable energy policies. Capacity expansion of solar plants to 35 GW and wind hybrid plants to 6 GW by 2030 could lead to carbon abatement of at least 65 million tonnes (in line with grid emission factor) (CEA, 2021). This expansion raises the total renewable energy capacity to 44 GW by 2030. In this scenario, the renewable electricity share in the mix will increase to 44% by 2030. In addition, the state will also have 2295 MW capacity of grandfathered coal thermal power plants in 2030. These power plants currently have emission factors in the range of 1.02 – 1.06 t CO_2/MWh and can be decommissioned in phases to mitigate emissions.

8.5.2. Industry

The industry sector as a whole is responsible for a large share of the CO_2 emission burden in Rajasthan. Fig. 8.9 shows the CO_2-eq. emissions of different industries from 2005-06 to 2015-16, and Table 8.16 shows the CO_2-eq. emissions of different industries, the overall CO_2-eq. emissions for the years 2005-06, 2011-12 and 2015-16, and the CAGR of CO_2-eq. emissions in 2015-16 compared to the base year (2005-06). Except the non-ferrous metals industry, all the other industries have shown an increasing trend in the CO_2-eq. emissions.

(**a) BAU scenario:** Given the CAGR values in Table 8.16, if we assume business as usual (BAU) scenario (i.e., without any emission reduction measures), the CO_2-eq. emissions of the industry sector will increase further, and the CAGR in the year 2029-30 will be 10.4% as against the CAGR of 8.8% in 2015-16. The CO_2-eq. emission profile for the BAU scenario can be seen in Fig. 8.31.

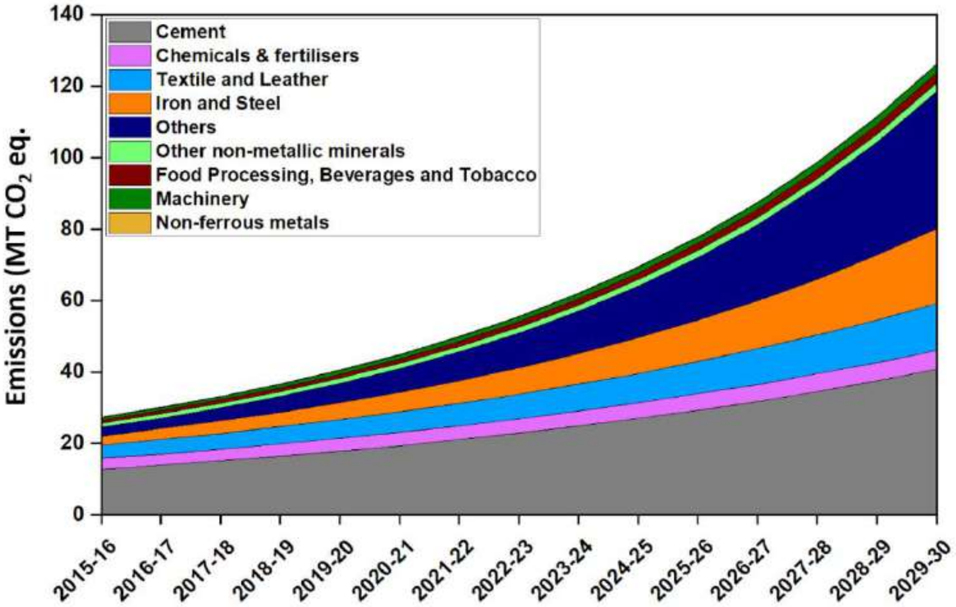

Figure 8.30. Projection of CO_2-eq. emissions for different industries in Rajasthan under the BAU scenario.

(b) Emission reduction scenario: If a target of 10% reduction in overall CO_2-eq. emissions is to be achieved within the industry sector every year from 2023-24, then various measures such as energy efficiency, fuel switching, electrification, etc. would need to be implemented in different industries. Despite these measures, the CO_2-eq. emissions from different industries will show an increasing trend, but the rate of increase would be lower than that in the BAU scenario. In this emission reduction scenario, the total CO_2-eq. emissions in the year 2029-30 will show a CAGR of 9.9% compared to 10.4% under the BAU scenario and the observed 8.8% in 2015-16.

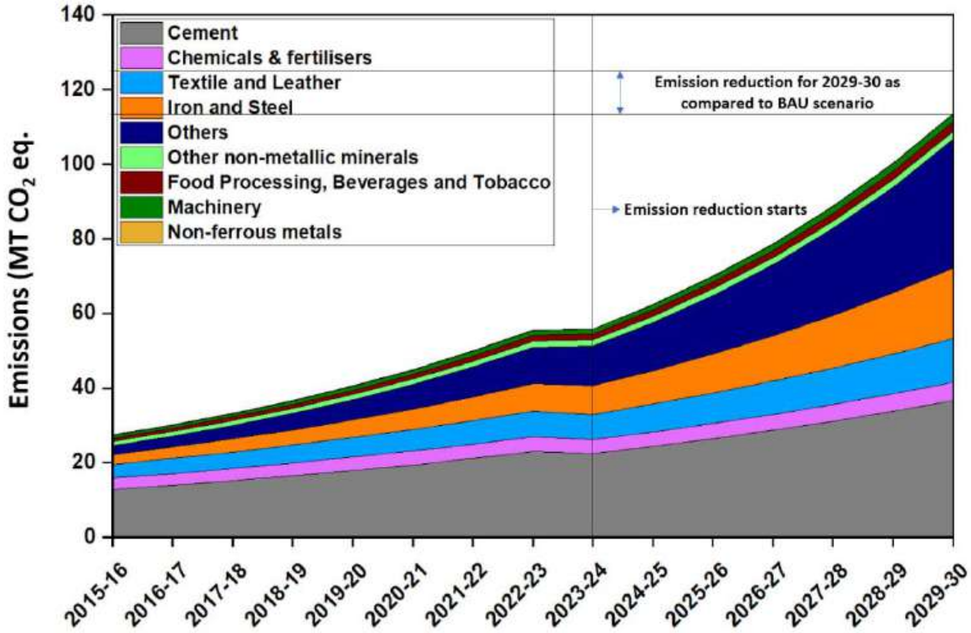

Figure 8.31. Projection of CO_2-eq. emissions for different industries in Rajasthan under the emission reduction scenario.

If successfully implemented, the emission reduction scenario for Rajasthan's industry sector can make a significant contribution to India's goal of reducing 1 billion tonnes of CO_2 emissions by 2030. For large-scale CO_2 emission reduction (decarbonization) in Rajasthan's industry sector, in line with India's goal of net zero emissions by 2070, all technology interventions such as CCU, use of renewable energy, use of low/zero carbon fuels, electrification, etc. should go hand in hand, and this calls for considerable support from the government in the form of various policy and/or regulatory measures.

8.5.3. Brick Production

Due to their polluting nature, FCBTKs have been encouraged to shift to cleaner technologies such as zigzag-fired kilns (MoEFCC, 2018). While the basic set-up of the kiln is the same, the difference lies in the zigzag movement of the hot air within the combustion zone, unlike the straight path in FCBTK (Yadav & Kumar, 2017). The zigzag movement causes the hot air to travel more, thus allowing more time for effective heat utilization of the hot air and making the process more energy efficient. Moreover, this yields better quality bricks due to better burning. However, a survey of two districts in Rajasthan (Bharatpur and Alwar) that fall in the NCR region showed that the transition to zigzag kilns is not easy. Of around 252 kilns in the NCR districts of Rajasthan, only about 14-17% have made the transition. While the lack of skilled or trained labour to carry out the zigzag firing is the chief hurdle, financial unaffordability and lack of awareness also contribute to slower shifts towards cleaner technologies.

Besides the shift to zigzag-fired kilns, other mitigation interventions available are shifts to VSBKs and production of resource-efficient bricks or shifting to non-fired bricks, as listed previously. With the rising population and government schemes on upgrading infrastructure, the demand for bricks is expected to increase at an annual compounded rate of 6% (Bhushan et al., 2016). We present the impact growing demand on the year 2030 under three different scenarios with varying technology shifts. The scenarios are (1) business as usual (BAU), which assumes a similar technology fraction i.e., FCBTKs and clamps; (2) the 50% scenario, which assumes that nearly half the state production is met by cleaner technology, i.e., zigzag and VSBKs; and (3) the 100% scenario, which assumes a complete shift from FCBTKs and clamps to a mix of zigzag (70%), VSBK (20%) and non-fired bricks (10%). It is estimated that if the shift from current technology mix does not occur, GHGs emissions can rise by ~2 times (up to 10.3 MT CO_2-eq./y) in 2030 from present day. On the other hand, a 50% shift to cleaner technologies will lead to emissions that ~1.7 times higher (up to 13.2 MT CO_2-eq./y) while a 100% shift will limit the increase in emissions in 2030 to 30% of the present-day levels.

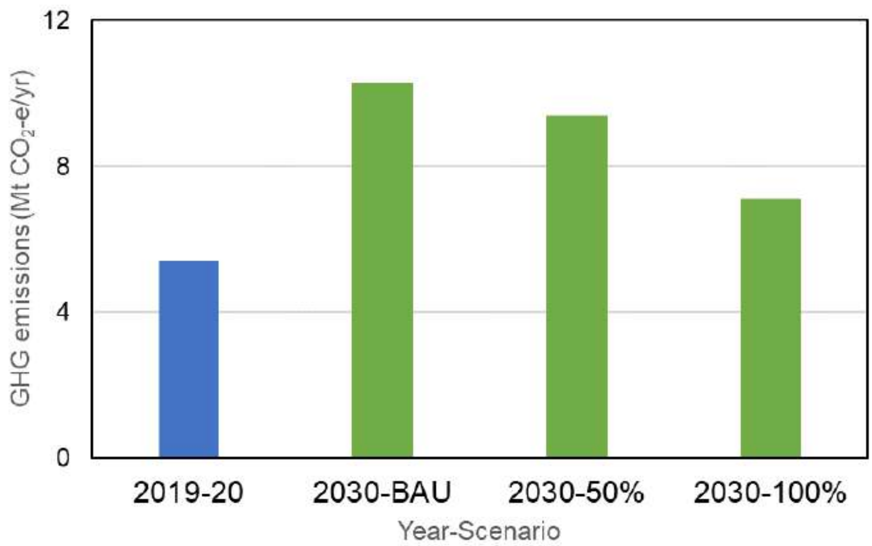

Figure 8.32. Future scenarios of GHGs (CO_2, CH_4 and N_2O) from the brick sector.

8.5.4. Transportation

Quantification of vehicular emissions from a reference year (2016) served as our benchmark for estimating future emission scenarios. Important policies have been introduced in Indian states that on implementation can lead to potential emission reduction from on-road vehicles. In the current analysis, mitigation potentials of different transport measures have been examined for the year 2030. For future emission analysis, the fleet as on 2019-20 (referred to as 2020) has been projected until 2030-31 (referred to as 2030) using a linear regression model with per capita state GDP. The GDP values for the projection analysis were obtained from CMIE (2020). The growth rate of the state GDP has been assumed on the basis of data from CEEW (Paladugula et al., 2018) until 2030: GDP growth rate is 7.6% in 2020, 7.4% in 2025, and 7.2% in 2030. The projected population values for Rajasthan were taken from the population projection report by Census of India (2019). Two-wheelers have been projected separately from the rest of the fleet vehicles because of their high growth rate. The projected fleet (total vehicle stock) shows a CAGR of 5% in 2030 from the reference year (2016).

Impacts of different transport sector interventions on GHGs (CO_2, N_2O, and CH_4) in Rajasthan are evaluated and estimated for 2030 under the following scenarios: BAU and three low-carbon scenarios of improve, scrap, and shift. BAU assumes that no new policies are introduced. The improve scenario considers retrofit measures such as a 30% improvement in emission standards and fuel efficiencies of vehicles and a 10% increase in CNG-fuelled vehicles by 2030. The scrap scenario assumes that vehicles older than 10 years will be removed from the fleet, which will account for 16% of the vehicles in 2030. Given India's incentive-based scrappage policy, emission reduction achieved from scrapping of old vehicles is analysed. The third – shift scenario – assumes a shift in passenger travel demand from private transport to mass transits and electric vehicles. Specifically, it assumes a 30% shift from two-wheelers and a 20% shift from cars. Results of all the four scenarios are shown in Fig. 8.34. GHG emissions under BAU (2030) are estimated to touch 27.22 MT CO_2-eq/y. The most significant scenario in terms of emission reduction is the improve scenario, which achieves a 22% reduction (21.32 MT CO_2-eq./y), followed by the scrap scenario which shows a 18% reduction (22.24 MT CO_2-eq./y) and, finally, the shift scenario which achieves a 12% reduction (23.95 MT CO_2 eq./y) compared to the BAU projection.

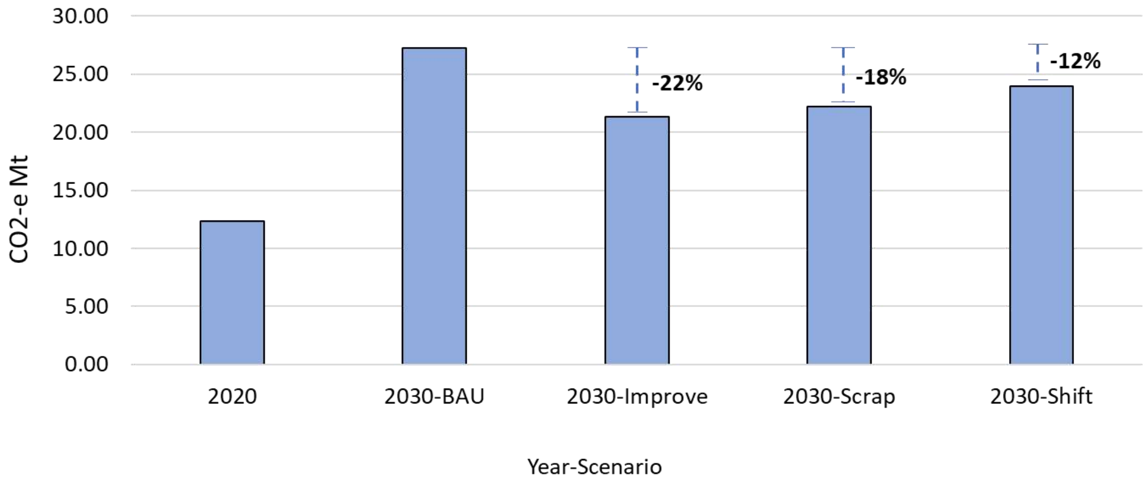

Figure 8.33. Projected GHGs emissions in 2030 (CO_2, CH_4 and N_2O) from the road transport sector of Rajasthan.

8.5.5. Residential

Ensuring access to clean energy is one of the sustainable development goals. It not only brings climate and air quality benefits by reducing emissions through shifts to cleaner technologies, but also improves the livelihoods of the rural population, especially women. By shifting away from traditional cookstoves, women can save time spent in collecting fuel wood or crop residue and in cooking, as food tends to get cooked slowly on traditional stoves. Through a few major central schemes, such as Pradhan Mantri Ujjwalla Yojana (subsidized LPG cylinders) Saubhagya Scheme (24x7 electrification of rural households), and Ujala Scheme (promotion of efficient lighting systems), the government is keen on improving access to clean energy within the country. With this in mind, we estimate GHG emissions for 2030 under three scenarios representing varying levels of clean energy penetration in the residential sector. The BAU scenario assumes the prevailing level of clean energy penetration among households, the "50% scenario" assumes partial success in the influx of clean energy, and the "100% scenario" assumes complete replacement of traditional technologies. For cooking, the shifts include transition to LPG cookstoves, biogas-based cookstoves, electrical induction cookers or solar cookers. For lighting, the low-emission alternatives considered are electrical and solar lighting systems. Similarly for space heating, we assume shifts from wood-burning to electric/solar powered heating devices. The estimates reveal that with no further shifts to cleaner energy systems (i.e., BAU scenario), GHGs emissions can increase by ~11% in 2030. If 50% of the presently deprived households shift to clear energy, GHG emissions will increase by ~6%. Finally, with all the households accessing cleaner fuels, the emissions can be maintained at present-day levels. It is important to note that, compared to other sectors, the mitigation measures assumed here (i.e., shifts to LPG fuel, which is a dominant source of emissions in the residential sector) emit larger CO_2 per unit amount of fuel consumed compared to traditional fuels. However, despite that we did not see a significant increase in emissions as these alternatives are more energy efficient; they consume less fuel for the same energy demand. Moreover, shifting towards LPG is of great significance with regard to indoor air quality and societal benefits.

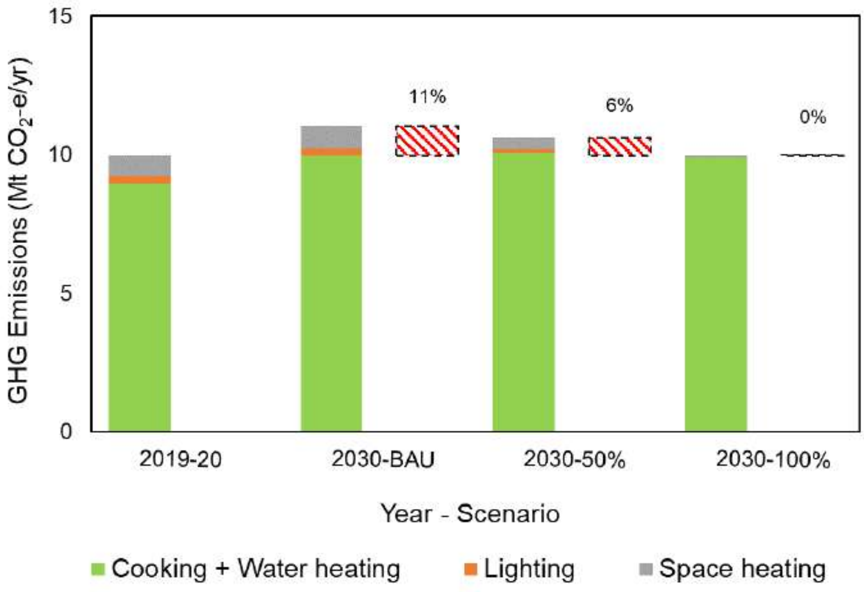

Figure 8.34. Future scenarios of GHG emissions (CO_2, CH_4 and N_2O) from the residential sector.

8.5.6. Agricultural

Research predicts an annual increase of 1.5% in crop production, 1.7% in fertilizer consumption, and 1.5% in livestock numbers until 2030 (Alexandratos & Bruinsma, 2012). With these estimates and assuming no other control measures are imposed, emissions in 2030 under the BAU scenario are as follows: 3.6 MT CO_2-eq. from crop residue burning, 33 MT CO_2-eq. from livestock enteric fermentation, 3.2 MT CO_2-eq. from livestock manure management and 7.2 MT CO_2-eq. from soil emissions. We also estimate emissions under two reduction-based scenarios: 50% adoption of reduction measures and 100% adoption of reduction measures in all sub-sectors. For crop residue burning, this means a complete stop in residue burning. Some other easy-to-achieve targets include subsidised sale and deployment of shredders or balers to facilitate easier management of crop residue. Also, small industries may be set up to utilize the excess residue, which can help provide employment in rural areas in addition to economic benefits. Some farmers wrongly believe that the burning of crop residue is beneficial to the soil. This calls for capacity building and dissemination of knowledge about the harmful effects of burning among farmers. This measure will need to be fulfilled to achieve the second (100%) scenario. In the livestock sector, emission reduction will involve the introduction of concentrates in the livestock feed. Additionally, improved application of manure and synthetic fertilizers has the potential to reduce emissions from soil. Reduction potentials for livestock and soil are based on the study by Sapkota et al. (2019). Figure 8.36 shows calculated emissions for each sub-sector in 2019 and projected emissions in 2030 under the BAU and mitigation scenarios. Understandably, emissions from crop residue burning drop to half and then to zero under the 50% and 100% scenario, respectively. Emissions from livestock reduce to 34.14 (32.06) MT CO_2-eq./y under 50% (100%) adoption rates, whereas those from improved fertilizer and manure application reduce to 5.66 (4.12) MT CO_2-eq./y with 50% (100%) adoption rates.

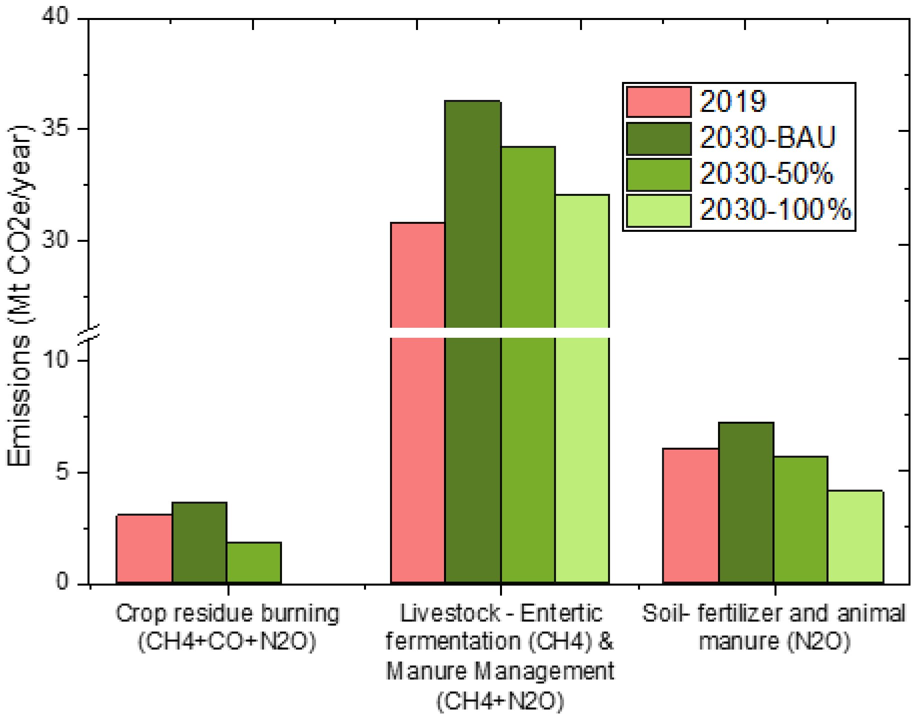

Figure 8.35. Emissions from the agricultural sector in the present day and under three future scenarios.

8.5.7. Waste Management

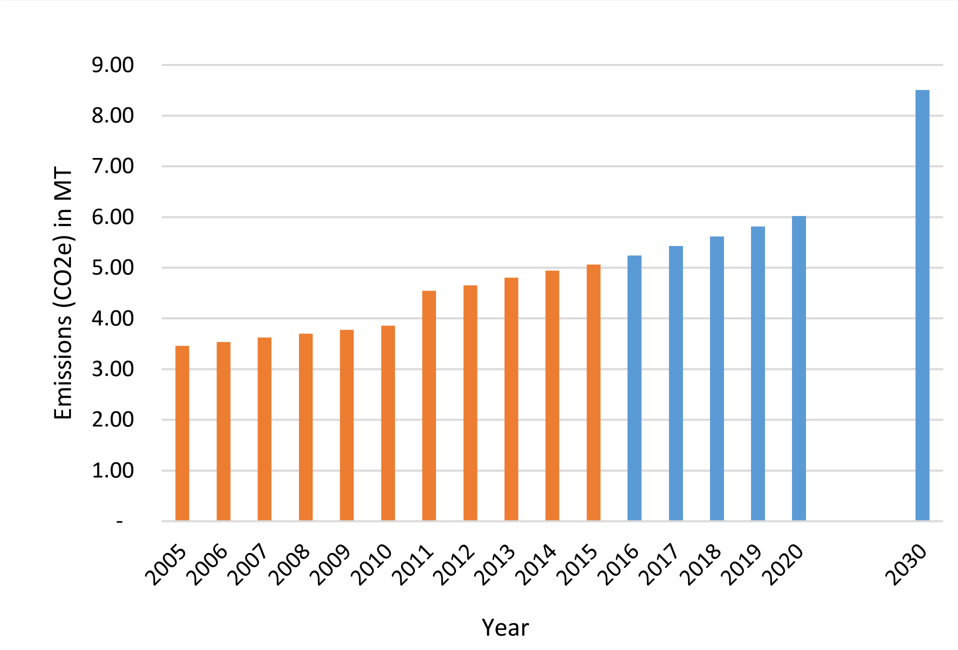

Figure 8.36. Estimation of cumulative GHG emissions from the waste sector using data from 2005-2015.

From the growth in emissions between 2005 and 2015, the CAGR was calculated to be 3.52%. The total waste increased from 5.06 MT in 2015 to 6.02 MT in 2020, and it is likely to reach 8.51 MT in 2030. By the end of this decade, the emissions from waste are estimated to increase by 40%.

Apart from the mitigation opportunities specified in the previous section, waste management also plays a role in climate adaptation and resilience building against climate change in the future. Accordingly, the following measures should also be considered:

- Training sessions for disaster response teams should be organized to tackle hazardous or non-hazardous disaster debris in case of extreme climatic events such as floods.
- Overfilling of landfills should be prevented to avoid catastrophic landslides and resource contamination during extreme climatic events such as rainfall or floods.
- Waste collection facilities must be examined for their resilience under new weather patterns of the future.

- Regular cleaning and maintenance of drainage and sewer systems will prevent water logging during floods.

To minimize emissions from the waste sector, emphasis should be placed on creating infrastructure for waste treatment facilities. These investments will reap multiple benefits in terms of pollution reduction, health benefits and beautification of community spaces. Sustainable waste management also promotes circularity in the supply chain system and hence should be aggressively targeted. A systemic change in the society regarding waste management calls for decentralization of infrastructure, massive public awareness campaigns and stakeholder engagement. Sustainable waste management practices play a crucial role in the mitigation of emissions and the preservation of resources and should be one of the priority areas to consider.

8.5.8. Tourism

Based on the current growth rates, domestic tourist footfall in Rajasthan will increase from 430 lakh in 2018 to 1 crore in 2030 (CAGR of 7%). On the other hand, international tourists will increase from 16 lakh to 24.8 lakh in 2030 (CAGR of 3%). Increase in the associated activities is also bound to follow, finally leading to a rise in the overall contribution to emissions. This is why have discussed a green tourism framework in section 8.4.5.

8.6. Summary

The present chapter has identified eight sectors of importance in terms of emissions in Rajasthan. Power is one of the highest CO_2 emitters in India; however, in Rajasthan, sectors like industrial production, agriculture and tourism are equally important. In 2019-20 (the base year), the highest CO_2-eq. emissions came from power generation (40 MT CO_2-eq./y) and the agricultural sector (40 MT CO_2-eq./y), followed by industrial production (27 MT/year), transport (10 MT CO_2-eq./y) and the residential (10 MT/year) sectors. Rajasthan is estimated to contribute a total of 137 MT CO_2-eq./y with significantly increasing trends. By 2030, emissions from brick manufacturing are expected to more than double with the present technology mix; in the transport sector, they will increase by 2.7 times; in the residential sector, it is likely to grow by 20%; and in the agricultural sector, it will increase by 18%. Overall, emissions are expected to increase by approximately 1.7 times the present value in 2030 under the BAU scenario. The interventions proposed in this report may be able to maintain emissions at the present level. Moreover, various existing schemes and projects are discussed to guide the future mitigation strategies for Rajasthan.

Chapter 9

Monitoring and Evaluation

9.1. Introduction

Monitoring and evaluation play a critical role in an action plan's success as policies should be in coherence with the ever-changing nature of an inherently dynamic society. One of the main challenges with framing a climate policy for the future is the uncertainty related to climate-related changes. Therefore, it is essential to ensure a systematic learning process that works parallel to the implementation of the policies.

Monitoring is the ongoing, systematic collection and analysis of data as a project progresses. It is aimed at measuring progress towards the achievement of programme objectives. **Evaluation** is a process that determines whether a programme has met the expected objectives and the extent to which changes in outcomes can be attributed to the programme. Through monitoring and evaluation (M&E), policy makers can assess the gaps between the current conditions and the desired conditions.

Why monitoring and evaluation are an integral part of a climate action plan?

- *To track progress and measure effectiveness*
- *Ensure policies progress with the demands of the society*
- *Ensure plans can be normalized with shifting baseline*
- *Easier to link the policies with their outcomes and long-term impacts*
- *Effective allocation of resources*
- *Lay foundation for better decision-making process in the future*

The M&E framework suggested in this chapter is essential for tracking the progress made on implementing the Rajasthan State Action Plan on Climate Change (RSAPCC). This assessment can help understand and improve the policy's effectiveness and generate evidence and lessons for future policy development.

The framework presented acts as a guide on how data should be collected, managed, analysed and reported. It provides indicators for each action point that are recommended by various sectors and interlinks with India's Nationally Determined Contributions (NDCs) and the UN Sustainable Development Goals (SDGs). The framework can facilitate decision-making with regard to the state of progress, additional funding requirements and future course of action.

9.2. Components of Monitoring and Evaluation

A monitoring and evaluation framework facilitates the mapping of policy contributions and outcomes. This process can become easier once the systems to be monitored are clearly defined and their interlinkages with other systems are established. The components of monitoring and evaluation are as follows:

A. Activity to be monitored: This refers to the specific project/policy/plan/scheme that has been launched and whose progress needs to be measured using monitoring and evaluation.

B. Indicators: An indicator is a quantitative or qualitative metric that provides information to monitor performance, measure achievement and determine accountability of a project. Indicators are essential for effective monitoring and evaluation as they help in understanding the effectiveness of the plan. The key to selecting indicators is to ensure that they are specific, measurable, attainable, relevant and time-bound (SMART). (Naswa et al., 2015). For monitoring and evaluation of the RSAPCC, the indicators are grouped into two categories on the basis of the tasks involved: processes and outputs.

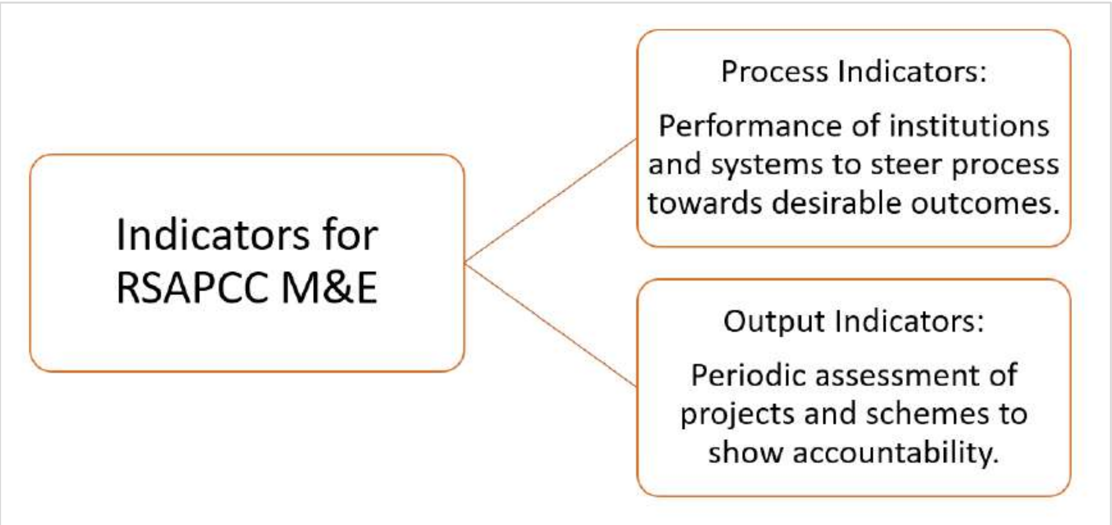

Figure 9.1. Process and output indicators for monitoring and evaluation

- Process-based indicators

Process indicators monitor the administrative, institutional and governance processes that are needed to ensure a robust system of implementation. Good governance plays a very crucial role in climate action and can ensure that all sectors remain transparent, participatory, and accountable.

- Output-based indicators

Output-based indicators keep track of the implementation of policies. These indicators reflect the immediate results of the programme activities, such as the percentage of completed programmes or the number of households impacted. Output indicators help monitor whether the actions taken are as per the plan, but they do not give an idea of the effect of those actions.

C. Baseline

It refers to the value of the indicator before the action plan is implemented. It can be considered as the *before* scenario, and the state of the project after its implementation constitutes the *after* scenario. The baseline for evaluation may change with time. Hence, monitoring different climate variables is crucial to allow climate action plans and actions to be normalized against a shifting baseline.

D. Target

It is the objective that the particular action plan/scheme is working towards. Along with its objective, an action plan may also be linked to some national and international goals. In the suggested framework, different SDGs and NDC targets submitted by India to the Paris Agreement are linked.

E. Periodicity of assessment

This refers to the frequency of collection and assessment of data needed for evaluation. For the M&E of the Rajasthan SAPCC, we recommend that assessments be conducted at least annually and be included in the annual reports of the concerned department.

F. Expected outcome

These are the longer-range cumulative effect results that will analyse the effectiveness and impact of the action plan. It is worthwhile to note that M&E is an extended process, and some results may take time to show. In such a case, the expected outcome gives an indication of the overall aim of the project. The impact of the state action plan could be assessed in terms of climate change resilience, reduction in emissions, the state targets achieved or the overall impact on national targets.

9.3. Institutional Mechanism

The Department of Environment and Climate Change (DECC) in collaboration with the Directorate of Economics and Statistics is proposed to be the nodal agency responsible for the monitoring and evaluating the state climate action plan. The progress-reporting of the action plan can be incorporated into their annual reports. The DECC should coordinate with the line departments as different sectors involved in making this action plan, and the sector-specific recommendations will be implemented by line departments (as given in section 9.4). The responsible line department will have to report the activity in their annual reports from where DECC will collate the data for a comprehensive reporting of the progress on the climate action plan.

Local governments have a unique opportunity to engage the relevant stakeholders – civil society and businesses – and thus expand the scope of what the action plan can accomplish. Identifying the multiple stakeholders responsible for carrying out the M&E at different scales is also very important. While some aggregate tracking will be done on the state level, local governments and civil society play a vital role in the constant improvement of adaptation strategies. It is only by engaging with these actors, and even by accompanying them through the transition, that DECC can motivate long-lasting behavioural change towards sustainability and climate justice.

Effective implementation of climate action strategies is only possible if a clear commitment exists in the state, and the institutions are capable. To build strong and capable institutions to deal with climate change in the state, the following points can be assessed.

Table 9.1. General metrics to assess institutional capacity at the state level

S. No.	Assessment Method
1.	Does a clear state-level roadmap for climate action exist?
2.	Is there sufficient intellectual and technological foundation to support the work? Number of personnel employed in the department with expertise in climate change.
3.	Allocation for climate action in the state budget Total annual and cumulative spending on climate action schemes
4.	Decentralization of action plan Number of cities with individual action plans Number of grassroot organizations/NGOs working in the climate change sector District-wise number of trained personnel in disaster management
5.	Knowledge building and sharing Publishing annual climate action report Platform for inter-departmental sharing of climate-related data
6.	Academic institutions Collaboration with academic institutions within the state for R&D on climate action Number of reports/ scientific studies published on climate change/action in Rajasthan from state-funded universities.

9.4. Sector-wise Recommendations and Indicators for M&E

The different sectors contributing to this action plan have shared sector-specific recommendations that will be taken care of by various line departments. This section looks into the indicators that can be used to assess the recommended actions and the line departments that are responsible for their implementation. The indicator lists are not exhaustive, and the concerned department may choose to take up an alternate indicator as long as it is specific, measurable and practical. The line departments are also suggestive, and other line departments can implement the action if it comes under their scope.

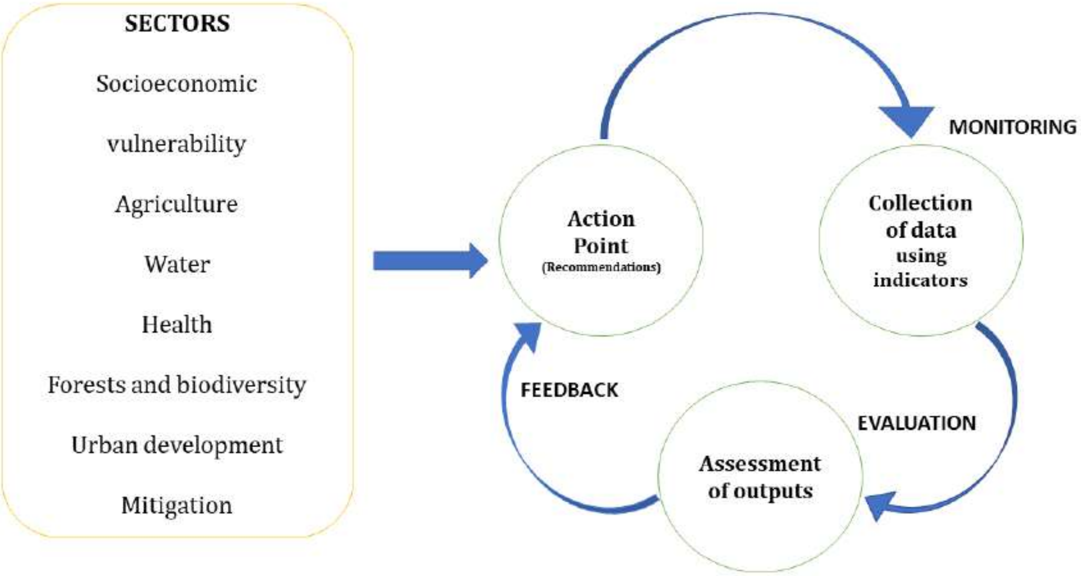

Figure 9.2. Illustration of the monitoring and evaluation process.

9.4.1 Health

Line department for the health sector: Department of Medical, Health and Family Welfare, Government of Rajasthan (GoR)

Table 9.2. Health sector – action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Improved monitoring and surveillance for climate-sensitive diseases to improve response time and capacity	Process Indicators: • Development of an integrated surveillance and monitoring system for climate-sensitive diseases (like malaria monitoring information system) • Development and deployment of early warning and real-time-response systems Output Indicators: • Sentinel surveillance hospitals for all vector borne diseases • Vulnerability assessment to determine health burden
2.	Research-based ranking of areas and interventions to address	Process Indicators: • Risk mapping to identify the hotspots for vulnerable population

	health risks from climate change	Output Indicators: • Identification of the proportion of high-risk areas to climate-sensitive diseases
3.	Training of health sector staff to increase consciousness and response readiness to possible influences on human health	Process Indicators: • Establishment of the State Environment Health Cell Output Indicators: • No. of districts with healthcare workers trained in climate change related health risks and diseases
4.	Improvements in primary, secondary and tertiary health care systems and involve facilities to handle and better manage climate risks and their potential health impacts	Process Indicators: • Capacity gap assessment Output Indicators: • Share of health infrastructure in districts as per IPHS
5.	Exploring the field of telemedicine for improved access	Process Indicators: • Setting up of telemedicine-compliant health centres Output Indicators: • Share of HWCs, PHCs, district hospitals with telemedicine facility
6.	Access to medicines (Increased focus on remote districts for equitable distribution)	Output Indicators • No. of districts with stock out events • No. of districts with stock excess events
7.	Investment in research related to climate change and health integration	Output Indicators • Share of state financial budget allocated to research projects related to climate change and health

9.4.2 Water

Line departments for the water sector: Public Health and Engineering Department, Public Works Department, India Meteorological Department

Table 9.3. Water sector – action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Modernization of irrigation system using drip, sprinkler systems	• Percentage area under efficient irrigation methods: drip irrigation and sprinkler irrigation
2.	Field-specific analysis for the state's rainwater harvesting strategy; generation of location maps and spatial database of rainwater harvesting structures Mandatory rooftop harvesting in new and existing building premises with sizes greater than a certain threshold in urban areas	Process Indicators • Is there a spatial data base for rainwater harvesting structures? (Yes/No) • Subsidies/incentives/financial support for rainwater harvesting systems • Development of building mandates for new residential complexes in urban areas Output Indicators • Creation and regular updating of database of government approved and supported rainwater harvesting systems
3.	Prevention of un-controlled use of groundwater. Charging farmers for irrigation water beyond a stipulated amount, especially those with land holdings greater than a threshold Centralization of groundwater extraction for judicious and regulated distribution of groundwater resource	Process Indicators • Any centralized agenda existing for groundwater extraction? (Yes/No) Output Indicators • Farmers with large land holdings may be charged for water extraction • Annual groundwater level change
4.	Greening of urban regions with paving materials that facilitate groundwater infiltration	Output Indicators • Area under green coverage in urban areas
5.	Development of state-specific tool for weather forecasting and disaster mitigation related to floods and droughts	Process Indicators • Any tool/department (e.g., IMD) engaged in disaster forecasting?

9.4.3. Agriculture

Line department for the agriculture sector: Department of Agriculture, Public Works Department

Table 9.4. Agriculture sector – action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Diversification of crops	• Yield per hectare of different crops • Crop rotation frequency • Land under mono and multi crops
2.	Awareness programmes for farmers on climate change	• KVK operations, periodic soil testing and information-sharing through training and initiatives • Training on water management
3.	Management of groundwater for agriculture	• Registration of rainwater harvesting systems o Provision of rainwater harvesting essential for digging tubewells • Farm pond needs to be encouraged under MNREGA
4.	Sustainable agriculture	• Number of farmers who have benefited from PM KUSUM Yojana • Registration of area under drip irrigation • Area covered under smart water irrigation systems • Area under solar-powered irrigation
5.	Use of technological aids for farmers for marketing and agriculture operations	• Proportion of farmers using technological aids (e.g., apps/ websites) for trading produce

9.4.4. Community Resilience and Socio-economic Development

Line departments for community resilience and socio-economic development: Social Justice and Empowerment Department; Education Department.

Table 9.5. Socio-economic development sector - action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Improvement in literacy rates and further initiatives to encourage rural female literacy	• Female school enrolment rate • Female school dropout rate
2.	Increased employment opportunities for the rural population	• Female workforce participation rate
3.	Alternative employment opportunities to marginal cultivators	• Share of formal employment in total employment
4.	More liveable urban spaces by improving housing conditions and reducing the number of houseless populations	• No of households covered under PM Aawas Yojana • Number of cities under smart city programme
5.	Climate education in school syllabus	• Inclusion of region-specific climate change education syllabus by state board.
6.	Skill development for marginal labourers	• Number of people trained under vocational training
7.	Promotion of agriculture-based industries to stimulate agro-based industrial activities	• 1. Number of units of agro-based industries 2. Number of people employed
8.	Extension of urban facilities to rural areas	• Number of people who have access to credit • Proportion of *pucca* to *kuccha* houses • Road length in the rural area • Internet penetration • Household access to electricity

9.4.5. Forestry and Biodiversity

Line departments for the forest and biodiversity sector: Forest Department; Department of Environment and Climate Change

Table 9.6: Forestry and biodiversity sector – action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Conservation of biodiversity and traditional knowledge	• Number of villages protecting and conserving commons • Increase in population of apex species and indicator species of plants and animals
2.	Enhanced use of agroforestry and traditional tree-based systems	Output Indicators • Total area under agroforestry • Number of households benefitted from agroforestry
3.	Afforestation/reforestation for adaptation and carbon sequestration	Process Indicator • Implement REDD+ (or similar) strategy in Rajasthan Output Indicator • Total area under forest cover
4.	Empowering local communities to conserve and utilize commons	Process Indicators • (Financial) benefits to village panchayats for monetizing village commons Output Indicators • Number of villages protecting and conserving commons • Increase in area under forests used as wind breaks • Increase in area under forests at desert margins
5.	Prevention of desertification	Process Indicator • Creation of a platform for collaboration between various line departments: agriculture, forestry, water management Output Indicators • Increase in area under forests used as wind breaks • Increase in area under forests at desert margins • Number of schemes introduced for water management in rural areas • Total agricultural land using drip irrigation

9.4.6. Urban Planning and Tourism

Line departments for urban planning and the tourism sector: Urban Development and Housing Department; Transport Department; Tourism Department

Table 9.7: Urban planning and tourism sector: Action points and indicators for M&E

S. No.	Action Point	Indicators
1.	Comprehensive mobility plans	• Increase modal share of public transport
2.	Creation of green corridors as a part of afforestation programmes and providing shade	• Planting of trees by the roadside to reduce emissions and reduce impact of heat waves. • Increase sheds/ infrastructures for heat waves
3.	Training a disaster management team for extreme climatic events	• Create incident response team for each ward and create vulnerability response mapping • Number of wards with incident response teams • Number of wards that have done vulnerability mapping
4.	Solar PV enabled charging stations in tourist spots	Process Indicators • Number of charging stations around tourist spots
5.	Electric buses for tourism purpose	Process Indicators • Number of electric buses in the state Output Indicators • Share of electric buses in total fleet
6.	Estimation of carbon footprint from the tourism sector	Process Indicators • Estimates of carbon footprint for tourist places Output Indicators • Total annual carbon footprint from the tourism sector
7.	Mandating solar PV and solar water heater (SWH) systems for hotels and tourist spots	Process Indicators • Solar rooftop promotion drives • Incentives for installation of solar PV/SWH Output Indicators • Cumulative installed capacity of SPV systems in hotels and tourist spaces

9.4.7. Mitigation Sector

The action points for mitigation are grouped by sector and listed below, along with the line departments responsible for the action points and the relevant indicators.

Table 9.8. Mitigation sector - action points and recommendations for M&E

S. No.	Action Point	Indicators
	Transport (Line Department: Department of Transport)	
1.	Higher share of green transportation systems	• Annual increase in the number of EVs on the road • Share of EVs in the total fleet • Increase state incentives for electric private vehicles • Increase in public transport modal share • Number of EV charging stations
2.	Transition of government official vehicles, school buses and tourist buses to electric vehicles (EVs)	• No of EV buses registered under city-tour buses for tourists • Incentives for schools for switching to EV buses (Yes/No)
3.	Infrastructure facilitating smooth transition to EVs	• Total number of EV charging stations
	Power (Line Department: Rajasthan Energy Department)	
4.	Greening of Rajasthan's electricity sector by increasing the shares of renewable capacity (both solar & wind) and generation	Process Indicators: • Are there any incentives in place for new investments in renewable market incentives? (Yes/No) • Number of new projects for solar and wind power generation Output Indicators: • Increase in state-owned power generation capacity • Annual CO_2 emissions by the electricity sector • Share of import of electricity from other states • Emission intensity of electricity generation • Installed capacity of renewable power plants in the state
5.	Higher proportion of locally sourced solar PV components in new capacity plants and development of Rajasthan as a manufacturing hub	Process Indicators: • Incentives and subsidies available for local sourcing of solar PV purchase • Number of plants manufacturing renewable components Output Indicators: • Number of new jobs created in the renewable sector

		• Percentage of local components used in new capacity additions
6.	Pilot project for generation of green hydrogen and carbon capture & storage by 2025 (To be the pioneers in GH and CCS)	Process Indicators: • To co-ordinate with the agencies to develop pilot. carbon capture and storage projects in the state • Establishing a nodal agency to develop the pilot project for green hydrogen in the state • Cumulative spending in R&D of green hydrogen and CCS Output Indicators: • Number of GH and CCS plants commissioned
7.	Provision of reliable, secure and affordable electricity to drive economic growth and development while safeguarding the infrastructure from potential climate hazards through holistic resilience planning	Process Indicators: • Vulnerability assessment report of electricity infrastructure (Pending/complete) • Training of locals to operate, maintain and become self-reliant in rural areas • Number of training programmes held for training locals in operation and maintenance of electrical systems • Number of personnel trained under the training programmes mentioned above
Brick Production (Line Department: State Pollution Control Board)		
8.	Shifts to advanced brick firing technologies – zigzag and VSBKs	Indicators • Number of kilns by technology type • Average specific fuel consumption per kiln
9.	Use of resource efficient bricks	Indicators • Market share of non-fired bricks • Utilization of fly-ash in fired-clay brick production
Residential (Line Department: Department of Energy)		
10.	Shifts to clean cooking fuels: LPG/biogas	• Number of LPG connections and number of annual refills • Number of households with biogas supply • Hours/number of meals cooked using clean fuel
11.	Rural electrification	• Number of households with access to electricity (grid or off-grid) • Number of hours of electricity supplied • Sale of electrical cooking / lighting devices
Waste Management (Line Departments: Local Self Government Department, RSPCB)		

12.	Infrastructure for sustainable waste management practices through stakeholder engagement	Process indicator • Number of awareness campaigns organized for waste management • Inclusion of waste management in school curriculum (Yes/No) • Total spending on awareness programmes and advertisements • Facilitating public-private partnerships Output indicators: • Number of corporate social responsibility (CSR) initiatives and total spending for waste management • Number of formal employees in the waste management sector
13.	Utilization of waste / landfill gas for generation of power	Process indicator • Number of waste-to-energy plants in the state Output indicator • Total avoided emissions by utilizing landfill gas for power generation
14.	Segregation of waste at the household level and circular-economy approach Waste minimization, re-use and recycling	Process indicator • Mandates for segregation of waste at the household level and deterrents for non-compliance (existent/non-existent?) Output indicator • Percentage of waste recycled from total waste • Installed capacity of gasifier power plants using organic waste for power generation
15.	Prevention of open burning of municipal solid waste	Process indicator • Imposition of fines for open burning of garbage (Yes/No)
16.	Control of air pollution from construction and demolition activities	Process indicator • Enforcement of construction and demolition rules (Yes/No) Output indicators • Number of green buffer zones along traffic corridors • CSR/government spending on greening and maintaining of open areas, gardens and community areas
17	Disaster waste management during	Process indicator • Regular cleaning and maintenance of drainage and sewer systems to prevent urban flooding (Yes/No)

	extreme weather events (rainfall)	
Agriculture and Animal Husbandry (Line Department: Agriculture Department, Department of Animal Husbandry)		
18.	Crop residue biomass as renewable fuel	• Total installed capacity of biomass energy • Number of crop residue based small capacity biogas plants • Quantity of crop residue biomass used for co-firing in coal power plant
19.	Reduction in crop residue fires	• Reduction in crop residue fires
20.	Improved efficiency of fertiliser application	• Reduction in per area fertiliser consumption • Reduction in total fertiliser consumption
21.	Energy audit	• Total number of energy audits conducted annually • Total yearly fuel consumption from agricultural industries • Total yearly electricity consumption
22.	CO_2 emission measurement	• Total emissions from the stack • Percentage of CO_2 in the flue gas leaving the stack • Total CO_2 emissions
23.	Switching over to renewables-based energy and/or electricity	• Amount of fossil fuel replaced • Savings in CO_2 emissions achieved
24.	Switching over to low/zero carbon fuels such as biomass, green hydrogen, green ammonia etc.	• Amount of fossil fuel replaced • Savings in CO 2 emissions achieved
25	Improving process efficiency	• Emission savings achieved compared to original process
Industry (Line Department: RIICO, RSPCB, DECC)		
26.	Carbon capture and utilization (CCU)	• Measurement of absolute CO_2 emissions before and after implementation of the CCU technologies

9.5. Guidelines to use the M&E Framework

We propose an M&E framework that can easily be created using any spreadsheet tool such as MS Excel or Google sheets. It consists of 11 components that are relevant to any activity associated with climate action in the state. The following section gives a detailed description of each component of the given M&E framework and guidelines to use them.

#	1	2	3	4	5	6	7	8	9	10	11
S. No.	Sector	Action point	Indicators	Target to be achieved	Baseline (with source)	Related Scheme	Implementing department	Current Progress	SDG Interlinkage	NDC interlinkage	Expected Outcome

1. Sector

#	1	2	3	4
S. No.	Sector	Action Point	Indicator	Target to be achieved

Identifying the **sector** corresponding to an action point is important as it helps in assigning the department responsible for carrying out the action point and the monitoring of the plan. Each action point is associated with one or more sectors. For example, *installation of rooftop solar power plants* corresponds to the energy sector, while *switching to drip irrigation for agriculture* can be associated with both the water sector as well as the agriculture sector**.**

2. Action Point

#	1	2	3	4
S. No.	Sector/ Line Department	Action Point	Indicator	Target to be achieved

Action point refers to the activity that the department will undertake as a part of its climate action initiative. For example, *organizing awareness programmes for farmers on climate change* is an action point for the agriculture sector. The action point can pertain to mitigation and adaptation, where mitigation options leads to reduction in emissions, and adaptation efforts require actions towards building resilience and ways to better deal with expected climate change impacts.

3. Indicator

#	1	2	3	4
S. No.	Sector/ Line Department	Action Point	Indicator	Target to be achieved

An **indicator** is a qualitative or quantitative measure to assess the progress of the action point. Indicators essentially are representative of whether any scheme introduced is making a difference or not. For example, *female workforce participation rate* is an indicator for the action point *increase employment opportunities for women in rural areas*.

Section 9.4 lists indicators for action points recommended under various sectors. The implementing department may refer to those tables for selecting the indicator or may use any other relevant measure depending on the action point. Choosing a specific, measurable, attainable, relevant and time-bound (SMART) indicator is crucial to ensuring that progress-monitoring is effective. It is suggested that the implementing department/agency clearly define the M&E indicators for a scheme once/before it is started.

In section 9.2 of this chapter, it is mentioned that an indicator can be process-specific or output-specific. This has been illustrated in the sector specific indicators in section 9.4. However, in the framework, the term *indicator* is used in general and can refer to any type.

4. Target

#	1	2	3	4
S. No.	Sector/ Line Department	Action Point	Indicator	Target to be achieved

Target refers to the goal to be achieved in the action plan. To set a target, it is important that the timeline of the project and the frequency of monitoring are clearly defined. The target can be set as a Yes/No, a percentage or a specific value. For example, *24x7 electricity in all villages by 2040* can be a target for the action point *rural electrification*.

5. Baseline

4	5	6	7	8
Target to be achieved	Baseline (with source)	Related Scheme	Implementing department	Current Progress

Baseline refers to current value of the indicator of the action plan or the information base against which the change brought about by an action point will be assessed. Without a baseline, it is not possible to know the impact of the project.

Sometimes primary data will be available for some sectors. In that case, the data corresponding to the indicator needs to be collated and inserted as the baseline. In other cases, it is recommended that a baseline survey be conducted as they are the starting point of a project. In case if the baseline has been assessed using secondary data, the source of data needs to be specified to ensure that subsequent M&E activities are carried out on the same baseline, and there is consistency.

6. Related Scheme

4	5	6	7	8
Target to be achieved	Baseline (with source)	Related Scheme	Implementing department	Current Progress

Related scheme refers to the policy or scheme under which the action point has been introduced. For example, the action point *Use solar pumps for extraction of groundwater* is supported by the PM KUSUM Yojana**.** However, it should be noted that an action point need not always be supported by a scheme. It may also happen that an action point is supported by more than one schemes.

7. Implementing Department

4	5	6	7	8
Target to be achieved	Baseline (with source)	Related Scheme	Implementing department	Current Progress

Implementing agency/department is the line department responsible for executing the action point and the corresponding M&E of the activity. For example, RRECL under

Department of Energy, government of Rajasthan, is responsible for the action points related to solar pumps.

8. Current progress

4	5	6	7	8
Target to be achieved	Baseline (with source)	Related Scheme	Implementing department	Current Progress

Current progress indicates the status of the indicator during the period of evaluation. It can be represented in several ways, such as

- Quantitative value of indicator
- Percentage of the target received
- Incomplete/pending/complete in case of a qualitative indicator

The implementing agency may choose any method to indicate current progress, based on the action point and the indicator.

9. SDG Interlinkage

7	8	9	10	11
Implementing department	Current Progress	SDG Interlinkage	NDC Interlinkage	Expected Outcome

The United Nations through its 2030 Agenda for Sustainable Development has declared 17 global sustainable development goals (SDGs), consisting of 169 targets, which set forth quantitative objectives across the social, economic and environmental dimensions that are to be achieved by 2030.

SDG interlinkage in the framework identifies if the action point is connected to any of the UN SDGs. For example, the action point *Afforestation/Reforestation for adaptation and carbon sequestration* can be linked to SDG 15, which is life on land. The different SDGs are listed in Annexure 1 (below). Interlinking with SDGs will help in identifying and streamlining the expected outcome.

10. NDC Interlinkage

7	8	9	10	11
Implementing department	Current Progress	SDG Interlinkage	NDC Interlinkage	Expected Outcome

India's nationally determined contributions or NDCs are commitments put forward by India as a response to the Paris Agreement, which includes mitigation and adaptation measures to deal with climate change. The NDCs submitted by India to the UNFCCC are listed in Annexure II.

NDC interlinkage connects the action point to NDC commitments, and it is a representation of how climate action taken up at a sub-national level eventually contributes to the climate commitments of the country. For example, the action point *Increase share of renewable energy in the total energy mix* contributes to the NDC of *increase total cumulative electricity generation from fossil free energy sources to 40% by 2030*.

11. Expected Outcome

7	**8**	**8**	**10**	**11**
Implementing department	Current Progress	SDG Interlinkage	NDC Interlinkage	Expected Outcome

Often, the outcome of any policy is the result that is seen from a long-term perspective and cannot be calculated or measured directly. Hence, in this framework expected outcome refers to the long-term relevance of the action point with respect to climate change.

They can be specified as

- Emission reduction
- Resilience building
- Climate-disaster management
- Food security
- Climate justice

As defined earlier, the framework can be utilized for any action point defined by the nodal department as well as the line departments. Some of the action points have been identified in Section 4 of this chapter; however, more details can be found in each of the individual chapters throughout the report.

Annexure **1**

Table: The 17 Sustainable Development Goals

SDG 1	No Poverty: End poverty in all its forms everywhere
SDG 2	Zero Hunger: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.
SDG 3	Good Health and Well-Being: Ensure healthy lives and promote well-being for all at all ages.
SDG 4	Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
SDG 5	Gender Equality: Achieve gender equality and empower all women and girls
SDG 6	Clean Water and Sanitation: Ensure availability and sustainable management of water and sanitation for all
SDG 7	Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable, and modern energy for all.
SDG 8	Decent Work and Economic Growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
SDG 9	Industry, Innovation and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
SDG 10	Reduced Inequalities: Reduce inequality within and among countries.
SDG 11	Sustainable Cities and Companies: Make cities and human settlements inclusive, safe, resilient and sustainable.
SDG 12	Responsible Consumption and Production: Ensure sustainable consumption and production patterns.
SDG 13	Climate Action: Take urgent action to combat climate change and its impacts.
SDG 14	Life Below Water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
SDG 15	Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss.

SDG 16	Peace and Justice: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
SDG 17	Partnership for Goals: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Annexure II

Table: India's Nationally Determined Contributions (NDCs)

NDC Goal 1: To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation
NDC Goal 2: To adopt a climate-friendly and a cleaner path than the one followed hitherto by others at a corresponding level of economic development
NDC Goal 3: To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level
NDC Goal 4: To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost international finance including from Green Climate Fund (GCF)
NDC Goal 5: To create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030
NDC Goal 6: To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management
NDC Goal 7: To mobilize domestic and new & additional funds from developed countries to implement the above mitigation and adaptation actions in view of the resources required and the resource gap
NDC Goal 8:

To build capacities, create domestic framework and international architecture for quick diffusion of cutting-edge climate technology in India and for joint collaborative R&D for such future technologies.

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Chapter 9

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