CSTEP
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Climate Change Risks to Rainfed Agriculture in Karnataka:

Implications for Building Resilience

Climate Change Risks to Rainfed Agriculture in Karnataka: Implications for Building Resilience

Kritika Adesh Gadpayle
Vidya S
Pratima Bisen
Indu K Murthy

CSTEP
February 2021

Center for Study of Science, Technology and Policy (CSTEP) is a private, not-for-profit (Section 25) Research Corporation registered in 2005.

Designed and Edited by CSTEP

Contributors: Kritika Adesh Gadpayle, Vidya S, Pratima Bisen, and Indu K Murthy.

(*The author list provided assumes no particular order as every individual contributed to the successful execution of the project.*)

This report should be cited as: CSTEP. (2020). Climate Change Risks to Rainfed Agriculture in Karnataka: Implications for Building Resilience. (CSTEP-RR-2021-<02>).

February 2021

Center for Study of Science, Technology and Policy

Bengaluru Office
No. 18, 10th Cross, Mayura Street
Papanna Layout, Nagashettyhalli, RMV II Stage
Bengaluru 560094, Karnataka (India)
Tel.: +91 (80) 6690 2500

Noida Office
1st Floor, Tower A
Smartworks Corporate Park, Sector 125
Noida 201303, Uttar Pradesh (India)

Email: cpe@cstep.in
Website: www.cstep.in

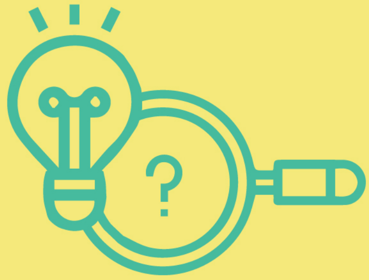
Acknowledgements

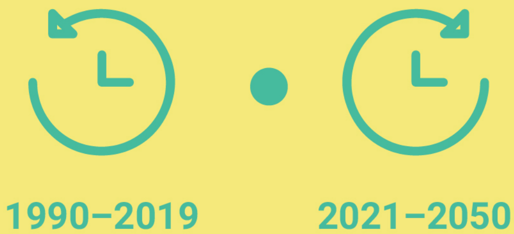
The authors would like to express their gratitude to Mr Thirumalai N C (Sector Head, Computational Tools and Project Management, CSTEP) for his critical review and inputs during the study and report preparation. Thanks are also due to Prof M B Rajegowda (former Professor and Head, All India Coordinated Research Project on Agrometeorology and former Registrar, University of Agricultural Sciences, Bangalore) for reviewing the report and providing valuable suggestions. The support and constant encouragement of Mr Priyavrat Bhati (Sector Head, Climate, Environment, and Sustainability, CSTEP) and Dr Jai Asundi (Executive Director, CSTEP) are duly acknowledged. The financial support of Nilekani Foundation for this study is gratefully acknowledged.

Additionally, the authors acknowledge the following CSTEP individuals for their timely contributions and reviews:

Editorial support: Mr Abhinav Pratap Singh

Report design: Ms Bhawna Welturkar




1990–2019
2021–2050


?
Yield loss!

Executive Summary

Background and motivation: Climate change increases strain on agriculture systems through changes in the magnitude, distribution, and timing of rainfall; rise in temperature; and an increase in the frequency of extreme weather events. In Karnataka, agriculture is the key contributing sector for the state's economy. Despite its importance, agriculture in the state is limited by the availability of irrigation (only 31.2%) and uncertainty in rainfall distribution. These factors greatly hamper the agricultural productivity of the state.

Objective: This study assesses climate risks likely to emerge owing to climate change during the short-term period of 2021–2050—termed the 2030s, its implications for yield of maize, sorghum and groundnut—the dominant rainfed crops of Karnataka, and suggests strategies for buffering losses, and building long-term resilience.

Methodology: We evaluated historical climate data from the India Meteorological Department for the period 1990–2019. In addition, we estimated future climate trends in temperature and rainfall, including extreme events, by using a CORDEX 15-model ensemble for two climate scenarios—RCP 4.5 (moderate emission) and RCP 8.5 (high emission)—at the district level for Karnataka.

Findings: The major findings of our study are as follows:

1. During 1990–2019, mean summer maximum and winter minimum temperatures increased in all the districts of Karnataka. In addition, the magnitude of rainfall too increased, during both kharif and rabi seasons.
2. Changes in rainfall during the kharif and rabi seasons show a significantly positive correlation with the yields of rainfed crops in Karnataka (maize, sorghum, ragi, groundnut, and red gram). However, there is no correlation between the yield of these crops and mean summer maximum temperature.
3. Relative to the historical period 1990–2019, during the 2030s,

- A 0.5°C–1.5°C increase in summer maximum temperature and a 0.5°C–2°C increase in winter minimum temperature is projected.
- For both RCP 4.5 and RCP 8.5 scenarios, increases of 7–28% and 7–39% in kharif and rabi rainfall, respectively, are projected.
- A greater number of high-intensity rainfall events—two to six times greater than that reported in the historical period—in some districts are projected, even for certain districts such as Bengaluru Rural, Chitradurga, Davanagere, and Yadgir that have historically never recorded >100 mm rainfall/day. Further, the incidence of rainfall-deficient years that can potentially become drought years is projected to decline in all the districts of Karnataka.

Discussion: Climate risks to rainfed crops at different crop-growth phases could result in crop yield losses. The changes in rainfall and temperature during the projected period have implications for crop growth as crops have specific temperature and rainfall requirements during the different growth phases.

- Maize is likely to be impacted by rainfall deficit during vegetative, flowering, and grain-filling stages, while groundnut is likely to be impacted during emergence to peg initiation stages. This could result in a yield loss of 21–50% for maize and 13–19% for groundnut.
- Sorghum—cultivated during the rabi season—is likely to be impacted by summer maximum temperature projected to be higher than the defined maximum temperature threshold for the crop by 0.1°C–1.7°C in some districts, potentially resulting in a yield loss of 7–18%.
- An increase in the frequency of heavy rainfall events is projected during the kharif season, which will result in excess soil moisture. This could induce flower shedding, root rotting, and wilting, resulting in the loss of overall yield and quality of produce from agricultural crops.

Resilience building for coping with projected climate risks requires targeted focus on flood management. Historically, Karnataka has witnessed several droughts, and several drought management strategies are in place. Agricultural universities and the disaster risk management cell in the state are prepared for drought management. However, the frequency of heavy rainfall events is projected to increase in the future, requiring the state to formulate more robust flood management mechanisms.

Although the magnitude of rainfall and the frequency of heavy rainfall events are projected to increase for most districts during both kharif and rabi seasons, dry spells are likely to occur in certain districts. This is because both rainfall distribution variability and temperatures are projected to increase.

Recommendations: A combination of flood and drought management strategies needs to be in place to tackle climate risks and to recover from loss and damage caused to rainfed agriculture. Certain innovations in current practices could make the existing mechanisms more robust and contribute to building long-term resilience in rainfed agriculture systems. Some such innovations are listed:

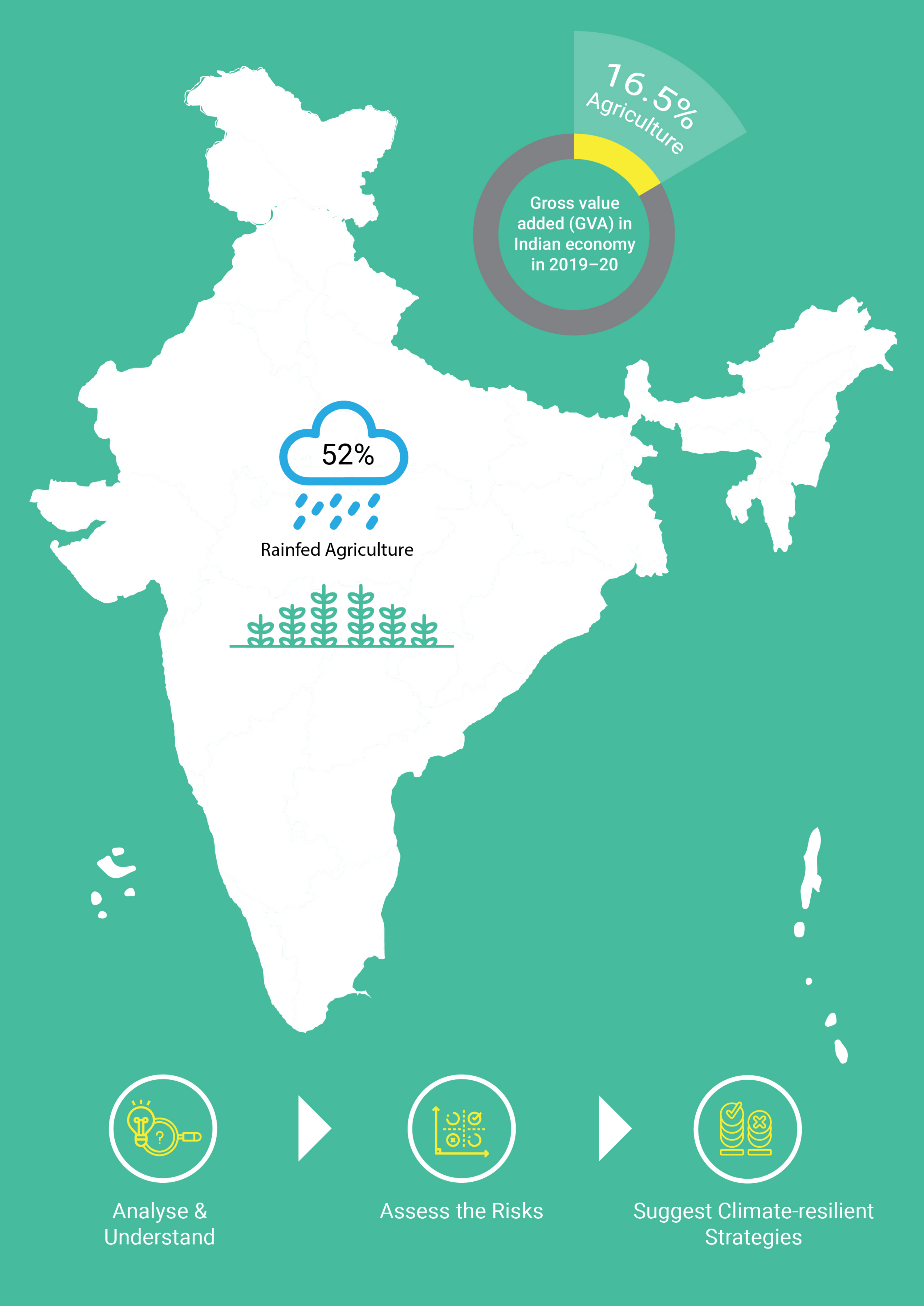
- *Crop insurance with 'no claims' process*: Unlike traditional crop insurance, this type of insurance clears claims on the basis of the realisation of an objectively measured weather variable such as rainfall that correlates with production losses.
- *Forecast-based financing for social protection*: This is a financial mechanism that anticipates hazards by using a set of pre-agreed triggers (or danger levels) and pre-defined actions when triggers signal crossing of danger levels.
- *Public–private partnership in agroforestry*: Schemes and programmes exist in Karnataka to promote agroforestry. However, there is a need to bring in private players into agroforestry so as to provide an assured market. In addition, strong linkages need to be developed between different institutions and clients to establish a complete value chain of agroforestry produce. This would also help realise the vision of doubling farmers' income by 2022.

Contents

Figures

Tables

Appendix


16.5%
Agriculture
Gross value added (GVA) in Indian economy in 2019–20
52%
Rainfed Agriculture
Analyse & Understand
Assess the Risks
Suggest Climate-resilient Strategies

1. Introduction

Climate variability, climate change, and extreme events such as droughts, floods, heat waves, frost, and hail are impacting agriculture globally; as such, India is not unaffected either. The projected increase in temperature, increases in the mean annual and summer monsoon rainfall, and increased rainfall variability—with more frequent and intense heavy rainfall events, and extended dry spells in the 21st century (Raghavan et al., 2020)—are likely to exacerbate the risks to agriculture. The possible changes in temperature and rainfall are expected to significantly impact crop growth. Weather conditions during the growing season of any crop govern its growth, development, water use efficiency, and yield.

Agriculture is a major component of the Indian economy, accounting for 16.5% of the gross value added (GVA) in 2019–20 (Economic Survey of India, 2020). Kharif season—extending from June to September—is the primary cropping season for most of India and is dependent on the southwest monsoon. The rabi season—extending from October to December—is dependent on the summer monsoon. In India, rainfed agriculture generates 60% of the agriculture produce, 75% of pulses, and more than 90% of sorghum, millets, and groundnut (Bhoochetna, 2013). States with a significant area under rainfed farming are hotspots of poverty and water scarcity, and have serious problems such as land degradation, droughts, and decreasing rainfall with low rainwater use efficiency (Wani et al., 2012). Increased rainfall variability in a country that is predominantly rainfed—52% of the cropped area in India is rainfed—runs the risk of decline in crop production, which in turn has adverse implications for farm income and farmer livelihoods.

1.1. Karnataka State Profile

Karnataka is situated on the western edge of the Deccan Peninsular region of India. It is located approximately between 11.5°N and 18.5°N latitudes and 74°E and 78.5°E longitudes. It has a geographical area of 1,91,790 km^2 and a population of 64 million (Census of India, 2011). Karnataka comprises the Deccan Plateau, the Western Ghats, and the Coastal Plains. The state can be divided into four physiographic landforms—the Northern Karnataka Plateau, the Central Karnataka Plateau, the Southern Karnataka Plateau, and the Coastal Karnataka Region. The state has 30 districts, of which 5 are tribal and 6 are hill districts, and 175 blocks.

Karnataka's climate is hot with excessive rainfall during the monsoon season (June to September) in certain districts. April and May are the hottest months, while December and January are the coldest. The normal rainfall (considering the period 1980–2013) in the state is 1191.6 mm (Venkatesh et al, 2016). Maximum rainfall is received from June to September from the southwest monsoon and is about 869 mm. Some amount of rainfall is also received from the northeast monsoon from October to December. Karnataka is divided into 10 agro-climatic zones (Figure 1), which can be broadly grouped into the following three zones:

- Dry zones: North-Eastern Dry Zone, Northern Dry Zone, Central Dry Zone, South-Eastern Dry Zone, and Southern Dry Zone
- Transition zones: North-Eastern Transition Zone, Southern Transition Zone, and Northern Transition Zone
- Hill and coastal zones: Hilly Zone and Coastal Zone

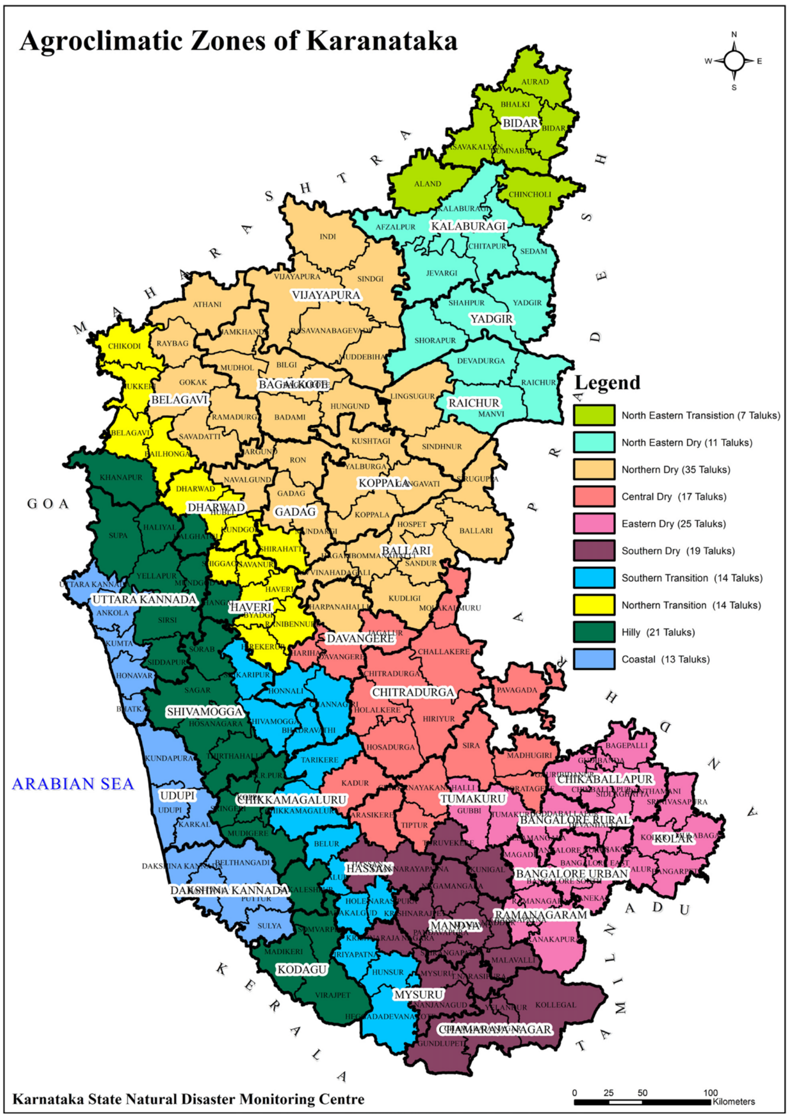


Figure 1: Agro-climatic zones in Karnataka
Source: KSNDMC, 2017

The soils in these agro-climatic zones are varied because of the complex topographic, geologic, vegetation, and climatic conditions. The soil resources of Karnataka have been characterised and mapped by Shiva Prasad et al. (1996). Traditionally, these soils could be grouped into five categories, namely, red soils, lateritic soils, black soils, alluvial soils, and forest soils.

1) Red soils: Red soils account for 35.15% of the total geographic area (TGA) and are the predominant soil type in Karnataka. These soils are formed under well-drained conditions. These include red loams, red gravelly soils, and red earths. The major constraints for crop production in red soils are very shallow to shallow rooting depth, low nutrient status, low moisture retentivity, soil erosion, etc. These soils support agriculture, horticulture, and plantation crops but require efficient soil, water, and nutrient management practices.

2) Lateritic soils: These soils extend over about 12% of TGA and are found in high-altitude and heavy-rainfall areas in Karnataka. These are well-drained and porous soils with high iron and magnesium content. They are suitable for growing paddy, areca nut, banana, coconut, cashew nut, cocoa, coffee, tea, and rubber.

3) Black soils: These soils are found mainly in the Deccan plateau region, spanning 6.9% of TGA, covering large parts of north interior Karnataka. These soils are highly clayey and have low drainage and low permeability. They are poor in organic matter, nitrogen, and available phosphorus. However, these soils are very fertile and predominantly used for growing cotton, millet, and sorghum.

4) Alluvial soils: These soils extend over 16.1% of TGA of the state. These soils are deficient in nitrogen, phosphorus, and humus, and require the application of manure and fertiliser for sustainable farming. These are one of the best agricultural soils and are suitable for most agricultural crops, including rice, maize, sugarcane, groundnut, potato, and sunflower.

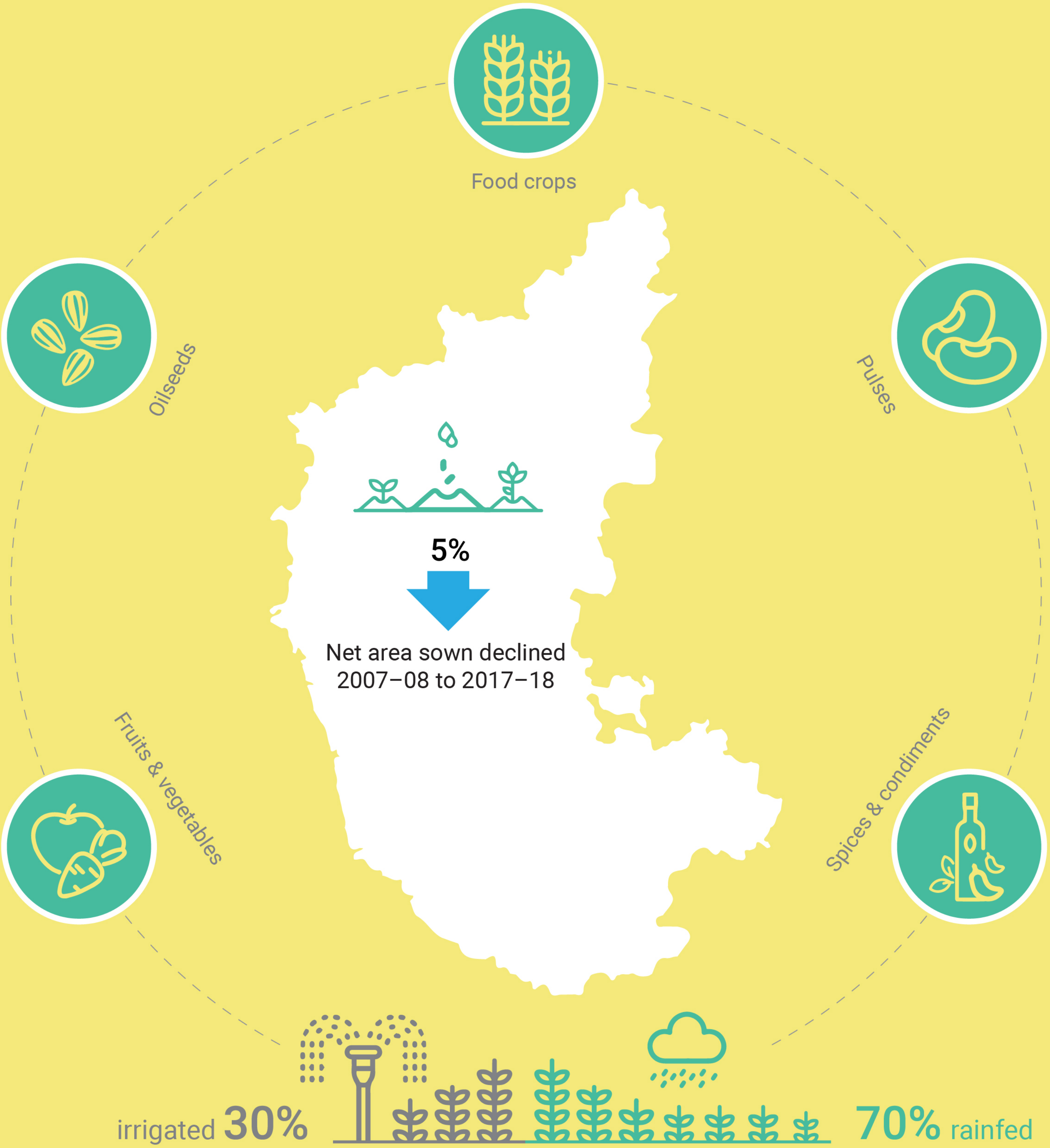
5) Forest soils: These soils occupy 6.1% of TGA and are found in the Western Ghats region of the state. These soils vary from deep alluvium in river basins to residual gravelly on higher altitudes. Various types of crops and fruit orchards are grown on this soil type.

In Karnataka, agriculture is the key sector contributing to the state economy and continues to be the highest-employment-generating sector. The gross state value added (GSVA) growth rate of the agriculture sector in 2018–19 was -4.8% compared to 14.2% in 2017–18. This decline was due to the fall in food grains production as a result of drought conditions in 100 taluks during the kharif season and 156 taluks during the rabi season (Economic Survey of Karnataka, 2019). Out of the 10 agro-climatic zones in Karnataka, five are dry zones. A large portion of the state has semi-arid conditions, facing severe agro-climatic and resource constraints. Agriculture in Karnataka is thus limited by availability of irrigation and uncertainty in or erratic distribution of rainfall, because of which the agricultural productivity suffers to a great extent.

1.2. Objectives

This study focusses on assessing risks that are likely to emerge owing to climate change, with particular focus on rainfed agriculture in Karnataka during the short-term period of 2021–2050—termed the 2030s. The specific objectives of the study are as follows:

- Analyse and understand at the district level the historical and future trends in climate—temperature and rainfall—including extreme events in Karnataka
- Assess the risks climate change poses to the productivity of dominant rainfed crops in Karnataka
- Suggest climate-resilient strategies for maintaining agricultural yields and help stabilise farm income from rainfed agriculture in Karnataka.



Food crops
Oilseeds
Pulses
Fruits & vegetables
Spices & condiments
5%
Net area sown declined
2007–08 to 2017–18
irrigated 30%
70% rainfed

2. Agriculture in Karnataka

Land use in Karnataka is dominated by agriculture. According to the Directorate of Economics and Statistics, the area under crops in Karnataka in 2017–18 was about 12 Mha, of which the net area sown[1] was 10 Mha. The maximum area under crops was recorded in Kalaburagi (about 1 Mha), followed by Belagavi and Vijayapura. In other districts, the recorded area under crops ranged from 0.03 Mha in Bengaluru Urban to about 0.5 Mha in Koppal and Mysuru. Considerable area of agriculture land was left fallow (current + long fallow)[2] in many districts, spanning about 2 Mha. In addition, there was area under permanent pastures[3] and other grazing land, spanning 0.9 Mha.

An analysis of the trends in land use in Karnataka for the period 2007–08 to 2017–18 shows that the net area sown declined by about 5% during this period. Concurrently, an increase in area left fallow—both current fallow and fallow land other than current fallow (long fallow)—was also recorded (Figure 2). During this period, the percentage increase in area that was current fallow and other fallow (excluding current fallow) was 20% and 36%, respectively.

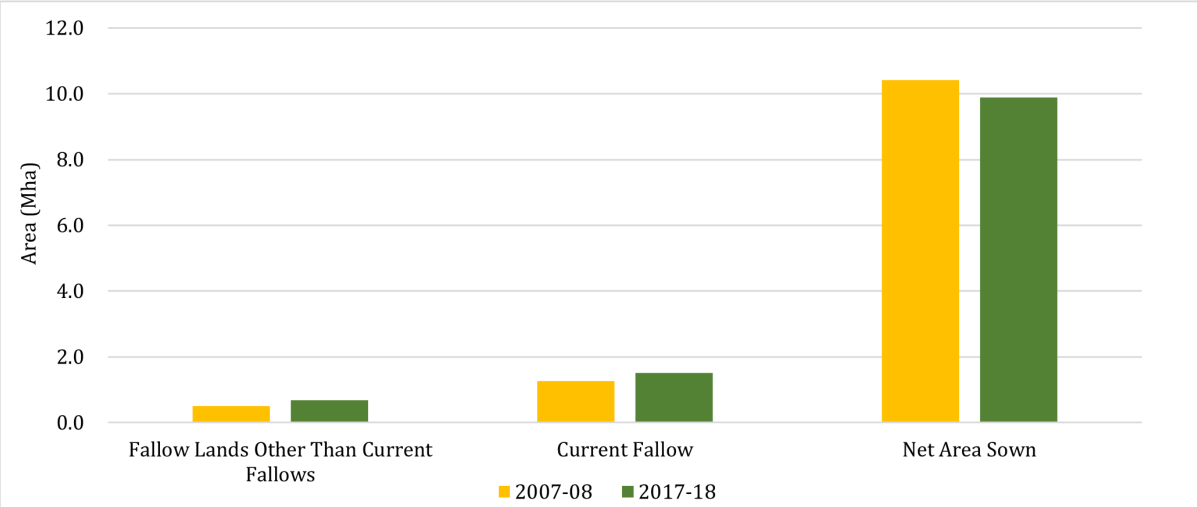


Figure 2: Net area sown and land left fallow during the period 2007–08 to 2017–18

The area under crops in Karnataka could be categorised on the basis of crops—food crops, pulses, oilseeds, spices and condiments, fruits, and vegetables. An assessment of the area under major food crops for the period 2007–18 shows a decreasing trend for most of the crops (Figure 3).

- *Food crops:* The area under rice, sorghum, bajra, ragi, and wheat declined by 29%, 21%, 46%, 4%, and 30%, respectively. However, the area under maize increased by 19%.

[1]Net area sown represents the total area sown with crops and orchards. Area sown more than once in the same year is counted only once.

[2]Current fallow represents cropped area which is kept fallow during the current year. Other fallow or long fallow includes all land which was taken up for cultivation but temporarily out of cultivation for a period of not less than one year and not more than five years.

[3]Area under permanent pastures includes all grazing land irrespective of whether it is permanent pasture/meadows. Village common grazing land is included under this category.

- *Pulses:* The area under major pulses showed mixed trends—an increase of 109% and 30% in the area under gram and arhar, respectively, but a decrease of 19% in the area under other pulses.

Figure 3: Trends in areas under different crop categories in Karnataka during 2007–18

- *Oilseeds:* The area under oilseeds such as groundnut, castor, sesame, rapeseed and mustard, linseed, niger seed, sunflower, and safflower decreased by 37%, 69%, 58%, 43%, 83%, 86%, 83%, and 52%, respectively, while the area under soybean and coconut increased by 145% and 10%, respectively.

- *Spices and condiments:* The area under major spices and condiments showed mixed trends—the area under black pepper, ginger, turmeric, and betel nut increased by 155%, 41%, 43%, and 60%, respectively, while the area under chillies, cardamom, garlic, and coriander decreased by 25%, 31%, 9%, and 84%, respectively.

- *Fruits and vegetables:* The area under major fruits such as mango, banana, citrus fruits, and grapes increased by 38%, 30%, 12%, and 101%, respectively. Similarly, the area under pome and papaya also increased. In contrast, the area under vegetables such as potato, tapioca, sweet potato, and onion decreased by 49%, 6%, 4%, and 20%, respectively.

2.1. Trends in Area under Irrigation

Karnataka is one of the few Indian states with a low proportion of area under irrigation and is second only to Rajasthan in the share of drought-prone area. Of the total area under agriculture in Karnataka, only 31.2% is under irrigation, leaving about 70% of the area rainfed (GoI, 2019).

The percentage area irrigated in a district as a proportion of the net cultivated area, ranges from 3% in Kodagu to 61% in Shivamogga (Figure 4). Only 6 out of the 30 districts have an irrigated area greater than 50%, aggregating to about 1.8 Mha. Among the districts in northern Karnataka which receive an average annual rainfall of <1000 mm, the area under rainfed agriculture is 41–86% of the total cultivated area (GOI, 2019).

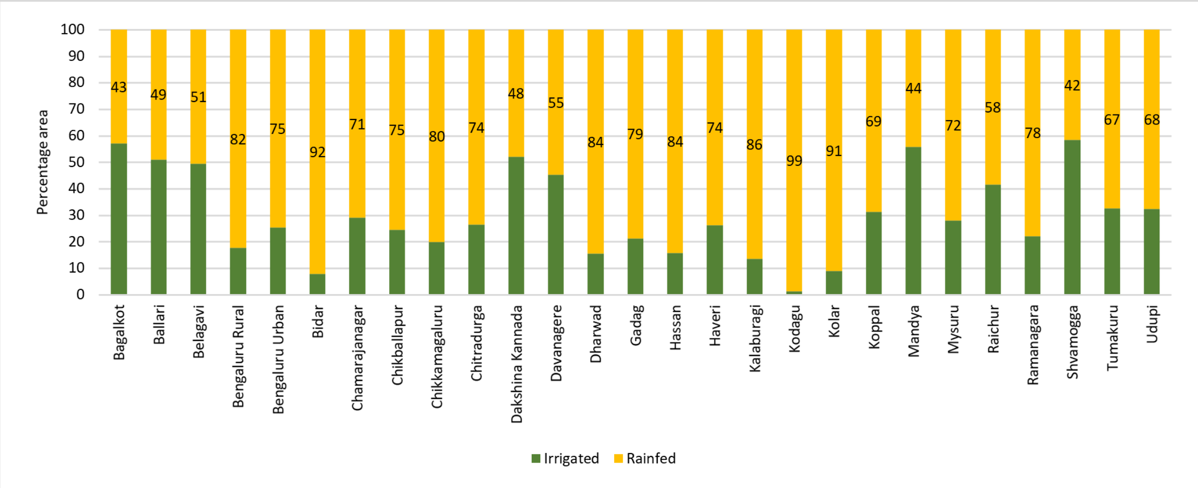


Figure 4: Percentage irrigated and rainfed area in the districts of Karnataka

Thus, a significant area in the various districts of Karnataka is under rainfed agriculture, making it vulnerable to the vagaries of monsoon, which has become erratic in the recent decades (Raghavan et al., 2020). In Section 3, the historical climate trends at the district level in Karnataka are analysed and presented. Further, the correlation of agricultural yield with temperature and rainfall is analysed for the period 2007–08 to 2017–18.

Average increase in temperature

0.18°C–0.61°C
Summer maximum

0.3°C–0.65°C
Winter minimum

Average increase in rainfall

Up to 15%
increase in most of the central and northern districts

20-25%
increase in the Western Ghats districts

Rainfall variability

Kharif
>20%
of variability in 90% of the districts

Rabi
>50%
of variability in 85% of the districts

1990–2019

2021–2050

3. Historical Climate Trends and Agricultural Yield in Karnataka

An analysis of climate in the districts for a 30-year period (1990–2019) was conducted to understand the past trends and to create a baseline for comparing climate projections. This district-level climate analysis for Karnataka involved the following approach and steps:

- *Rainfall*: A gridded daily rainfall dataset for grids of 0.25° latitude × 0.25° longitude provided by the Indian Meteorological Department (IMD) for the period 1990–2019 was used for analysing trends in rainfall and its variability.
- *Temperature*: Gridded daily temperature datasets for grids of 1.0° × 1.0°, spanning the period 1990–2019 for maximum and minimum temperatures, were used to assess the trends in temperature. The temperature analysis was conducted for summer (MAM: March to May) and winter (DJF: December to February) seasons.

3.1. Trends in Temperature

The summer (MAM) maximum temperature was generally moderate to high and ranged from 31°C in Mysuru and Mandya to 38.8°C in Kalaburagi. The increase in maximum temperature during this period was in the range 0.18°C–0.61°C (Figure 5, left panel). The winter (DJF) minimum temperature ranged from 14.1°C in Mysuru and Mandya to 18.3°C in Dharwad, with the increase in minimum temperature being in the range 0.3°C–0.65°C (Figure 5, right panel).

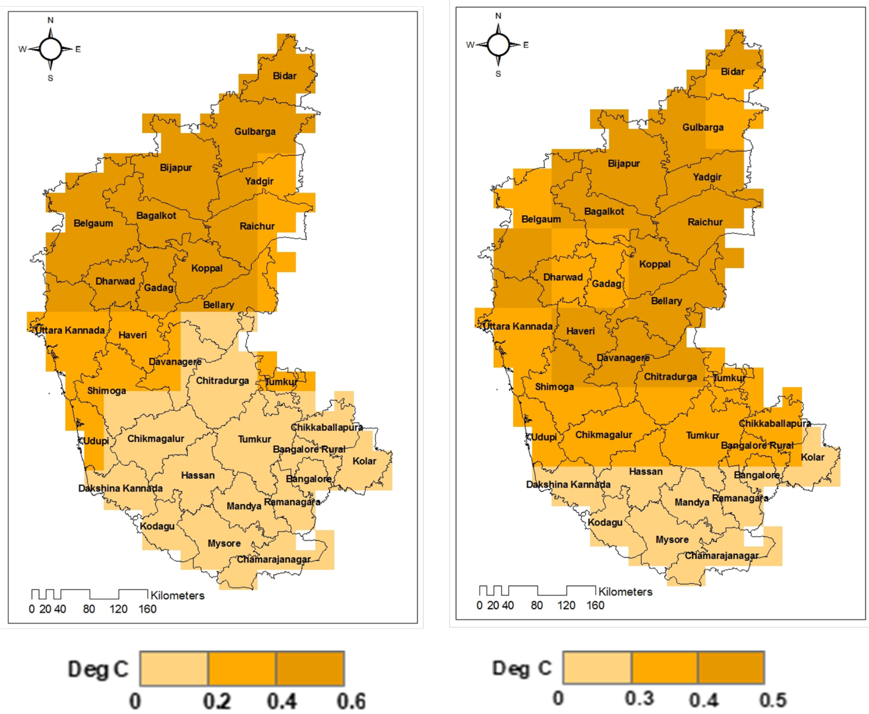


Figure 5: Trends in summer maximum (left) and winter minimum (right) temperature (°C) during 1990–2019

3.2. Trends in Rainfall

Total rainfall and its distribution are critical for agriculture. The trends in rainfall in the districts were analysed for the kharif (June–September) and rabi (October–December) seasons during the period 1990–2019. In this section, we discuss the spatial trends in rainfall, and Table 1 presents the mean annual, kharif, and rabi season rainfall for the districts.

The analysis of historical annual rainfall showed an increase in rainfall for most districts (Figure 6, left panel). The increase was up to 25%, with up to 15% increase in the majority of districts. Rainfall increased by up to

- 10% in parts of the northern districts of Kalaburagi, Bidar, Vijayapura, Raichur, Bagalkot, Koppal, etc., and parts of the southern districts of Chamarajanagar, Chitradurga, Tumakuru, Mandya, etc;
- 10–15% in Kolar, Bengaluru Urban, Bengaluru Rural, Chikkamagaluru, Chitradurga, etc;
- 15–20% in parts of the Western Ghats districts of Kodagu, Hassan, Uttara Kannada, Belagavi, etc.;
- 20–25% in parts of the Western Ghats districts of Kodagu, Udupi, Shivamogga, and Uttara Kannada.

In most districts, the kharif season rainfall dominated the annual rainfall, even by up to 92% (Udupi). Further, the kharif season rainfall trends were similar to the annual rainfall trends (Figure 6, right panel).

Annual rainfall **Kharif (June–September) season rainfall**

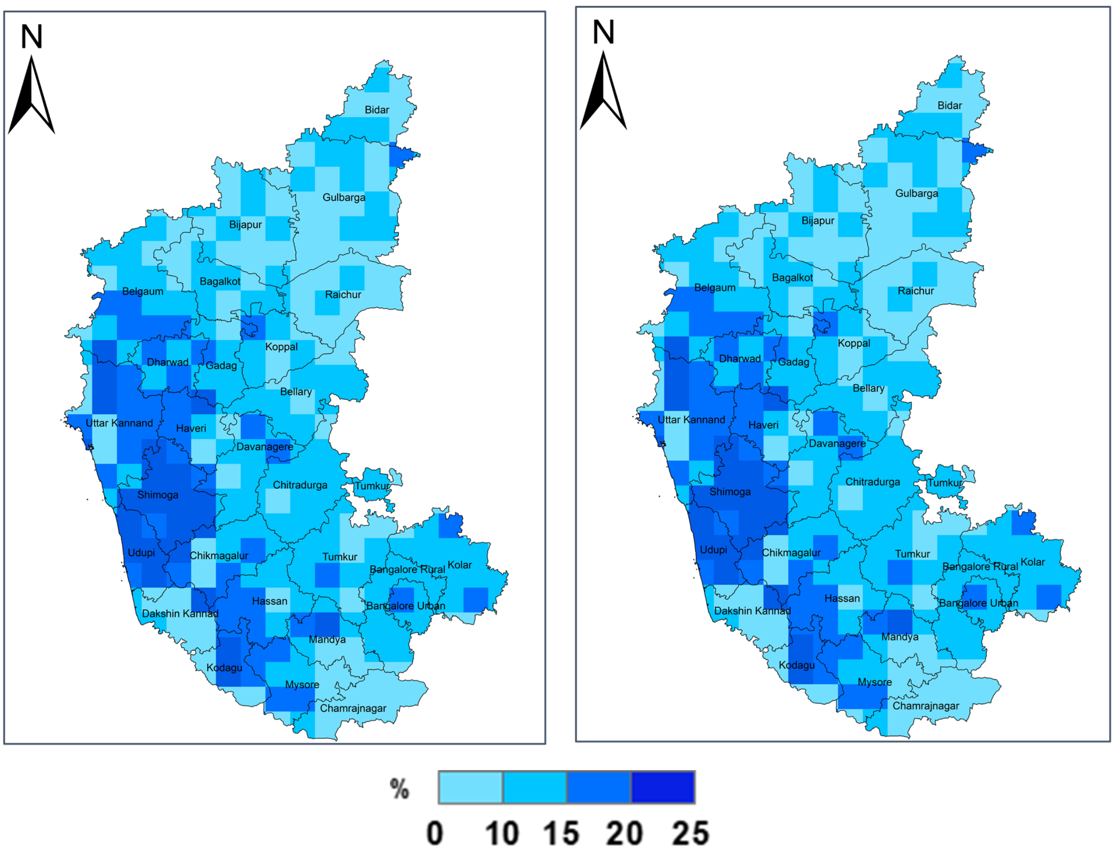


Figure 6: Trends in mean annual and kharif season rainfall (in percentage) during 1990–2019

An increase in the annual and kharif season rainfall was observed, with a relatively higher increase in the wetter Western Ghats districts (in the range 15–25%) compared to the drier central, southern, and eastern districts.

3.2.1. Rainfall Variability

Rainfall variability creates uncertainty and significantly impacts water availability and crop production. In this section, the kharif and rabi season rainfall variability for the period 1990–2019 is analysed (Table 1). Here, coefficient of variation is used as an indicator of rainfall distribution and is expressed as percentage deviation from the long-period average rainfall for the season.

Table 1: Historical (1990–2019) mean annual, kharif, and rabi season rainfall; standard deviation of kharif season rainfall; and coefficient of variation (CV) of kharif and rabi season rainfall

District	Mean Annual Rainfall (mm)	Kharif Season Mean Rainfall (mm)	Kharif Season Rainfall CV (%)	Rabi Season Mean Rainfall (mm)	Rabi Season Rainfall CV (%)
Bagalkot	586	336	46	124	65
Ballari	563	334	42	154	60
Belagavi	1129	693	40	158	57
Bengaluru Rural	819	442	27	224	51
Bengaluru Urban	846	424	31	252	43
Bidar	978	775	28	129	72
Chamarajanagar	659	259	39	251	40
Chikballapur	640	346	39	185	63
Chikkamagaluru	2336	1597	34	205	56
Chitradurga	484	250	43	138	47
Dakshina Kannada	3900	3170	21	506	45
Davanagere	640	356	28	174	65
Dharwad	649	416	30	145	51
Gadag	592	350	38	139	66
Hassan	786	390	31	229	52
Haveri	690	375	36	182	71
Kalaburagi	718	556	36	110	47
Kodagu	2157	1603	33	305	54
Kolar	771	392	33	267	52
Koppal	628	383	34	162	57
Mandya	732	321	42	240	54
Mysuru	781	358	36	243	64
Raichur	643	455	29	114	75
Ramanagara	908	465	30	242	58
Shivamogga	866	591	37	168	77
Tumakuru	847	466	26	215	39
Udupi	4458	3944	16	464	42
Uttara Kannada	2165	1898	29	198	59
Vijayapura	585	340	37	121	65
Yadgir	687	506	26	112	47

Kharif (June to September) season rainfall variability: The coefficient of variation (CV) or variability of kharif season rainfall was generally high, and it ranged from 10% in Chikkamagaluru to 89% in Belagavi. Twenty-four districts had rainfall variability in the range 25–50%, including Bengaluru Rural, Bagalkot, Ballari, Mandya, Gadag, Chitradurga, Vijayapura, Hassan, Bidar, Tumakuru, Shivamogga, Kodagu, Uttara Kannada, and others. Moderate rainfall variability of <25% was recorded in Dharwad, Udupi, Hassan, Dakshina Kannada, and Chikkamagaluru. Notably, around 90% of the districts have a CV greater than 20%, implying that there is deficit or surplus in the mean rainfall during the kharif season.

Rabi (October to December) season rainfall variability: The CV of rabi season rainfall was very large compared to that of kharif season rainfall and ranged from 40% in Dakshina Kannada to 81% in Raichur. A variability of >50% was recorded in 25 of the 30 districts, including Bengaluru Rural, Bagalkot, Ballari, Mandya, Gadag, Chitradurga, Vijayapura, Hassan, Bidar, Belagavi, Kodagu, Chikkamagaluru, Uttara Kannada, Hassan, Shivamogga, and others. High variability of 25–50% was recorded in the remaining five districts of Bengaluru Urban, Chamarajanagar, Tumakuru, Dakshina Kannada, and Udupi.

3.2.2. Extreme Rainfall Events

One of the major consequences of global warming is an increase in the intensity and frequency of extreme weather events. Climate change also leads to changes in the spatial extent, duration, and timing of extreme weather and climate events, sometimes resulting in unprecedented extremes.

> *An extreme (weather or climate) event is generally defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable.*
>
> *—Seneviratne, 2012*

In this section, high-intensity rainfall (>50 mm/day) events that could potentially cause flooding, soil erosion, and crop damage, and 'rainfall-deficient' years that could potentially cause droughts are analysed.

Rainfall-deficient years: The IMD (2018) considers rainfall that is −20% to −59% of the long-period average rainfall as deficient. In this study, years that received a kharif season rainfall of <20% of the long-period average rainfall during the kharif season are considered as rainfall-deficient years. During 1990–2019, rainfall-deficient years were common (ranging from 3 to 11 years in this period) in a majority of the districts in Karnataka (Figure 7, left panel).

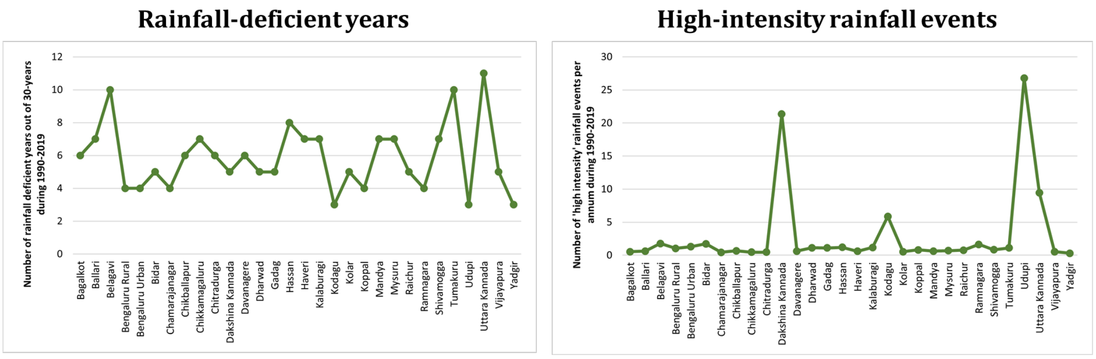


Figure 7: Frequency of rainfall-deficient years (left panel) and high-intensity rainfall events (right panel) during 1990–2019

High-intensity rainfall events: Such events were recorded in 26 of the 30 Karnataka districts during 1990–2019, with 1–2 annual events occurring in a majority of the districts. However, in

Kodagu, Uttara Kannada, Dakshina Kannada, and Udupi, more such events were recorded (Figure 7, right panel).

Temperature analysis revealed that both summer maximum and winter minimum temperatures increased during 1990–2019. Similarly, both annual and kharif season rainfall increased during the historical period. This increase was higher in the wetter Western Ghats districts (in the range 15–25%) than in the drier central, southern, and eastern districts (in the range 10–15%). Further, the kharif and rabi season rainfall variability was high, with implications for agriculture, particularly rainfed agriculture, as evident from the frequent occurrence of high-intensity rainfall events and rainfall-deficient years during the historical period.

3.3. Trends in Area and Yield of Dominant Rainfed Crops in Karnataka

The area under crops in Karnataka in 2017–18 was about 12 Mha, and trends in areas under key categories of crops—food crops, pulses, oilseeds, spices and condiments, fruits, and vegetables—have already been presented in Section 2. Table 2 presents area data for the dominant rainfed crops grown in the various districts of Karnataka.

Table 2: Dominant rainfed crops and area under crops in Karnataka districts

Crops	Area ('000 ha)	Districts
Maize	805	Bengaluru Rural, Belagavi, Chamarajanagar, Chikballapur, Chikkamagaluru, Chitradurga, Davanagere, Dharwad, Hassan, Haveri, Kolar, Koppal, Mandya, Mysuru, Shivamogga, Tumakuru
Sorghum	794	Bagalkot, Belagavi, Bidar, Dharwad, Gadag, Kalaburagi, Haveri, Koppal, Raichur, Yadgir
Ragi	738	Bengaluru Rural, Chamarajanagar, Chikballapur, Chikkamagaluru, Chitradurga, Davanagere, Hassan, Kolar, Mandya, Mysuru, Ramanagara, Tumakuru
Red Gram	690	Bengaluru Rural, Bidar, Vijayapura, Chikballapur, Chitradurga, Davanagere, Kalaburagi, Kolar, Raichur, Ramanagara, Tumakuru, Yadgir
Sunflower	496	Bidar, Vijayapura, Chamarajanagar, Chikkamagaluru, Davanagere, Kalaburagi, Hassan, Koppal, Raichur, Yadgir
Groundnut	341	Bagalkot, Bengaluru Rural, Belagavi, Chamarajanagar, Chikballapur, Chikkamagaluru, Davanagere, Dharwad, Gadag, Hassan, Kolar, Koppal, Ramanagara, Tumakuru, Udupi, Yadgir
Pearl Millet	271	Vijayapura, Kalaburagi, Kolar, Koppal, Raichur, Yadgir
Green Gram	229	Bagalkot, Bidar, Dakshina Kannada, Davanagere, Dharwad, Gadag, Hassan, Yadgir
Cotton	205	Belagavi, Davanagere, Dharwad, Haveri, Koppal, Mysuru, Shivamogga
Chickpea	159	Gadag, Kalaburagi

(*Source: Contingency Plan for Karnataka,* 2011)

In Section 2, it was seen that the area under food crops, pulses, oilseeds, and other crop categories has undergone changes—mainly decreased—during the past decade. Here, we analyse the changes in yield in relation to area for five crops—cereals: maize, sorghum, ragi; pulses: red gram; and oilseeds: groundnut—for which area and yield data are available for a 10-year period (Figure 8). Area and yield data for the period 2007–08 to 2017–18 show:

- Area under maize and red gram have increased by 18% and 29%, respectively, with concurrent increase in yield.
- Area under sorghum, ragi, and groundnut have decreased by 21%, 4%, and 40%, respectively, with a decline in yield of sorghum and ragi. However, in the case of groundnut, despite a decrease in area, the yield increased by 27% during this period.

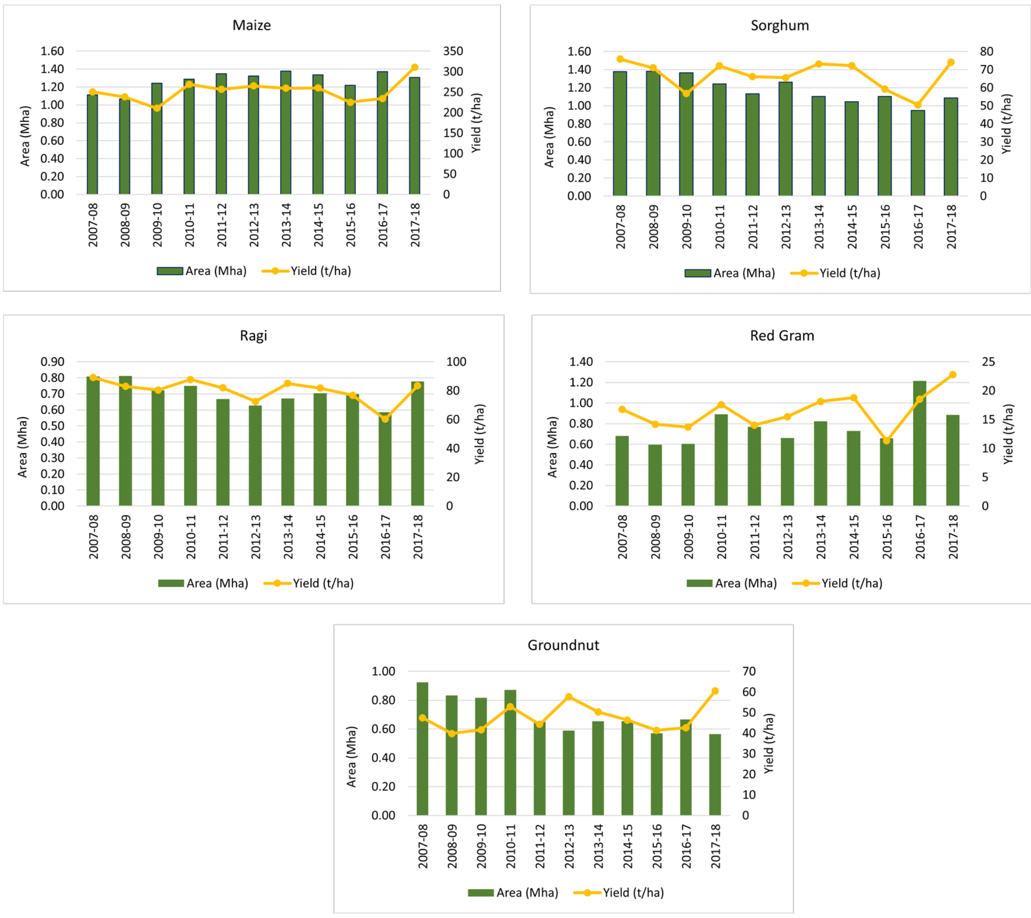


Figure 8: Trends in area and yield for major rainfed crops in Karnataka during the period 2007–08 to 2017–18

3.4. Implications of Climate Variability on Yield

Water availability at different growth stages of agricultural crops is crucial for obtaining a normal yield. A correlation analysis of yield vs. kharif and rabi season rainfall was conducted for the five dominant rainfed crops of Karnataka. The results of the analysis are presented in Table 3. It is evident from the analysis that the correlation between yield and rainfall varies across districts and seasons. Some noteworthy points are presented below:

- ***Maize:*** A positive correlation between kharif season rainfall and yield is observed in all but one (Koppal) of the 16 districts where maize is cultivated. The correlation[4] is, however, weak in most districts and strong only in Chikballapur, Davanagere, and Tumakuru. Further, a positive correlation between rabi season rainfall and yield is observed in 10 of the 16 districts. However, the correlation is strong only in Belagavi and Hassan—positive correlation—and Tumakuru—negative correlation.
- ***Sorghum:*** Of the 10 districts where sorghum is cultivated, a significant positive correlation between kharif season rainfall and yield is observed only in Yadgir. In the

[4]The correlation coefficient can range in value from −1 to +1. A value close to 0 indicates no linear relationship between the variables. The sign of the coefficient indicates the direction of the relationship. If both variables tend to increase or decrease together, the coefficient is positive, and if one variable tends to increase as the other decreases, the coefficient is negative.

remaining districts, a weak positive correlation is observed in all but Bidar. However, for rabi season rainfall, a strong positive correlation is observed in 7 of the 10 districts.

- ***Ragi:*** Of the 12 districts where ragi is cultivated, a significant positive correlation between yield and kharif season rainfall is observed in five districts, and a significant positive correlation between yield and rabi season rainfall is observed in six districts.
- ***Red gram:*** A significant positive correlation between yield and kharif season rainfall is observed in 3 of the 12 districts where red gram is cultivated. In the remaining districts, a weak correlation is observed.

Table 3: Analysis of correlation between yield and rainfall for kharif and rabi crops

District	Maize		Sorghum		Ragi		Red Gram	Groundnut	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Kharif	Rabi
Bagalkot			0.09	**0.46**				0.01	0.10
Belagavi	0.33	0.45	0.01	**0.52**				-0.40	**-0.69**
Bengaluru Rural	0.34	-0.13			0.27	0.16	0.23	0.25	-0.30
Bidar			-0.19	0.23			**0.52**		
Chamarajanagar	0.24	-0.02			0.17	0.14		-0.01	0.08
Chikballapur	0.45	-0.36			0.00	**0.74**	0.06	**0.48**	**0.79**
Chikkamagaluru	0.21				0.60	**0.86**		0.34	-0.25
Chitradurga	0.04	0.22			0.31	0.44	0.38		
Davanagere	**0.54**	0.15			**0.51**	0.35	0.44	**0.61**	-0.42
Dharwad	0.25	0.36	0.04	**0.77**				-0.08	-0.14
Gadag			0.38	0.35				0.38	0.01
Hassan	0.36	0.43			**0.58**	**0.60**		0.08	0.08
Haveri	0.28	0.05	0.38	**0.73**					
Kalaburagi			0.09	0.36			**0.58**		
Kolar	0.30	-0.02			0.07	0.37	-0.08	0.12	-0.24
Koppal	-0.01	0.21	0.39	**0.48**				0.35	0.17
Mandya	0.39	0.32			**0.70**	0.28			
Mysuru	0.18	0.14			**0.48**	**0.50**			
Raichur			0.20	**0.47**			0.34		
Ramanagara					0.18	**0.68**	**0.54**	0.27	**-0.49**
Shivamogga	0.29	0.18							
Tumakuru	**0.49**	-0.44			**0.61**	**0.53**	0.34	0.21	-0.21
Udupi								0.35	
Vijayapura							0.17		
Yadgir			**0.52**	**0.70**			0.41	-0.11	-0.40

- ***Groundnut:*** Groundnut is cultivated in 16 districts of Karnataka. A strong positive correlation between yield and kharif season rainfall is observed in only Chikballapur and Davanagere. In Belagavi, Chamarajanagar, Dharwad, and Yadgir, a weak but negative correlation between yield and kharif season rainfall is observed. During the rabi season, in 9 of the 16 districts, a negative correlation between yield and rainfall is observed with the correlation being significant in Belagavi and Ramanagara. In the remaining districts, a positive correlation is observed with it being significant only in Chikballapur.

The results obtained in this study for correlation between yield and rainfall are in concurrence with those reported by Revadekar and Preethi (2012), wherein the correlation between kharif rainfall and yield was reported to be stronger than that between rabi rainfall and yield. This is because the yield of crops grown during the rabi season is dependent on not only the kharif season precipitation but on the northeast monsoon as well.

A similar correlation analysis was conducted for yield vs. summer maximum temperature for the top five crops. However, no correlation was found for any of the crops. Jacoby et al. (2011), Guiteras (2007), and Schlenker and Roberts (2006) have also reported that the effect of temperature on crop yield is generally non-linear, as found in this study.

Notably, many of the Karnataka districts were affected by droughts and floods during the period 2007–08 to 2017–18. About 63 lakh hectares of cropped area is reported to have been affected by natural disasters as of 25/03/2019 (Disaster Management Division, Ministry of Home Affairs). The Karnataka districts are prone to two extreme calamities—droughts and floods. Drought has been recorded in several districts of the state since 2001. In 2019, the Karnataka districts faced the dual wrath of droughts and floods, with 16 districts bearing the impact of both climate extremes.

3.5. Summary of Trends in Historical Temperature, Rainfall, and Implications for Yield

It is clear from the historical climate analysis that:

- There is a warming trend in both summer maximum and winter minimum temperatures, and the mean annual and kharif season rainfall has increased during this period.
- Despite the increase in mean rainfall, the state has recorded several drought and flood events during this period — an indication of the increasing climate variability.

The implications of these changes in temperature and rainfall on crop yield of five of the dominant rainfed crops was analysed. It shows that:

- Correlation between kharif season rainfall and yield is significant for four of the five crops, except sorghum.
- Correlation between rabi season rainfall and yield is significant in the case of sorghum, ragi, red gram, and groundnut in a few districts.
- Temperature has no correlation with yield of the five crops analysed in any of the districts.

Projected increase in temperature

0.5°C–1.5°C
Summer maximum

0.5°C–2°C
Winter minimum

Projected increase in rainfall

Kharif

RCP 4.5: **2–17%** increase in rainfall projected

RCP 8.5: **5–26%** increase in rainfall projected

Rabi

RCP 4.5: **1–27%** increase in rainfall projected

RCP 8.5: **2–34%** increase in rainfall projected

2030s

1990–2019

2021–2050

4. Projected Climate Change in Karnataka

In this section, the results of a modelling analysis for temperature and rainfall over the future period of 2021–2050 (2030s) are presented and compared with the corresponding data for 1990–2019. The likely changes are also discussed. The results of this assessment form the basis for a climate risk analysis of three dominant crops grown under rainfed conditions in Karnataka, the details of which are presented in Section 5.

Climate-related hazards manifest locally, and the impacts of climate risk need to be understood in that context. Climate risk creates spatial inequality, as it may simultaneously benefit some regions while adversely impacting others.

In this context, an analysis of climate at the district level for Karnataka has been conducted to assess the emerging climate risks.

4.1. Approach and Methods

Data modelled by the Coordinated Regional Climate Downscaling Experiment (CORDEX) South Asia (Appendix 1) on rainfall and temperature have been analysed for districts of Karnataka. The ensemble mean values from bias-corrected 15 CORDEX simulations of 0.5° × 0.5° resolution are used for estimating climate change projections. All data in this analysis are first re-gridded to a common 0.25° × 0.25° resolution to agree with the resolution of IMD data.

The analysis has been conducted for two of the four Intergovernmental Panel on Climate Change (IPCC) climate scenarios or representative concentration pathways (RCPs), namely, RCP 4.5 and RCP 8.5. These pathways refer to a range of future anthropogenic greenhouse gas emissions and their atmospheric concentrations.

- ***RCP 4.5 scenario:*** This scenario is described by the IPCC as an intermediate scenario with emissions peaking in 2040 and then declining. This scenario will quite likely result in a global temperatu re increase of 2°C.
- ***RCP 8.5 scenario:*** This is the worst-case scenario in which emissions continue to rise throughout the 21st century. This is likely to result in a global temperature increase of up to 2.6°C.

Changes in temperature and rainfall during the projected period are computed as a difference between the model-simulated 15-model ensemble[5] average values for the 30-year historical period and the projected 30-year period. District-level averages of climatic variables are obtained using outputs from the re-gridded 0.25° × 0.25° resolution data. The mean value for a district is obtained as the mean of the values for multiple grids that may cover a district. For this computation, only grids that fall fully within a district and those with >60% area falling within a district, are considered. If a district falls within only one grid cell, that single grid cell value is considered.

[5] An ensemble is a group of climate model simulations used for climate projections.

4.2. Projected Changes in Temperature

Summer maximum and winter minimum temperatures are analysed as they are crucial for agricultural crop growth and productivity.

4.2.1. Summer Maximum Temperature

An increase in the summer maximum temperature of 0.5°C–1.5°C is projected in the short term, considering RCP 4.5 and RCP 8.5 scenarios (Figure 9).

Under the RCP 4.5 scenario, (for the 2030s), warming is projected to be in the range 0.5°C–1°C for the Western Ghats districts. In the northern districts, and some of the central and eastern districts such as Chitradurga, Tumakuru, and Davanagere, warming in the range 1°C–1.5°C is projected for the short term.

Under the RCP 8.5 scenario, warming is projected to be in the range 0.5°C–1°C for the Western Ghats districts. For all the northern and eastern districts, warming is projected to be higher—in the range 1°C–1.5°C for the short term.

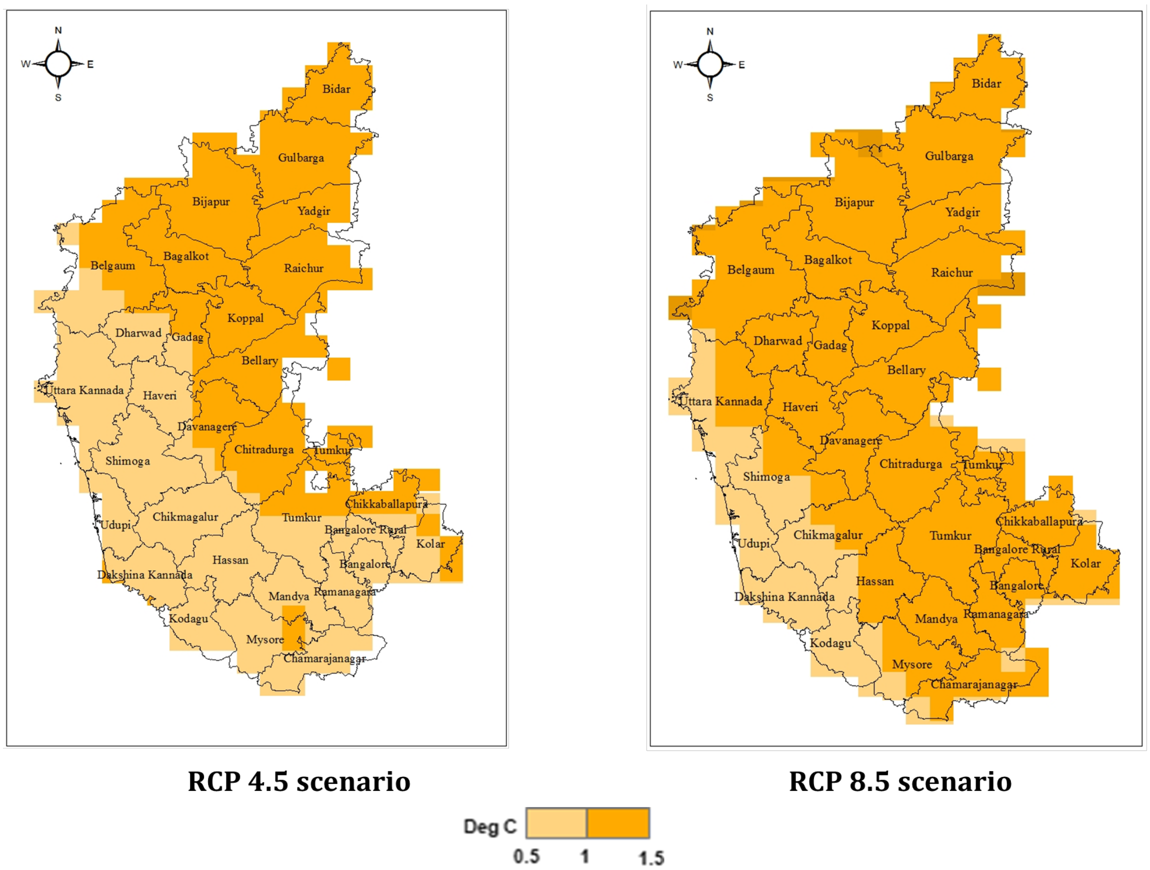


Figure 9: District-wise projected changes in summer maximum temperature (°C) for the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

4.2.2. Winter Minimum Temperature

An increase in the winter minimum temperature of 0.5°C–2°C is projected in the short term, considering the RCP 4.5 and RCP 8.5 scenarios (Figure 10).

Under the RCP 4.5 scenario, warming in the range 0.5°C–1.5°C is projected across the districts. The warming is higher in the northern districts—in the range 1°C–1.5°C. In the southern and central districts, lower levels of warming—in the range 0.5°C–1°C—are projected.

Under the RCP 8.5 scenario, warming in the range 0.5°C–1°C is projected for the southern and eastern districts; 1°C–1.5°C for the central and western districts; and 1.5°C–2°C for the northern-most districts.

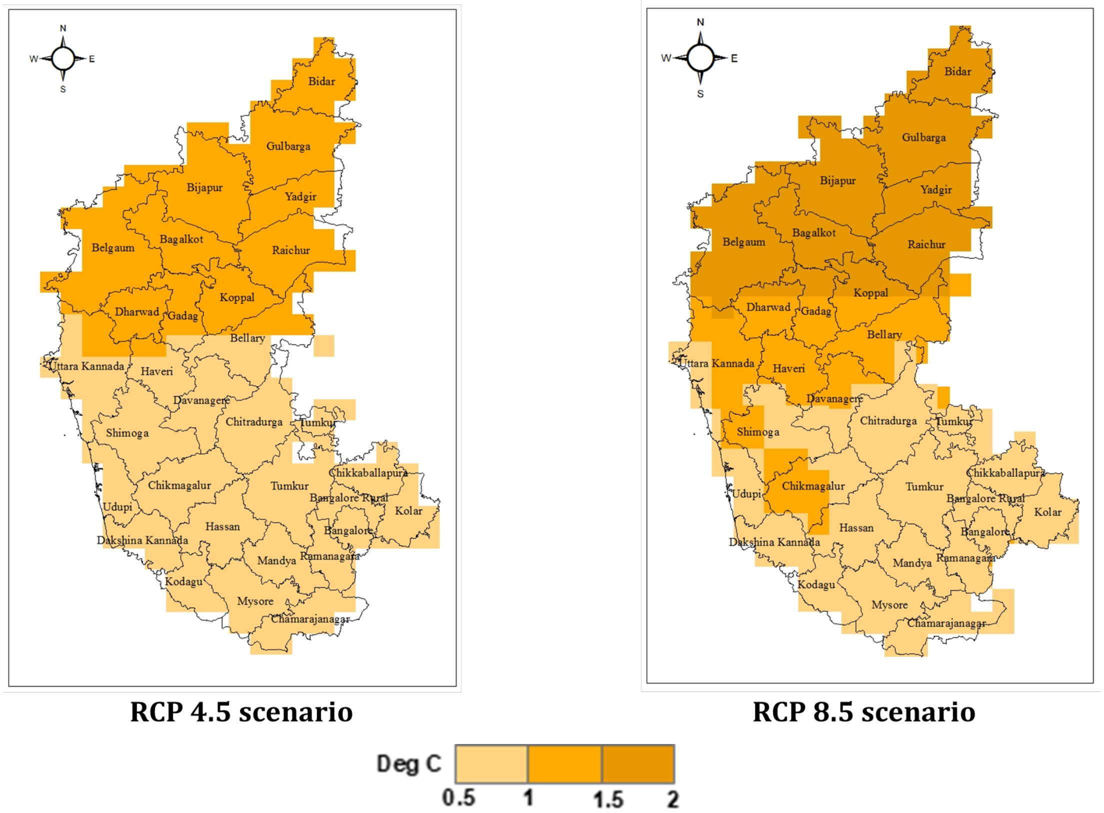


Figure 10: District-wise projected changes in winter minimum temperature (°C) for the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

4.3. Projected Changes in Rainfall

Rainfall is analysed for kharif and rabi seasons separately. In addition to the total quantum of rainfall during a season, the variability of rainfall and extreme events—high-intensity rainfall and rainfall deficiency—are also projected.

4.3.1. Changes in Kharif Season Rainfall and Variability During the Projected Period

Changes in kharif season rainfall and the coefficient of variation or rainfall variability under projected RCP 4.5 and RCP 8.5 scenarios are discussed here.

RCP 4.5 Scenario

An increase in kharif season rainfall—relative to the historical period—of 2–17% is projected for the Karnataka districts (Figure 11).

- The projected increase is >10% for 8 of the 30 districts.

During this period, the variability of rainfall is projected to decline in 10 districts and increase in the remaining 20 districts (Figure 12).

- The projected decline in CV is in the range 1–7%.
- The projected increase in CV is larger and is in the range 1–14%.

RCP 8.5 Scenario

An increase in kharif season rainfall—relative to the historical period—of 5–26% is projected for the Karnataka districts (Figure 11).

- The projected increase is >15% in 12 of the 30 districts.

During this period, the variability of rainfall is projected to decline in 14 districts, remain unchanged in Uttara Kannada, and increase in the remaining 15 districts (Figure 12).

- The projected decline in CV is in the range 1–9%.
- The projected increase in CV is larger than the corresponding value for the historical period and is in the range 1–10%.

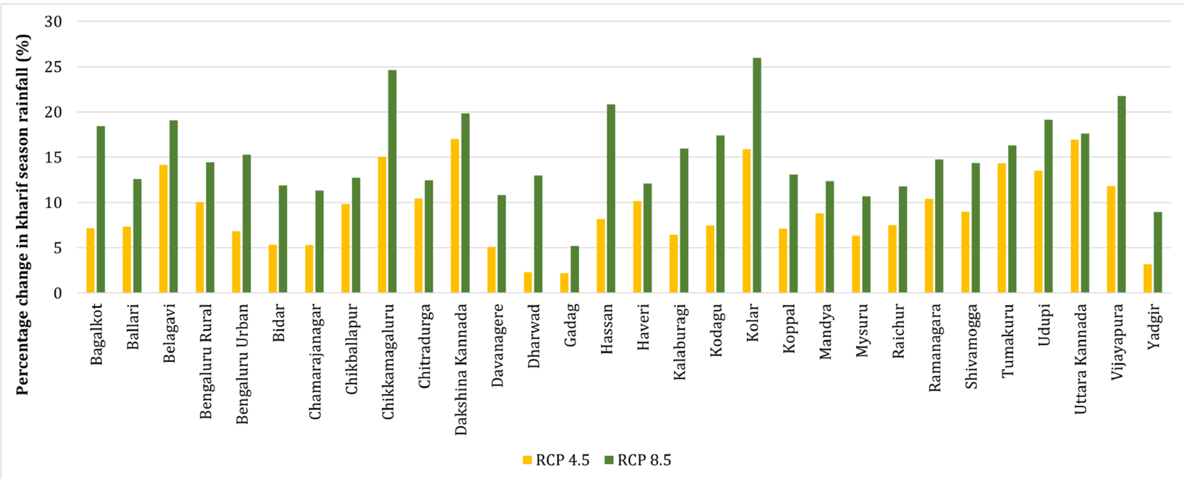


Figure 11: Projected percentage changes in kharif season rainfall relative to the historical period (1990–2019) during the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

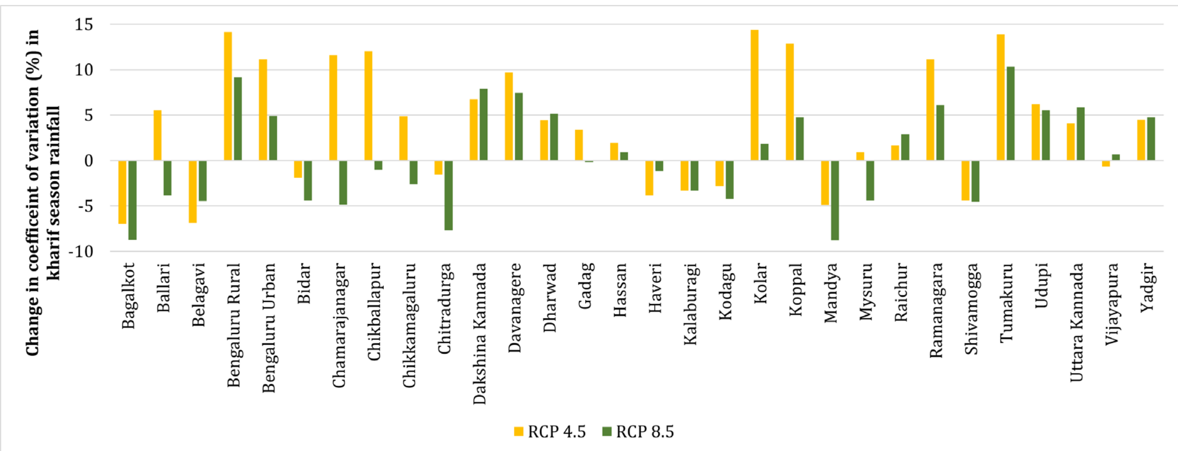


Figure 12: Changes in variability (CV) of kharif season rainfall during the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

4.3.2. Projected Changes in Sowing Rains during the Kharif Season

Monsoon arrives in Karnataka in June. Rainfall during this month is critical for crop production. The decision of farmers on the cropping pattern depends on the extent of rainfall received in June. Projections of rainfall to be received during June over the 30-year short-term period is compared with the rainfall data available for the historical period.

It is evident from Figure 13 that in a majority of the districts, significant rainfall is received in June. Projections of rainfall during June indicate that there is a general increase in the amount of rainfall received in many of the districts.

RCP 4.5 Scenario

In 17 of the 30 districts, an increase in June rainfall—relative to the historical period—of 3–63% is projected, and in 10 districts, a decline in the range 1–36% is projected. In Koppal, Dakshina Kannada, and Mysuru districts, no change relative to the historical period is projected.

- Of the 17 districts for which an increase in June rainfall is projected,
    - An increase of >30% is projected for five districts—Chitradurga, Chikkamagaluru, Chamarajanagar, Gadag, and Tumakuru.
    - An increase of 21–30% is projected for six districts—Mandya, Raichur, Vijayapura, Yadgir, Haveri, and Kalaburagi.
    - An increase of 3–15% is projected for six districts—Bagalkot, Ballari, Davanagere, Ramanagara, Shivamogga, and Uttara Kannada.
- Of the ten districts for which a decline in June rainfall is projected,
    - A decline of 18% is projected for Chikballapur and Bengaluru Urban districts, and a decline of 36% for Kolar.
    - A decline of 1–15% is projected for Hassan, Belagavi, Dharwad, Kodagu, Udupi, Bidar, and Bengaluru Rural.

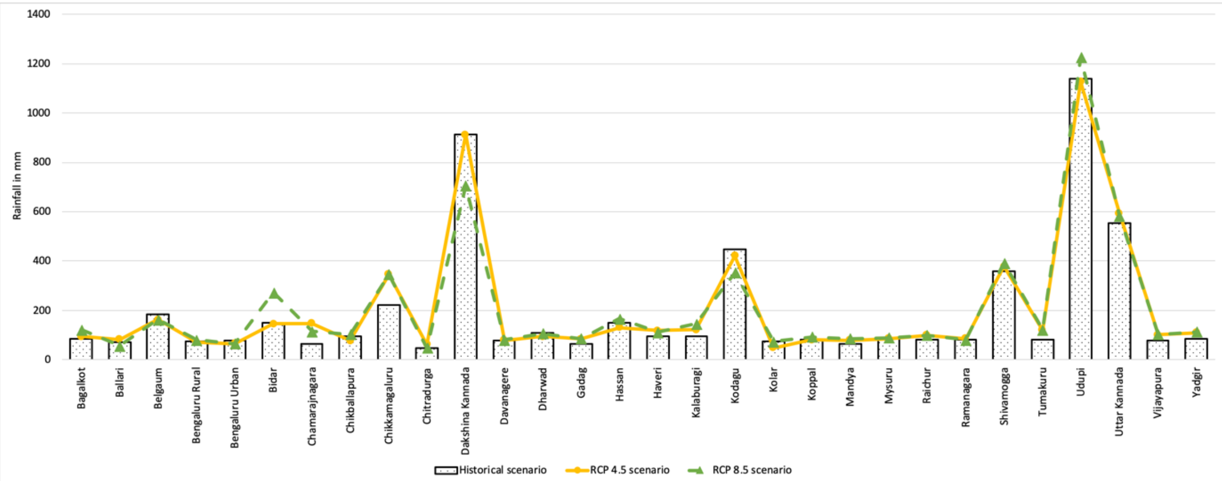


Figure 13: Historical and projected rainfall for June

RCP 8.5 Scenario

In 21 of the 30 districts, an increase in June rainfall—relative to the historical period—of 4–81% is projected, and in seven districts, a decline in the range 1–23% is projected. In Dharwad and Chitradurga districts, no change relative to the historical period is projected.

- Of the 21 districts for which an increase in June rainfall is projected,
  - An increase of 50–100% is projected for five districts—Bidar, Chikkamagaluru, Chamarajanagar, Kalaburagi, and Tumakuru.
  - An increase of 25–50% is projected for five districts—Chikballapur, Mysuru, Bengaluru Rural, Bagalkot, and Tumakuru.
  - An increase of 10–25% is projected for six districts—Bagalkot, Gadag, Mandya, Yadgir, and Vijayapura.
  - An increase of 1–10% is projected for five districts—Bengaluru Rural, Davanagere, Mysuru, Udupi, and Uttara Kannada.
- Of the seven districts for which a decline in June rainfall is projected,
  - A decline of 1–15% is projected for three districts—Belagavi, Kolar, and Ramanagara.
  - A decline of 18–23% is projected for four districts—Ballari, Bengaluru Urban, Dakshina Kannada, and Kodagu.

4.3.3. Changes in Rabi Season Rainfall and Variability during the Projected Period

Under RCP 4.5 and RCP 8.5 scenarios, the quantitative increase in rabi season rainfall—relative to the historical period—is projected to be in the range 2–34% in the short term, while the variability of rainfall is projected to decline in almost all the districts.

RCP 4.5 Scenario

An increase in rabi season rainfall—relative to the historical period—of 1–27% is projected for all districts, except Uttara Kannada where there will be no change (Figure 14).

- The projected increase is >10% in 14 districts.

The rainfall variability during the same period is projected to decline in the range 1–35% in 24 districts (Figure 15).

- In the following six districts, an increase in rainfall variability in the range 4–16% is projected—Chamarajanagar, Bengaluru Urban, Tumakuru, Udupi, Kalaburagi, and Yadgir.

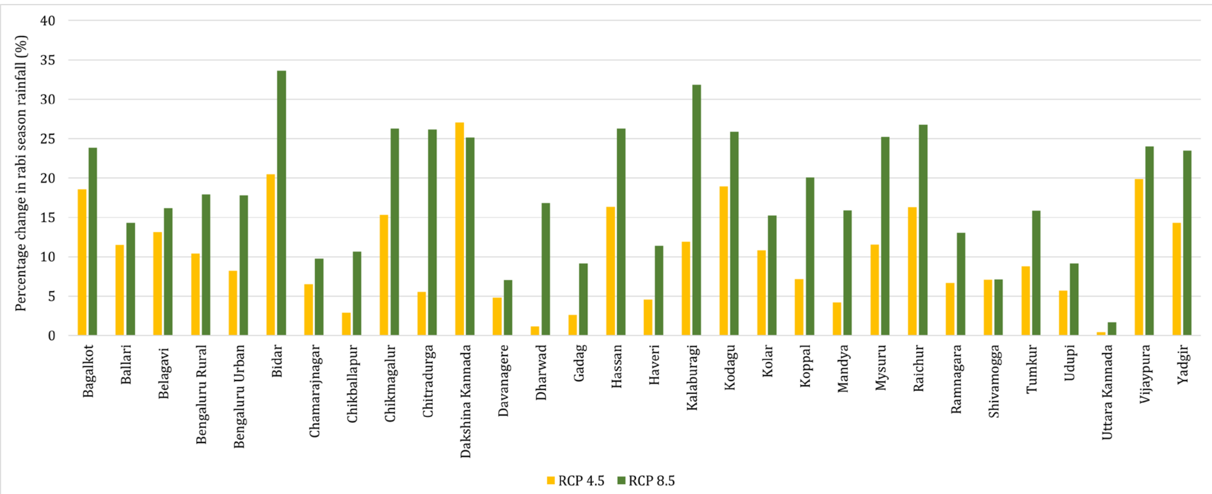


Figure 14: Projected percentage changes in rabi season rainfall relative to the historical period (1990–2019) during the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

RCP 8.5 Scenario

An increase in rabi season rainfall—relative to the historical period—of 2–34% is projected for all Karnataka districts (Figure 14).

- The projected increase is >20% in 12 of the 30 districts.

The rainfall variability during the same period is projected to decline in the range 7–43% in 26 districts (Figure 15). The decline in rainfall variability is >20% in the following 13 districts—Koppal, Yadgir, Bagalkot, Vijayapura, Dakshina Kannada, Mysuru, Kodagu, Chitradurga, Chikmagaluru, Hassan, Raichur, Kalaburagi, and Bidar.

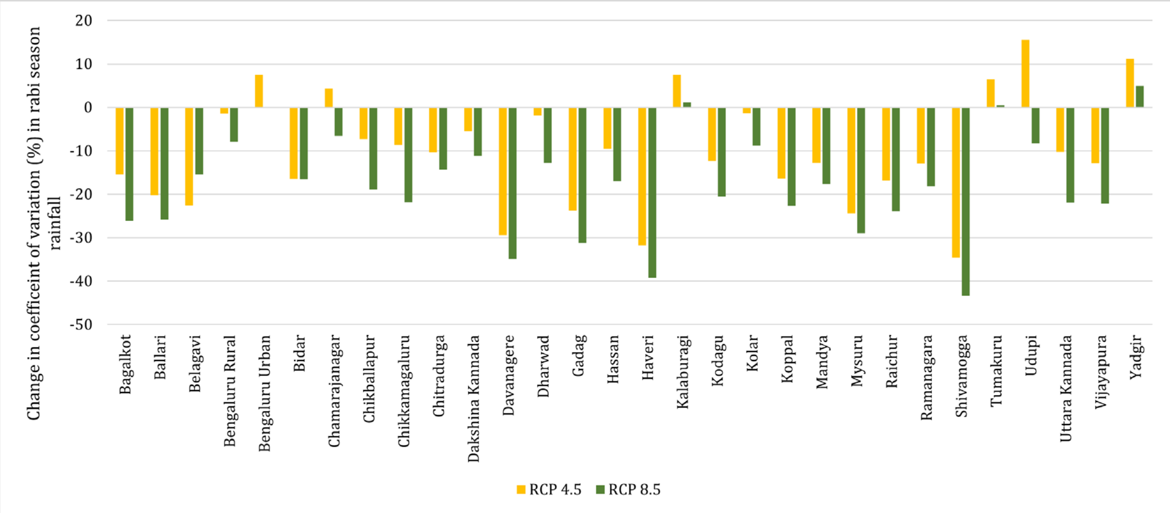


Figure 15: Changes in variability (CV) of rabi season rainfall during the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

Overall, rainfall in Karnataka is projected to increase during the kharif and rabi seasons, compared to the historical period of 1990–2019. An important aspect of rainfall is its distribution, and it determines agricultural productivity.

- An analysis of rainfall variability during the kharif season for the state districts shows that it is likely to decline in some districts and increase in others during the projected period, considering RCP 4.5 and RCP 8.5 scenarios. Increasing rainfall with an increase in variability will have adverse implications for crop growth, yield, and productivity.
- Conversely, the rabi season rainfall variability is projected to decline in almost all the Karnataka districts during the projected period, which could contribute positively to crop production, particularly rainfed crops. The implications of these changes are discussed in Section 5.

4.4. Projected Changes in the Frequency of Occurrence of Extreme Events

According to IMD, a rainy day is defined as one receiving >2.5 mm rainfall. In Karnataka, an increase in the number of rainy days is projected for almost all the districts, under both RCP 4.5 and RCP 8.5 scenarios. The increase in the number of rainy days under RCP 4.5 and RCP 8.5 scenarios is ≥5 days annually in 4 and 16 districts, respectively. The following sections present an analysis of the number of days likely to receive high (51–100 mm/day) or very high (>100 mm/day) intensity rainfall during the 2030s, and the number of years likely to be rainfall deficient during the same period in comparison to the historical period of 1990–2019.

Heavy Rainfall Events

For this analysis, rainfall events are categorised on the basis of the intensity of rainfall received per day: <50 mm, 51–100 mm (high intensity), and >100 mm (very high intensity). In this section, changes in the number of rainfall events—relative to the historical period—in the high- and very-high-intensity categories are presented, as they have implications for crop growth and productivity.

High-Intensity Rainfall (51–100 mm/Day) Events (Figure 16)

RCP 4.5 Scenario

An increase in high-intensity rainfall events—relative to the historical period—is projected for all the Karnataka districts, except Vijayapura. The increase is in the range 1–5 events annually over the projected 30-year period. A higher increase in high-intensity rainfall events (3–5 events annually) is projected for the high rainfall districts of Dakshina Kannada, Udupi, Uttara Kannada, and Kodagu.

RCP 8.5 Scenario

An increase in high-intensity rainfall events—relative to the historical period—is projected for all districts in the state. The increase is in the range 1–7 events annually over the projected 30-year period. A higher increase in high-intensity rainfall events (4–7 events annually) is projected for the high rainfall districts of Dakshina Kannada, Udupi, and Uttara Kannada.

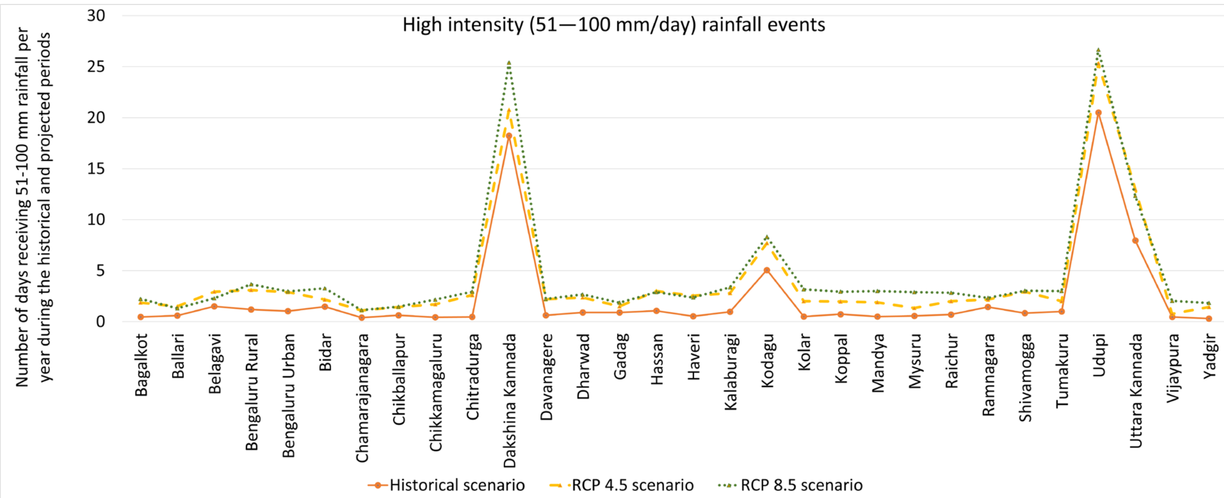


Figure 16: Frequency of high-intensity rainfall events (51–100 mm/day) per year during historical and projected short-term periods under RCP 4.5 and RCP 8.5 scenarios

Very-High-Intensity Rainfall (>100 mm/Day) Events (Figure 17)

RCP 4.5 Scenario

An increase in very-high-intensity rainfall events—relative to the historical period—is projected for 25 of the 30 districts. The projected increase is in the range 1–2 events annually over the projected 30-year period. No change relative to the historical period is projected for Kolar, Ballari, Bagalkot, Vijayapura, and Udupi.

RCP 8.5 Scenario

An increase in very-high-intensity rainfall events—relative to the historical period—is projected for all the districts, except Gadag and Uttara Kannada. The increase is in the range 1–3 events annually over the projected 30-year period.

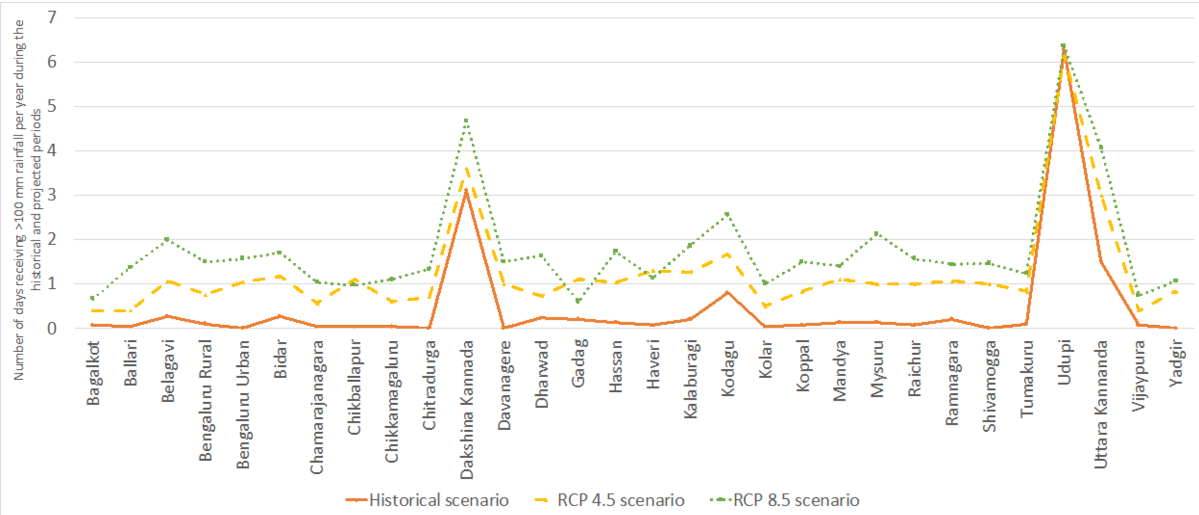


Figure 17: Frequency of very-high-intensity rainfall events (>100 mm/day) per year during historical and projected short-term periods under RCP 4.5 and RCP 8.5 scenarios

The occurrence of high-intensity rainfall is an indicator of flood-causing rainfall events. More than 100 mm of rain/day may cause excessive runoff and even flooding, leading to crop damage. These high-intensity rainfall events could damage the soil and water conservation structures that may have been created.

Rainfall-Deficient Years

Changes in the occurrence of rainfall-deficient years for the short-term period under RCP 4.5 and RCP 8.5 scenarios, considering the kharif season rainfall, are presented in Figure 18. Under both the scenarios, a decline in the frequency of occurrence of rainfall-deficient years is projected for a majority of the districts.

RCP 4.5 Scenario

A decline of 1–2 years—compared to the historical period—is projected for 12 districts, while an increase of 1 year is projected for only Chikkamagaluru. In 17 districts, no change in the number of rainfall-deficient years, relative to the historical period, is projected.

RCP 8.5 Scenario

A decline of 1–3 years—compared to the historical period—is projected for 28 of the 30 districts. In Kolar and Bengaluru Rural, no change relative to the historical period is projected.

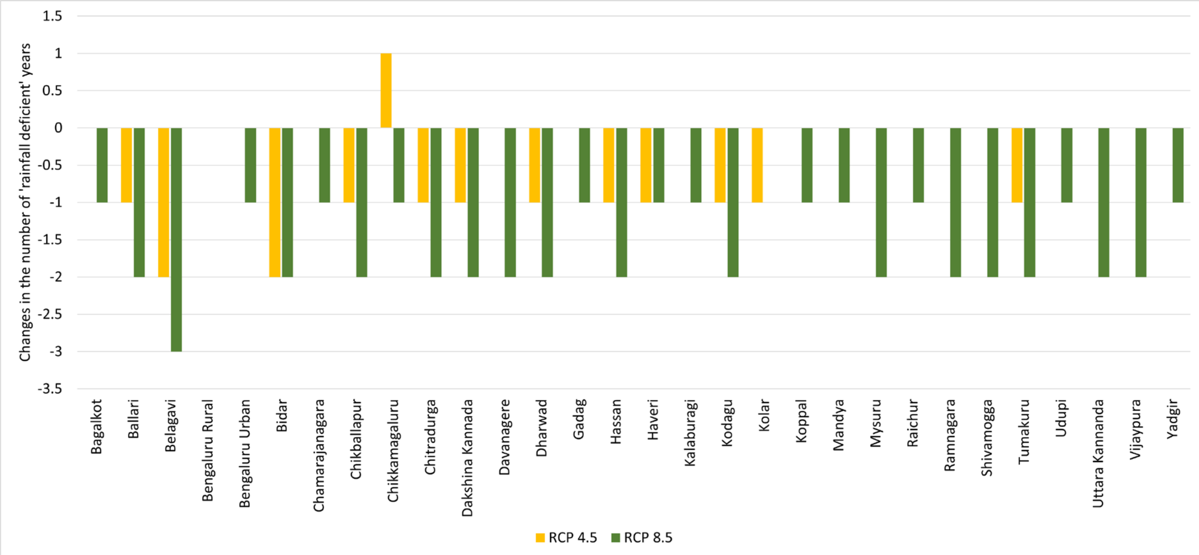


Figure 18: Changes relative to the historical period in the number of rainfall-deficient years during the projected period under RCP 4.5 and RCP 8.5 scenarios

4.5. Summary of Trends in Projected Temperature and Rainfall

Following are the key highlights of climate projections for the Karnataka districts when compared to the historical period:

- ***Temperature:*** An increase in both summer maximum by 0.5°C–1.5°C (Figure 9) and winter minimum temperature by 0.5°C–2°C (Figure 10).
- ***Rainy days*:** An increase in the number of rainy days by 1–8 days in 25 districts under the RCP 4.5 scenario and by 1–13 days under the RCP 8.5 scenario (Figure 19).
- ***Magnitude of rainfall and variability:*** An increase in the kharif (Figure 11) and rabi season (Figure 14) rainfall by up to 26% and 34%, respectively, under the RCP 8.5 scenario, but mixed trends in rainfall variability—an increase in a few districts, decline in a few, and no change in others—for both kharif and rabi season rainfall.
- ***Sowing rainfall:*** Changes in the magnitude of sowing rainfall received during June, with an increase in a majority of the districts and a decline in a few districts (Figure 13).
- ***Extreme events:*** A large decline in the number of rainfall-deficient years by 1–3 years (Figure 19) and a concurrent large increase in the number of high-intensity rainfall events (Figure 20).

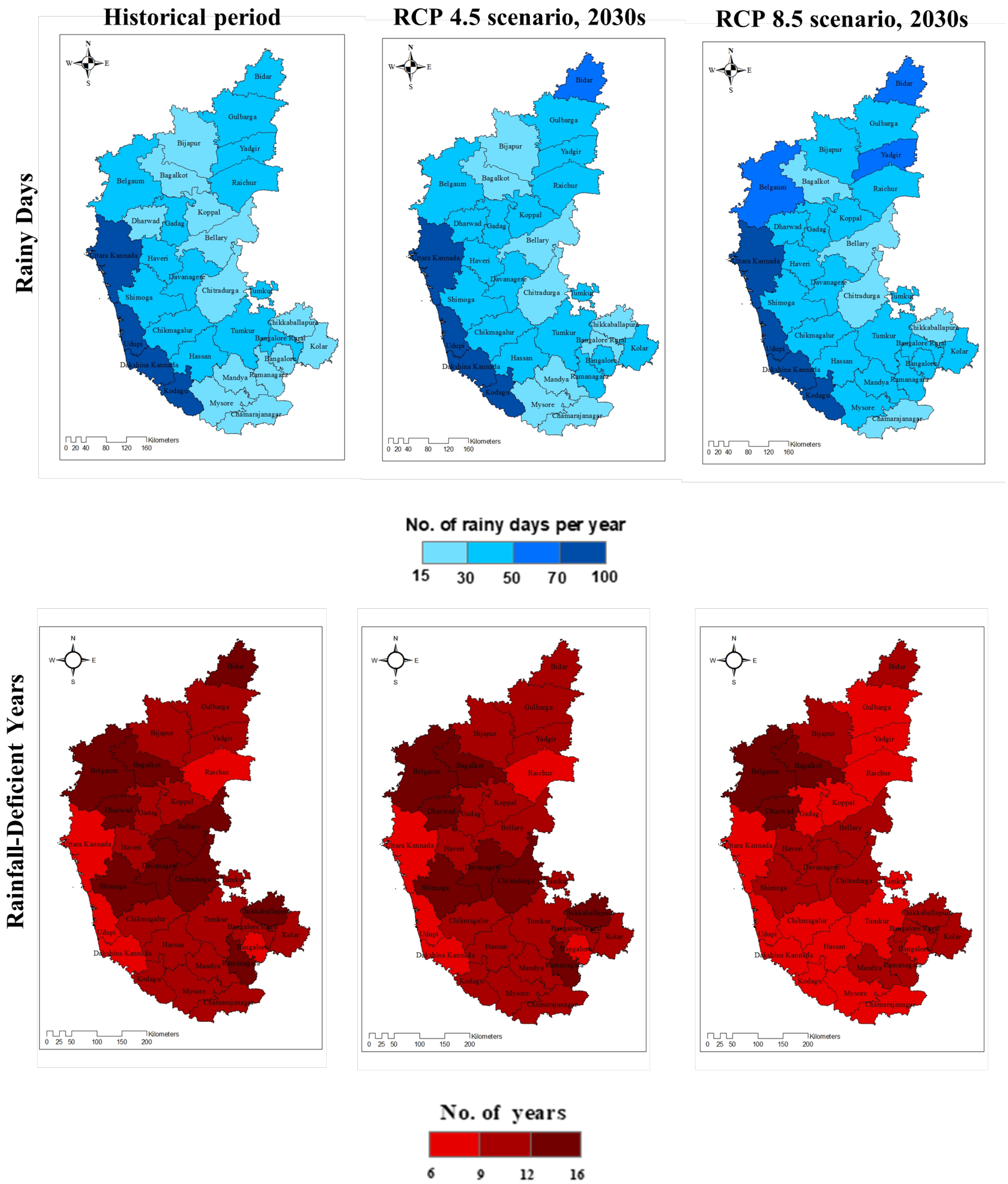


Figure 19: Number of rainy days and rainfall-deficient years during the historical period (1990–2019) and projected short-term period (2021–50) under RCP 4.5 and RCP 8.5 scenarios

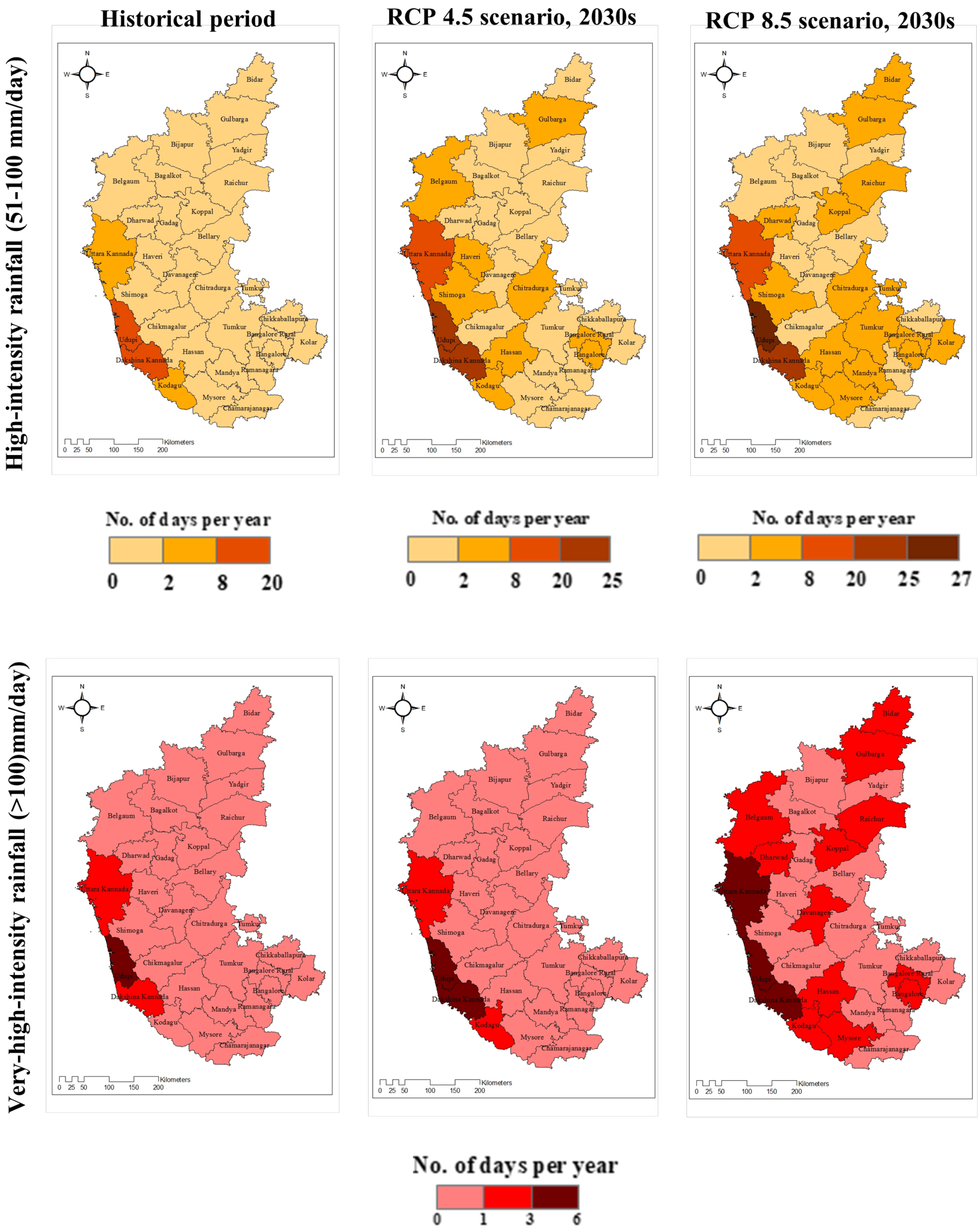
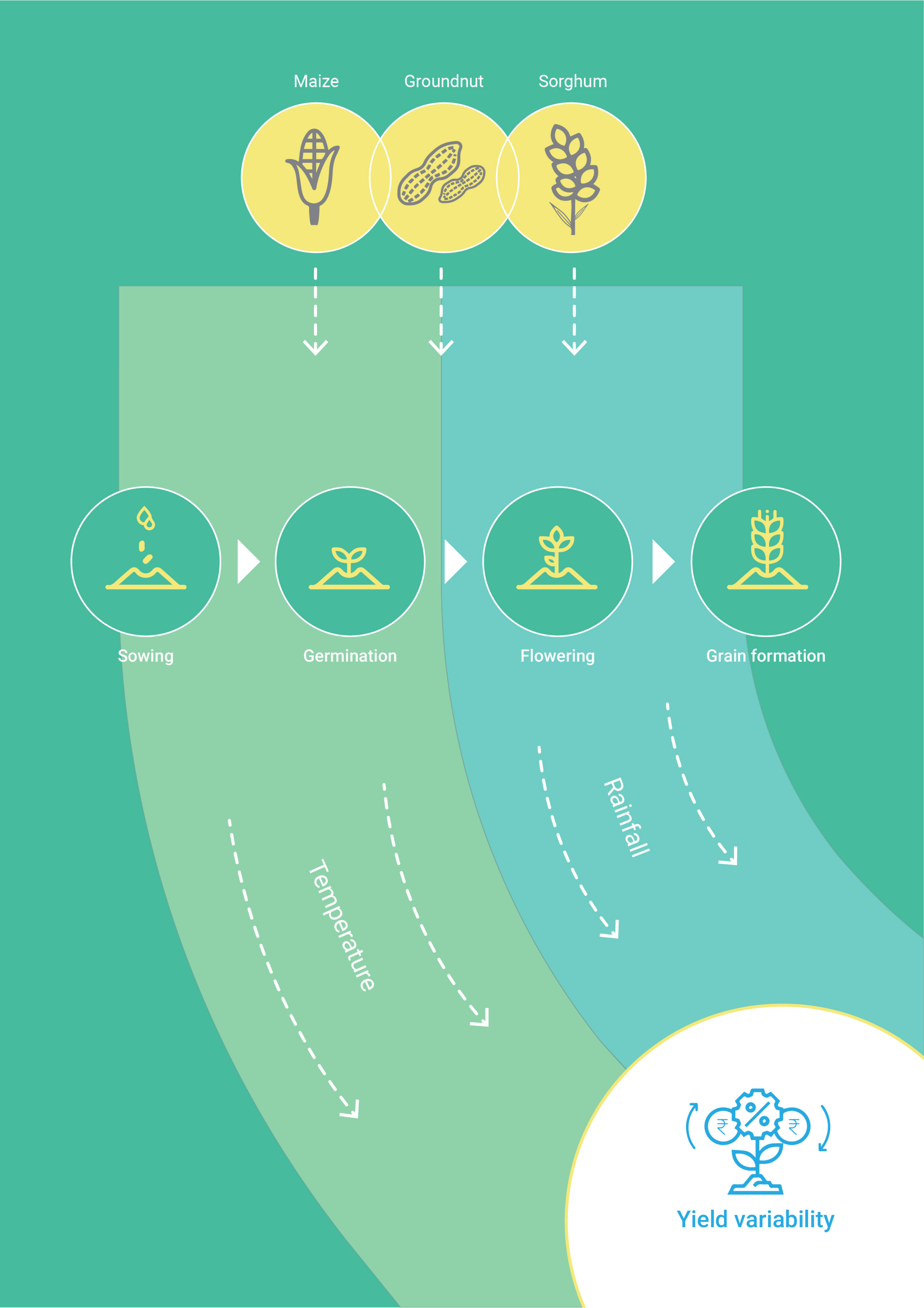


Figure 20: Number of high- and very-high-intensity rainfall events per year during the historical period (1990–2019) and projected short-term period (2021–50) under RCP 4.5 and RCP 8.5 scenarios

In Section 5, we analyse the risks posed by the projected changes in temperature, rainfall, and rainfall variability, including high-intensity rainfall events, to productivity of the three dominant rainfed crops of Karnataka—maize, sorghum, and groundnut—considering the cropping calendar, crop thresholds, and climate parameters.


Maize
Groundnut
Sorghum
Sowing
Germination
Flowering
Grain formation
Temperature
Rainfall
Yield variability

5. Risks of Climate Change to Crop Production and Implications

Climate determines the growth and productivity of crops. The crop–weather relationship has been studied by several scientists (Varma et al., 2007; Sarkar, 2005; Sarkar and Thapliyal, 2003). Studies have also investigated the impact of droughts and floods on food grain production (Krishna Kumar et al., 2004; Selvaraju, 2003; Kulshreshtha, 2002) and the resulting impact on economy (Gadgil et al., 1999; Kumar and Parikh, 1998).

The potential crop yields in the tropical and subtropical regions are projected to decline under increased temperatures. An increase in temperature, depending on the current ambient temperature, can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, and affect the survival and distribution of pest populations, developing a new equilibrium between crops and pests. Increased temperature coupled with reduced rainfall may lead to upward water movement, resulting in accumulation of salts in the upper soil layers (Xu et al., 2019). An increase of 1°C in global temperature would reduce the global yield of rice by an average of 3.2 ± 3.7%, maize by 7.4 ± 4.5%, and wheat by 6 ± 2.9% (Zhao et al., 2017). In their analysis of the impacts of global warming on farmers in Brazil and India, Sanghi and Mendelssohn (2008) conclude that by the next century global warming can reduce annual crop yield in India by 4–6%.

Kumar et al. (2004) assessed the effect of monsoon droughts on the production, demand, and prices of rice, sorghum, pearl millet, maize, pigeon pea, groundnut, and cotton, and concluded that the greatest impact of drought is on the yield of pearl millet and sorghum. A drought of 10% intensity is projected to result in a decline in the pearl millet yield of 7.6%; sorghum, 6.8%; and maize, 2.8%. Similarly, heavy rainfall events that lead to stagnant flooding or flash floods restrict the growth of crops; growth is restored only after water removal.

Thus, deviations from normal temperature and rainfall have adverse effects on crop growth, yield, and productivity. The impact of these events on crops is determined by the length of the growing period (LGP). LGP for a given district or region represents the climatically determined number of days during which a crop receives enough moisture from soil for its growth. Venkatesh et al. (2016) have determined the LGP for various taluks of Karnataka to range from 90 to 120 days. During this period, any deviation in temperature and rainfall from the normal will impact crop growth. For example, a temperature increase for a short period around pollen formation can lead to partial or complete sterility of the rice crop (Endo et al., 2009; Horie et al., 1996). An increase in temperature would also lead to increased evapotranspiration, which may result in lowering of the groundwater table. Crops also need adequate moisture, especially during critical stages of germination and fruit development.

In Karnataka, under climate change scenarios, a rise in temperature and increase in rainfall are projected. However, these changes are not uniform and there are spatial variations in warming and rainfall magnitude and variability across the districts. These projected changes in temperature and rainfall have implications for water resources and agriculture sector, particularly rainfed crops. The magnitude of risk to the different crops grown in the various Karnataka districts will be determined on the basis of the cropping calendar and the climate threshold of the crops.

5.1. Cropping Season and Climate Thresholds for Crops

Farmers in Karnataka traditionally follow a cropping calendar with respect to sowing and other agricultural operations pertaining to a crop. Sowing for the kharif season is done in May for sorghum[6] and ragi, and June for maize[7], red gram, sunflower, and groundnut[8]. However, sowing can be done till July for sorghum and red gram, and till August for maize, ragi, sunflower, and groundnut. Similarly, rabi crops are sown between September and December.

For rainfed agriculture, sowing is dependent on the onset of monsoon. The temperature, rainfall, and other climate requirements of crops are specific for various stages of growth—termed phenophases. Depending on the sowing date, the various phenophases of a crop are attained. At different phenophases, there are certain water, soil moisture, and temperature requirements (Table 4).

Table 4: Crop phenophases and crucial stages of growth for maize, sorghum, and groundnut

Crop	Sowing	Total Duration (Days)	Phenophase	Crucial Stage Requiring Irrigation or Rain
Maize	June (last week)–July	100–110	Emergence	Germination (usually after 10 days of sowing)
			Vegetative growth	
			Tasselling	
			Silking	
			Physiological maturity	Grain formation (10–14 days after silking)
Sorghum	April 1st–June end	110–120	Seed establishment	Germination (usually 8 days after sowing)
			Vegetative	
			Panicle initiation	Panicle initiation (about 32 days after emergence)
			Flowering	
			Grain development	80–96 days after emergence
			Maturity	
Groundnut	First week of June	95–120	Sowing	Germination (usually 5–10 days after sowing)
			Seedling	
			Vegetative	
			Flowering to pegging	30–40 days after sowing
			Pod filling	50–60 days from flowering to maturity
			Physiological maturity	

5.2. Projected Changes in Climate and Implications for Crop Phenophases

Fluctuations in weather during the critical growth phase can have substantial impact on the crop yield. Changes in temperature and soil water induced by changes in rainfall may affect all soil processes and ultimately crop growth. Further, rise in extreme events such as floods, droughts, and heat waves can cause direct hazards to standing crops. The risks likely to emerge from projected changes in temperature and rainfall for maize, sorghum, and groundnut under the RCP 8.5 scenario—which is the worst-case scenario—is discussed in the following sections.

5.2.1. Changes in Temperature and Implications for Crop Phenophases

Birthal et al. (2014) found in their analysis that the negative effect of maximum temperature on crops is greater than the positive effect of minimum temperature. A rise in maximum temperature has a negative, and significant effect on the yields of both kharif and rabi crops. The opposing effects of rise in minimum and maximum temperatures suggest that temperature

[6]http://agritech.tnau.ac.in/agriculture/millets_Sorghum.html
[7]http://www.cropweatheroutlook.in/crida/amis/AICRPAM%20Bulletin%20(District%20Level%20Wthr%20Calendars).pdf
[8]http://agropedia.iitk.ac.in/content/growth-groundnut-plant#:~:text=Normally%2060%2D80%20days%20are,development%20declines%20during%20pod%20filling

has a non-linear effect on crop yields. However, an increase in growing degree days—a derived parameter of temperature—has positive impacts on crop growth, provided the available soil moisture is sufficient (Murari et al., 2019).

Maize

Maize is considered one of the most adaptable crops under varied agro-climatic conditions (Swamy et al., 2017). It is usually sown during the last week of June for the kharif season and in October for the rabi season. Appendix 3 presents optimum climate thresholds for kharif season maize.

- **The ideal T_{max} (°C) or maximum temperature during the growth period is in the range 32°C–36°C, while T_{min} (°C) or minimum temperature is in the range 15°C–22°C.**

For maize, it has been well documented that a temperature increase can hinder its physiological processes, resulting in yield reduction. Temperature across Karnataka is predicted to generally increase during the 2030s. The level of warming varies across the districts. Under the RCP 8.5 scenario, in three districts, temperature is projected to be higher than the optimum during certain periods of maize growth (Table 5).

- In Davanagere, temperature is projected to be higher than optimum by 0.5°C during the sowing period or vegetative phase.
- In Chikballapur, temperature is projected to be higher than optimum by 0.2°C during August and September, which coincides with the reproductive and maturity phases, respectively.
- In Chamarajanagar, temperature is projected to be 0.1°C higher than optimum during September, which coincides with the maturity phase.

Table 5: Optimum maximum temperature and deviation from optimum under RCP 8.5 scenario for maize

<table>
<tr><th></th><th>June</th><th>July</th><th>Aug</th><th>Sep</th><th>Oct</th></tr>
<tr><td>Optimum T_{max}</td><td>36.2</td><td>36.4</td><td>33.5</td><td>33.5</td><td>33.6</td></tr>
<tr><td>Chamarajanagar</td><td rowspan="2">Below optimum</td><td rowspan="3">Below optimum</td><td>Below optimum</td><td>0.1</td><td rowspan="3">Below optimum</td></tr>
<tr><td>Chikballapur</td><td>0.2</td><td>0.2</td></tr>
<tr><td>Davanagere</td><td>0.5</td><td colspan="2">Below optimum</td></tr>
</table>

Sorghum

Sorghum is grown in Karnataka during May (kharif season) and September (rabi season). Sorghum is grown under rainfed conditions in the districts of Bagalkot, Belagavi, Bidar, Dharwad, Gadag, Kalaburagi, Haveri, Koppal, Raichur, and Yadgir. Appendix 4 presents the critical climate thresholds for sorghum.

- **The ideal T_{max} (°C) or maximum temperature during the growth period is in the range 28°C–31°C, while T_{min} (°C) or minimum temperature is in the range 13°C–22°C.**

Analysis of temperature at the district level for Karnataka shows that temperature is projected to rise under the RCP 8.5 scenario. A comparison of optimum temperature required for sorghum at different stages (Table 7) between September and February shows that the maximum temperature in nine districts will be higher than optimum, in the range 0.1°C–1.7°C. Further, temperature is projected to rise during September in the range 0.7°C–1.7°C; in October, 0.1°C–1.4°C; in November, 0.4°C–1.3°C; and in December, 0.5°C–1.5°C. However, during January and February the projected temperature in these districts is well below the optimum temperature required for sorghum.

Table 6: Optimum maximum temperature and deviation from optimum under RCP 8.5 scenario for sorghum

	Sep	Oct	Nov	Dec	Jan	Feb
Optimum T_{max}	30.0	32.0	31.0	30.0	32.0	35.0
Bagalkot	1.2	0.4	0.7	0.7	Below optimum	
Bidar	0.7	0.1	Below optimum			
Dharwad	0.9	Below optimum	0.5	1.0		
Gadag	1.7	0.1	0.4	0.6		
Kalaburagi	1.3	0.9	1.0	0.9		
Haveri	1.2	Below optimum	0.6	1.1		
Koppal	1.4	0.3	0.4	0.5		
Raichur	1.5	1.4	1.3	1.3		
Yadgir	1.4	0.6	0.6	1.5		

Groundnut

Groundnut is one of the vastly cultivated oilseed crops in the world. In India, most of the groundnut production is concentrated in five states—Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, and Maharashtra (Pandey, Karande, and Mote, 2016). Although the crop can be grown in all seasons, it is grown mainly in the kharif season (during June) in Karnataka and harvested during September–December, depending on when the sowing is done. Appendix 5 presents the critical climate thresholds for groundnut.

- **The ideal T_{max} (°C) or maximum temperature during the growth period is in the range 27.5°C–30.3°C, while T_{min} (°C) or minimum temperature is in the range 17.6°C–19.7°C.**

Analysis of temperature at the district level for Karnataka shows that temperature is projected to rise under the RCP 8.5 scenario. Maximum temperature (T_{max}) is projected to be higher than the optimum temperature during all the months of groundnut cultivation (Table 7).

A comparison of the optimum temperature required for groundnut at different stages between June and November shows that the maximum temperature in 12 districts will be higher than optimum in the range 0.2°C–2.7°C.

- During June, temperature is projected to be higher than optimum by 0.6°C in Belagavi to 2.4°C in Yadgir.
    - It is projected to be higher than optimum by 1°C in Bagalkot, Bengaluru Rural, Chamarajanagar, Gadag, Kolar, Koppal, Ramanagara, Tumakuru, and Yadgir.
- During July, temperature is projected to be higher than optimum by 1.3°C–2.2°C in 9 of the 12 districts.
    - It is projected to be higher than optimum by 2°C in Bagalkot and Ramanagara.
- During August, temperature is projected to be higher than optimum in all districts except Belagavi, in the range 0.2°C–2.4°C.

- During September, temperature is projected to be 0.4°C–2.6°C higher than optimum, and in October and November, 1.1°C–2.7°C higher than optimum in all the 12 districts.

Table 7: Optimum maximum temperature and deviation from optimum under RCP 8.5 scenario for groundnut

	June	July	Aug	Sep	Oct	Nov
Optimum T_{max}	30.3	28.8	27.9	28.2	28.2	26.9
Bagalkot	1.8	2.2	1.5	1.5	2.2	1.8
Bengaluru Rural	1.7	1.3	1.2	1.2	2.0	2.0
Belagavi	0.6	Below optimum			1.1	1.7
Chamarajanagar	1.3	1.4	2.1	2.4	1.9	1.2
Gadag	1.8	1.4	1.2	2.5	1.9	1.5
Hassan	0.7		0.9	1.5	1.8	1.8
Kolar	1.7	1.7	2.4	2.6	2.7	1.2
Koppal	1.6	1.4	2.2	2.2	2.1	1.5
Ramanagara	1.6	2.1	2.1	1.4	2.5	1.9
Tumakuru	1.9	1.3	2.3	2.6	1.8	2.1
Yadgir	2.4	1.9	2.3	1.8	2.4	2.7

5.2.2. Implications of Higher Than Optimum Temperature for Crop Production

From the climate analysis and the discussion on the optimum temperature requirement for crops, it is clear that T_{max} or maximum temperature will be higher than the optimum temperature for all the three crops—maize, sorghum, and groundnut—during the projected period in some districts. The impact is greater in the case of sorghum cultivated during the rabi season wherein the maximum temperature is projected to be higher than the optimum in nine districts, in the range 0.1°C–1.7°C. Similarly, temperatures higher than optimum are projected during the growth period of maize. However, the T_{min} or minimum temperature in the various districts growing maize, sorghum, and groundnut are well within the optimum temperature range, despite the rise in temperature compared to the historical period.

Maize

The risks due to temperature being higher than the optimum for the growth of maize include

- Shortened length of the growing season (Luhunga, 2017)
- Increased rate of evapotranspiration that can lead to water stress in plants and ultimately lower grain yields (Chatterjee, 1998)
- Decline in radiation-use efficiency when mean maximum temperatures are between 29.2°C and 31.3°C (Reynolds et al., 2007)
- Reduced pollen viability, pollen water potential, quantity of pollen shed, and pollen tube germination (Impe et al., 2020)
- Lower yield due to a decrease in the number of grains and kernel weight if temperature is high during the reproductive phase (Cairns et al., 2012). The final kernel mass is adversely impacted when temperature is high during early kernel stages (Jones et al., 1984).

Sorghum

Temperature influences the sorghum yield in the following manner:

- Decline in the rate of biomass accumulation through photosynthesis (Fuhrer, 2003) as the activation state of Rubisco reduces at temperatures above optimum, impacting the duration of crop growth (Holaday et al., 1992; Brooks and Farquhar, 1985)
- Rapid accumulation of growing degree days leading to faster growth and development of the crop, resulting in the reduction of phenophase duration and hence yield (Attri and Rathore, 2003)
- Decrease in seed-filling duration (Fuhrer, 2003), resulting in smaller seed size and lower seed yields (Kiniry and Musser, 1988)

Boomiraj et al. (2012) primarily attributed the decline in sorghum productivity under climate change scenarios at different locations in India to reduction in the crop growth period with an increase in temperature. Further, Kalra et al. (2007) and Mall et al. (2006) reported that a 1°C rise in temperature reduces the yield of sorghum by 7% and 18%, respectively.

Groundnut

Temperature plays a crucial role in the growth and development of groundnut. Studies show that high temperatures impact groundnut yield adversely in the following ways:

- According to Prasad, Craufurd, and Summerfield (2000), both long- and short-term exposure to air and soil temperatures above the optimum levels can cause significant yield loss in the groundnut crop. This is because high temperature significantly reduces total dry matter production, partitioning of dry matter to pods, and pod yield.
- Temperatures higher than optimum during flowering can affect pollination (Prasad et al., 2003; Mohamad, 1984).
- Vara Prasad et al. (2003), based on their growth chamber studies, outlined that the seed yield of groundnut decreased with an increase in temperatures. Decreased seed yields at high temperatures were a result of lower seed set due to poor pollen viability, and smaller seed size due to decreased seed growth rates and decreased shelling percentage.

Many of the districts of northern Karnataka such as Bagalkote, Belagavi, Chitradurga, Davanagere, Dharwad, Gadag, Haveri, and Yadgir are also the districts identified by KSNDMC (2020) as heatwave-prone districts.

5.2.3. Changes in Rainfall and Implications for Crop Phenophases

The magnitude, timing, and distribution of rainfall play a crucial role in crop growth and production, particularly in rainfed agriculture.

Maize

- Water requirement at the time of sowing is 37–63 mm/week; in the vegetative phase, 60–100 mm/week; in the reproductive phase, 74–66 mm/week; and at maturity, 12–15 mm/week.

Maize is a water-sensitive crop—its life cycle is dependent on water availability. Under the RCP 8.5 scenario, rainfall is projected to increase in magnitude during the kharif (June–September) season in the maize-growing districts. The percentage increase in rainfall ranges from 13% in Davanagere to 28% in Belagavi. This could have positive impacts if the distribution of rainfall is uniform. However, a comparison of weekly projected rainfall with optimum rainfall (mm/week) required for maize at different crop phenophases shows that the distribution of rainfall is skewed (Table 8).

Table 8: Optimum rainfall required during the maize growth period and difference in rainfall projected to be received under the RCP 8.5 scenario

Standard Meteorological Week	Week 26	Week 27	Week 32	Week 33	Week 36
Crop Phenophase	**Sowing**	**Germination**	**Tasselling**	**Silking**	**Grain formation**
Optimum Rainfall Required (mm/w)	**37**	**63**	**74**	**66**	**12**
Deviation in Projected Rainfall from Optimum Required under RCP 8.5 Scenario					
Bengaluru Rural	-15	-50	-65	-50	105
Belagavi	28	-9	-37	-44	18
Chamarajanagar	28	-24	-66	-60	0
Chikballapur	13	-33	-63	-58	6
Chikkamagaluru	-5	-31	-45	-38	35
Chitradurga	-8	-49	-67	-54	85
Davanagere	12	-39	-67	-60	10
Dharwad	13	-14	-24	-14	30
Hassan	-8	-41	-61	-45	83
Haveri	15	-24	-44	-41	66
Kolar	-11	-42	-58	-53	112
Koppal	-14	-50	-69	-55	55
Mandya	-6	-34	-58	-46	103
Mysuru	-1	-31	-50	-43	104
Shivamogga	31	6	-18	-27	49
Tumakuru	-10	-44	-62	-48	74

Maize is usually sowed during the last week of June (Week 26). During this week, of the 16 districts, only five—Belagavi, Chamarajanagar, Dharwad, Haveri and Shivamogga—are projected to receive higher than optimum rainfall.

- In the remaining 11 districts, rainfall is projected to be lower than the optimum by 1–15 mm at the time of sowing.

Germination of maize occurs 10 days after sowing; therefore, rainfall during the first week of July (Week 27) is critical. The optimum rainfall required for maize during this week is 63 mm. In all but Shivamogga district, projected rainfall during this week is lower than the optimum.

- The projected shortfall in rainfall during this week is 9–50 mm, with 10–20 mm shortfall in Belagavi and Dharwad; 21–40 mm shortfall in seven districts, namely, Chamarajanagar, Chikballapur, Chikkamagaluru, Davanagere, Haveri, Mandya, and Mysuru; and 40–50 mm shortfall in six districts, namely, Hassan, Kolar, Chitradurga, Bengaluru Rural, Koppal, and Tumakuru.

Tasselling is the next important phenophase requiring an optimum rainfall of 74 mm/week (Week 32). A shortfall in rainfall of 30–70 mm is projected in 14 of the 16 maize-growing districts under rainfed conditions. In Dharwad and Shivamogga, a shortfall in rainfall compared to the optimum is projected, but it is lower at 10–20 mm.

- The projected shortfall in rainfall is 50 mm and more—up to 69 mm—in 10 of the 16 districts growing rainfed maize.

Silking is a phenophase that occurs a week after tasselling (Week 33). This phase requires an optimum rainfall of 66 mm. Even during this week, the projected rainfall is 14–60 mm lower than the required optimum.

- The shortfall in rainfall is 10–40 mm in Dharwad, Shivamogga, and Chikkamagaluru; 40–50 mm shortfall in seven districts, namely, Haveri, Belagavi, Hassan, Bengaluru Rural, Mysuru, Mandya, and Tumakuru; and 50–60 mm shortfall in the remaining districts, including Kolar, Davanagere, Chitradurga, etc.

Grain formation or physiological maturity in maize occurs 10–14 days after silking. This occurs around the first week of September (Week 36) and requires an optimum rainfall of 12 mm/week. In all except Chamarajanagar district, rainfall during this week is projected to be much higher than the optimum required. Only Chamarajanagar receives the optimum rainfall.

- In the other districts, the rainfall received in excess is very large (51–100 mm/week), particularly in nine districts, namely, Koppal, Haveri, Tumakuru, Hassan, Chitradurga, Mandya, Mysuru, Bengaluru Rural, and Kolar.

Sorghum

- Water requirement at germination is around 32–45 mm/week; vegetative stage, 40–49 mm/week; panicle initiation, 40 mm/week; flowering, 14–24 mm/week; grain development, 2–3 mm/week; and at maturity, as little as 0–1 mm/week.

Sorghum yield is influenced by the amount of rainfall received during the growing season and its distribution, soil moisture level at the time of planting, and plant-available water (Assefa et al., 2010). Varshneya et al. (2004) reported that sorghum phenology is inversely proportional to change in temperature, and grain yield is directly proportional to change in rainfall.

An analysis of the total rabi season rainfall, variability, and weekly rainfall during the projected period shows that not only does the total rabi rainfall increase but the variability decreases in the sorghum-growing districts. The projected rabi rainfall is more evenly distributed and will meet the optimum rainfall requirements for growing sorghum during the season. The risk of crop failure or crop losses due to rainfall variability and failure are, therefore, reduced in the sorghum-growing districts of Karnataka in the future.

Groundnut

- Water requirement at the sowing stage is 20–24 mm/week; seedling stage, 8–10 mm/week; vegetative stage, 8–18 mm/week; flowering to pegging, 25–26 mm/week; pod filling, 31–43 mm/week, and for physiological maturity, 26–30 mm/week.

Among the various limitations which can cause a low groundnut yield, the most important one is erratic, insufficient, and unevenly distributed rainfall during the kharif season (Pandya et al., 2019; Challinor et al., 2003). This is particularly important during the growth phase as the various growth phases have varied rainfall requirements (Madhusudhana, 2013). The efficacy of rainfall in crop development, production, and yield depends largely on the commencement of sowing rains (Sahu et al., 2004).

Analysis of rainfall received during the specific weeks when groundnut is cultivated (Table 9) indicates that during June (Week 23), which coincides with sowing, all the districts are projected to receive much higher rainfall than the optimum requirement of 20 mm/week.

During Week 24, when groundnut germination occurs, the projected rainfall in the districts cultivating groundnut is much higher than the optimum requirement of 10 mm/week.

Week 27 is when flowering and pegging of groundnut will occur if there is sowing in Week 23. The optimum rainfall required for this phenophase is 25 mm/week. The projected rainfall for the week is higher than the optimum in six districts (by 6–29 mm). The projected rainfall is lower than the optimum in five districts by 3–12 mm, namely, Koppal, Kolar, Bengaluru Rural, Tumakuru, and Hassan. It is during this week that flowering to pegging occurs and has implications for pod yield—pod formation and flowering stages are sensitive to moisture stress (Thiyagarajan et al., 2010).

The pod-filling phenophase takes about 50–60 days (Week 36) from flowering to maturity, and this phase has an optimum rainfall requirement of 50 mm/week. The projected rainfall for this week is lower than the optimum, by 16–38 mm, in Bagalkot, Belagavi, Gadag, and Chamarajanagar. Rainfall higher than the optimum by 17–78 mm is projected in Koppal, Yadgir, Kolar, Tumakuru, Hassan, Bengaluru Rural, and Ramanagara.

Table 9: Optimum rainfall required during the groundnut growth period and difference in rainfall projected to be received under the RCP 8.5 scenario

	Week 23	Week 24	Week 27	Week 36
Crop Phenophase	**Sowing**	**Germination**	**Flowering to Pegging**	**Pod Filling**
Optimum Rainfall Required (mm/w)	20	10	25	50
Deviation in Projected Rainfall from Optimum Required under RCP 8.5 Scenario				
Bagalkote	101	111	22	-16
Belagavi	75	88	29	-20
Bengaluru Rural	49	36	-12	67
Chamarajanagar	103	73	14	-38
Gadag	87	84	6	-26
Hassan	74	77	-3	45
Kolar	53	38	-4	74
Koppal	30	32	-12	17
Ramanagara	82	84	14	78
Tumakuru	35	41	-6	36
Yadgir	33	26	18	28

5.2.4. Implications of Changes in Rainfall Magnitude and Distribution for Crop Production

Although increasing in magnitude, rainfall distribution is skewed and certain crop growth periods will receive much lower than optimum rainfall during the projected period in some districts. Karnataka has about 16 districts that are perpetually drought prone. Food grain production in Karnataka dropped from 126 lakh tonnes during 2014–15 to 110 lakh tonnes in

2015–16 owing to drought; further, in 2019, Karnataka declared 23 of its 30 districts as drought-hit (Shanker, 2019).

Maize

A deficit in rainfall compared to the optimum requirement is projected at the stages of germination, tasselling, and silking in all the districts growing maize under rainfed conditions. A shortfall in rainfall is projected in some of the districts at the time of sowing as well.

Water deficiency at any phenological stage leads to different responses and can damage the grain yield (Cakir, 2004). The loss of yield in maize varies from 30% to 90% depending on the crop stage and the degree and duration of water-deficit stress (Pandit et al., 2018). The stages of maize susceptible to water-deficit stress are the vegetative, silking (flowering), and ear (grain filling) stages, where the yield loss may be as high as 25%, 50%, and 21%, respectively (Denmead and Shaw, 1960). During the stem elongation or vegetative growth stage, maize requires a sufficient amount of water as the growth of leaves and stem is very rapid, and water stress at this stage can affect the height and leaf development of the plant, which in turn could hamper the yield (Muchow, 1989). The most critical time of water stress in maize is 10–15 days prior to and after flowering (silking). Water stress or deficiency at this stage can decrease the grain yield by 2–3 times more than that due to water deficit at any other growing stage (Grant et al., 1989).

Groundnut

Rainfall lower than the optimum is projected in some of the districts growing groundnut under rainfed conditions at the flowering-to-peg initiation, and pod-filling stages.

Reduction in groundnut yield resulting from drought has been well documented, and drought during pod- and seed-forming stages could result in a reduction of 56–85% in the pod yield (Reddy et al., 2003; Nageswara Rao et al., 1989). Alternatively, higher moisture (above optimum) levels during the vegetative and flowering stages results in higher vegetative growth and reduces flowering and pod initiation. Lower moisture may reduce vegetative growth and increase flowering efficiency and pod initiation. Hence, lower moisture availability during flowering may help increase groundnut yield. Availability of low levels of moisture and rain for groundnut during emergence-to-peg initiation could lead to yield losses of 13–19% (Rao et al., 1986).

5.2.5. Heavy Rainfall Events and Implications for Crop Phenophases

Notably, during the maize and groundnut growth periods, in addition to maximum temperature and rainfall projected to be lower or higher than the optimum for some districts during certain crop phenophases, heavy rainfall events are projected. This is a likely risk, depending on the time of occurrence of such events.

- The frequency of high-intensity rainfall events of 51–100 mm/day is projected to double in Belagavi, Bidar, Chikballapur, and Ramanagara; treble in Chamarajanagar, Dharwad, Gadag, and Tumakuru; quadruple in Davanagere and Koppal; increase by five times in Bagalkot, Bengaluru Rural, Chikkamagaluru, Haveri, Hassan, and Shivamogga; and increase by six times in Chitradurga, Kolar, Mandya, Mysuru, and Yadgir.

- Very-high-intensity rainfall events of >100 mm/day are projected in all the districts and will be much more frequent than high-intensity rainfall events. Further, these events are projected in districts such as Bengaluru Rural, Chitradurga, Davanagere, and Yadgir that historically have not recorded such events.

It is clear from the analysis and results presented for the three dominant rainfed crops of Karnataka that the projected temperature and rainfall are likely to pose risks to crop production due to increases in maximum temperature and rainfall received during the kharif season. This will be further compounded by the variability in the distribution of rainfall across the cropping season and the projected occurrence of high- and very-high-intensity rainfall events during the crop growth period. During 2019, about 2.42 lakh hectares of agricultural land in Karnataka was reported to be inundated because of excess rainfall received during the monsoon season (Acharyya, 2019). The districts of Bagalkot, Belagavi, Chikkamagaluru, Chitradurga, Dharwad, Hassan, Haveri, Mysuru, and Shivamogga were the worst hit. Moreover, heavy rains in mid-September 2019 adversely impacted crop yield and productivity.

- In some of the maize-growing districts, high- and very-high-intensity rainfall events are projected during the kharif season. Rainfall during the week of grain formation in maize is projected to be much higher than the optimum in all the districts. This will lead to accumulation of excess soil moisture that, in turn, will induce flower shedding, root rotting, and wilting, resulting in an overall loss in yield and quality of the agricultural produce.

- In the groundnut-growing districts, heavy wet spells are projected at the time of sowing and germination. Further, in many of the districts, heavy rainfall events are projected at the time of pod filling. Prolonged monsoon rainfall post-harvest is also projected, potentially leading to major yield losses (Pandey, Karande and Mote, 2016).

The effect of flooding on crop productivity ranges from yield reduction of 10–40% in severe cases (Kozlowski and Pallardy, 1984), as flooding negatively affects the physiological functioning, and vegetative and reproductive growth of plants (Kramer and Boyle, 1995). Maize is susceptible to waterlogging—in the tropics and subtropics, this could lead to yield loss. Fifteen per cent of maize-growing areas in Southeast Asia face waterlogging, which may lead to yield loss of 25–30% annually (Rathore et al., 1998). Similarly, high rainfall during the early stages of groundnut growth is also harmful to the crop, as it may result in more vegetative growth, leading to disease infestation and lesser yields. High monsoon showers of >20 mm in June–July favour mass emergence of white grub beetles and an outbreak of red-headed hairy caterpillars (Rao et al., 2015). Table 10 summarises the district-wise projected changes in rainfall at crucial crop phenophases and the implications for yield, based on literature. In addition to heavy rainfall events, districts in north interior Karnataka, which are semi-arid regions, continuously experience hailstorms. These include districts such as Yadgir, Koppal, and Gadag (KSNDMC, 2020).

Table 10: Percentage deviation in rainfall from optimum at different crop phenophases of maize and groundnut, and implications for crop production in different districts of Karnataka

	Crop Growth Stage	Percent Deviation in Rainfall from the Optimum Required for Rainfed Crops during the Projected Period and Districts	Implications
Maize	Sowing	50–100% higher —Belagavi, Chamarajanagar, Shivamogga	Germinates under wet soil conditions with nominal amounts of oxygen, but further growth is highly susceptible to excess soil moisture stress. Submergence during germination and seedling stages leads to poor seedling establishment, stunted growth, and delayed development
		1–50% higher—Chikballapur, Davanagere, Dharwad, Haveri	
		1–25% lower—Chikkamagaluru, Chitradurga, Mandya, Mysuru, Hassan	Up to 25% loss in yield
		25–50% lower—Bengaluru Rural, Kolar, Koppal, Tumakuru	
	Germination	9% higher in Shivamogga	Flooding could cause crop damage and yield loss
		1–25% lower—Belagavi, Dharwad	Adverse impact on height and leaf development, hampering crop yield by up to 25%
		25–50% lower—Chamarajanagar, Chikkamagaluru, Haveri, Mysuru	
		50–100% lower—Bengaluru Rural, Chitradurga, Chikballapur, Davanagere, Hassan, Kolar, Koppal, Mandya, Tumakuru	
	Tasselling	1–50% lower—Belagavi, Mandya	25–29% loss in yield
		50–100% lower—Bengaluru Rural, Chamarajanagar, Chikballapur, Chikkamagaluru, Chitradurga, Davanagere, Dharwad, Hassan, Haveri, Kolar, Koppal, Mysuru, Shivamogga, Tumakuru	
	Silking	50–100% lower—Belagavi, Bengaluru Rural, Chamarajanagar, Chikballapur, Chikkamagaluru, Chitradurga, Davanagere, Hassan, Haveri, Kolar, Koppal, Mandya, Mysuru, Tumakuru	Up to 50% loss in yield
		1–50% lower—Dharwad, Shivamogga	
	Grain formation	100% and higher—Belagavi, Bengaluru Rural, Chikballapur, Chikkamagaluru, Chitradurga, Davanagere, Dharwad, Hassan, Haveri, Kolar, Koppal, Mandya, Mysuru, Shivamogga, Tumakuru	Waterlogging for more than 3 days can decrease maize production by 40–100% Flower shedding, root rot, and wilting
		1% lower—Chamarajanagar	21% loss in yield
Groundnut	Sowing	>100% higher—Bagalkot, Belagavi, Bengaluru Rural, Chamarajanagar, Gadag, Hassan, Koppal, Kolar, Ramnagara, Tumakuru, Yadgir	Delay in sowing and change in crop variety, resulting in yield loss
	Germination		More vegetative growth and disease infestation
	Flowering and pegging	1–50% higher—Chamarajanagar, Gadag, Ramnagara	
		50–100% higher—Bagalkot, Belagavi, Yadgir	
		1–30% lower—Kolar, Hassan, Tumakuru	13–19% loss in pod yield
		30–50% lower—Bengaluru Rural, Koppal	
	Pod filling	50–100% higher—Bengaluru Rural, Kolar, Koppal, Hassan, Ramanagara, Tumakuru, Yadgir	25–36% decline in pod filling (Martin et al., 1991)
		20–75% lower—Bagalkot, Belagavi, Chamarajanagar, Gadag	56–85% loss in yield

Several policies and programmes have been formulated at both national and state levels to address issues related to the agriculture sector, and the same is discussed in Section 6.

Pradhan Mantri Krishi Sinchayee Yojana

On-Farm Water Management programme

Climate Change and Sustainable Agriculture: Monitoring, Modelling and Networking programme

Bhoochetana

Krishi Bhagya Scheme

19.5 lakh farmers are insured for a sum of **INR 9,702 crores**

encompassing an area of **22.4 lakh hectares**

Pradhan Mantri Fasal Bima Yojana

6. Policies and Programmes for Rainfed Agriculture and Crop Insurance

Many policies are in place for rainfed agriculture both at the national and state levels. The Department of Agriculture, Cooperation & Farmers Welfare of India, under the Ministry of Agriculture, has a division—Rainfed Farming System—that specifically works on the development and/or rejuvenation of the rainfed agriculture sector in India. Further, under the National Action Plan on Climate Change, one of the eight missions is the National Mission for Sustainable Agriculture (NMSA). This mission focusses on integrated farming, soil health management, and resource conservation synergy. Among the many schemes under NMSA, Rainfed Area Development Programme (RADP) is aimed at enhancing productivity and minimising risks associated with climate variabilities. Appendix 2 provides district-wise achievement details under RADP in Karnataka for the FY 2019–20. Below we present policies and programmes relevant to rainfed agriculture at the national and state levels.

- The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), with the motto of 'Har Khet Ko Paani', is a scheme that focusses on creating sources for not only assured irrigation but also protective irrigation by harnessing rainwater at the micro-level through 'Jal Sanchay' and 'Jal Sinchan'[9].
- The On-Farm Water Management (OFWM) programme is focussed on enhancing water use efficiency by promoting efficient on-farm water management technologies and equipment. This programme emphasises effective harvesting and management of rainwater, and provides assistance for adoption of water conservation technologies, efficient delivery and distribution systems, etc.
- The Climate Change and Sustainable Agriculture: Monitoring, Modelling and Networking (CCSAMMN) programme is aimed at bidirectional (land/farmers to research/scientific establishments and vice versa) dissemination of climate-change-related information and knowledge by way of piloting climate change adaptation/mitigation research/model projects in the domain of climate smart sustainable management practices and integrated farming systems suitable for local agro-climatic conditions.

6.1. Karnataka State—Rainfed Agriculture Schemes

Karnataka framed a rainfed farming policy in 2014. The salient features of this policy relevant to rainfed farming are as follows:

- Focus on small and marginal farmers who account for 76% of the holdings and operate 40% of the area
- Increasing public investment in rainfed agriculture
- Preserving the germplasm of dryland crops and developing resource conservation technologies
- Developing systems for efficient medium- and long-term prediction of weather
- Market intelligence and price forecasting ahead of the sowing season

[9]https://pmksy.gov.in/microirrigation/index.aspx

The following two targeted programmes for rainfed agriculture are being implemented in Karnataka districts:

- ***Bhoochetana:*** The Government of Karnataka in 2009–10 initiated this novel dryland farming project with the goal of increasing the average productivity of selected rainfed crops by 20%. The main strategies adopted under this scheme include soil-test-based nutrient management, with major thrust to micronutrients; distribution of inputs at 50% subsidy at the village cluster level; services of farmer facilitators for transfer of technology; farmer field schools; wide publicity through wall writings, posters, village meetings, and mass media; and effective project monitoring and feedback.
    - Project implementation under this scheme started during the 2009–10 kharif season in six districts spanning 2.25 lakh hectares, 1,440 villages, and 2 lakh farmers. By 2012–13, the programme was extended to all the 30 districts, covering 50 lakh hectares of dryland area and 5 lakh hectares of irrigated area.
- ***Krishi Bhagya Scheme:*** The Government of Karnataka launched this scheme exclusively for dryland farmers. This scheme incorporates effective rainwater conservation measures to improve productivity. The government has aided over one lakh farmers in rainfed areas of 131 taluks in 25 districts, extending financial assistance of INR 968.37 crores. The scheme is executed in five agro-climatic zones that receive an average annual rainfall ranging between 450 mm and 850 mm. Under this scheme, farmers obtain grants for constructing farm ponds (*Krishi Honda*) to conserve rainwater and for buying lift pumps and diesel motors to draw water during deficit rainfall. The programme also assists farmers to earn higher income by enabling them to construct polyhouses and put up shade nets to cultivate hybrid vegetables and flower crops.

In the current budget for the 2020–21 fiscal year, INR 32,260 crore has been allotted for agriculture and irrigation sectors, with a clear focus on micro-irrigation projects. Thus, the Government of Karnataka has some dedicated programmes for rainfed agriculture in the state. However, despite these policies and programmes, agriculture in Karnataka suffers from losses year after year due to droughts, floods, and other factors.

6.2. Crop Insurance

Crop insurance is a financial tool that can mitigate the impacts of climate change. However, risks and insurance requirements vary according to agro-climatic zones and socioeconomic status of farmers. Crop insurance is also a desirable alternative to the government provision of ex-post disaster relief and/or assistance. In India, the first-ever insurance scheme was advocated by Prof. V. M. Dandekar—the pilot crop insurance scheme (PCIS), implemented in 1979 with the help of General Insurance Corporation (GIC). It covered 13 states and 6.27 lakh farmers till 1984–1985. During 1985, a Comprehensive Crop Insurance Scheme was implemented, which subsequently was replaced by the National Agricultural Insurance Scheme in 1999 to include non-loanee farmers and it continued till 2015–16. Over a period, many modifications were tried, and the weather-index-based insurance scheme was one of them—introduced in 2007, particularly for horticultural crops.

To remove the inherent flaws in existing crop insurance schemes, a new scheme called the Pradhan Mantri Fasal Bima Yojana was launched during the 2016 kharif season; this let farmers pay a very low premium to insure their crops. Its coverage includes losses due to non-preventable risks (natural fire, lightning, storm, hailstorm, cyclone, typhoon, tempest, hurricane, tornado, flood, inundation, landslide, drought, dry spells, pests, and diseases) and farmers who have an intent to sow/plant and have incurred expenditure for the purpose but are prevented from sowing/planting crop due to adverse weather conditions, post-harvest losses (up to a maximum period of 14 days from harvest), and certain localised problems (Jamanal, Natikar and Halakatti, 2019). Table 11 provides a comparison of the aforementioned three crop insurance schemes in India.

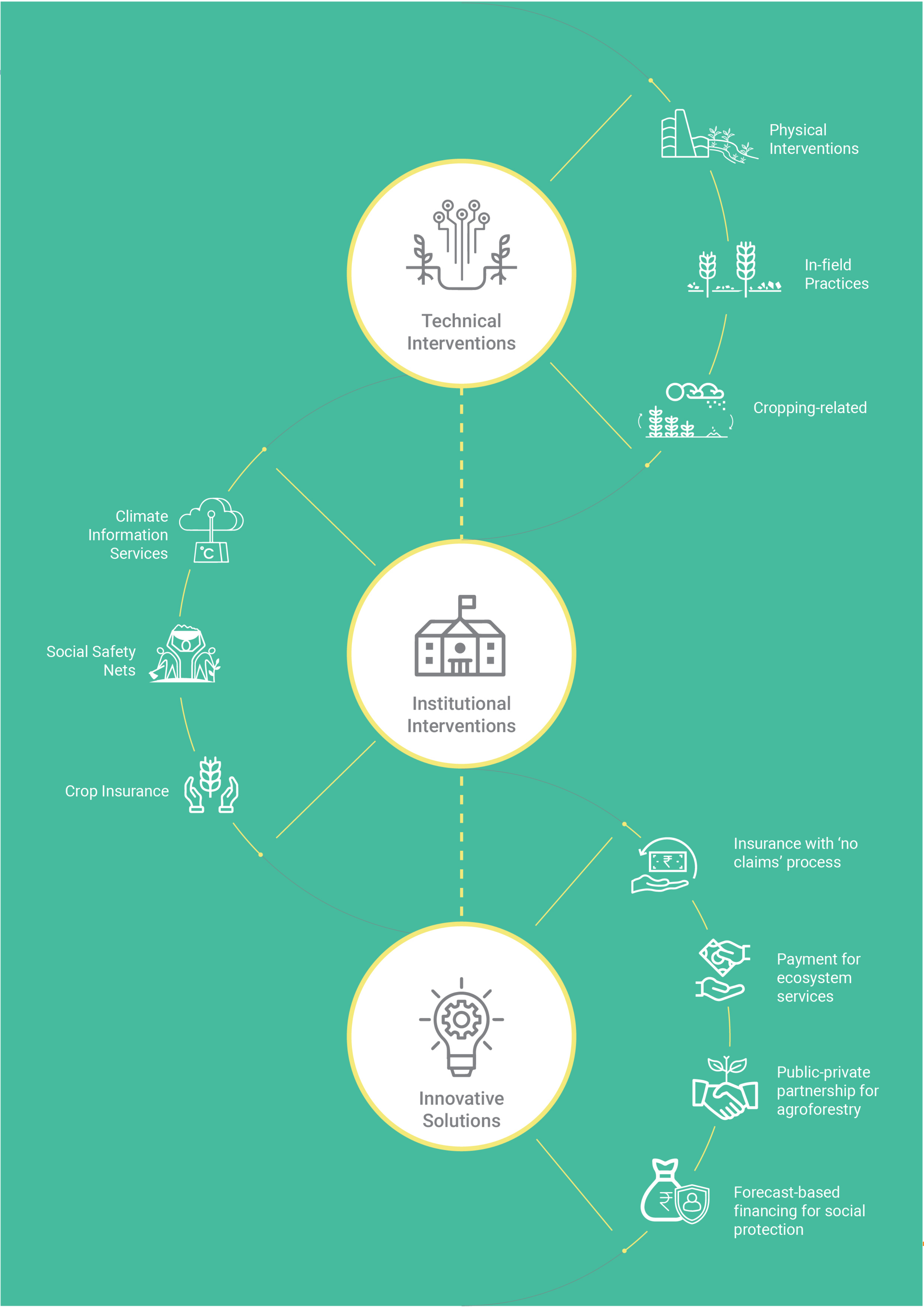
Table 11: Comparison of crop insurance schemes in India

Feature	NAIS (1999)	MNAIS (2010)	PMFBY (2016)
Premium rate	Low	High (9–15%)	Low (Govt to contribute five times that of farmer)
One season–one premium	Yes	No	Yes
Insurance amount covered	Full	Capped	Full
On account payment	No	Yes	Yes
Localised risk coverage	No	Hailstorm, landslide	Hailstorm, landslide, inundation
Post-harvest losses coverage	No	Coastal areas	All India
Prevented sowing coverage	No	Yes	Yes
Use of technology	No	Intended	Mandatory
Awareness	No	No	Yes (target to double coverage to 50%)
Insurance companies	Only government	Govt and private companies	Govt and private companies

(*Source: PIB, Ministry of Agriculture and Farmers Welfare, January 2016; NAIS: National Agricultural Insurance Scheme; MNAIS: Modified National Agricultural Insurance Scheme; PMFBY: Pradhan Mantri Fasal Bima Yojana.*)

As of 13/07/2020, under the PMFBY and RWBCIS crop insurance schemes, 19.5 lakh farmers are insured for a sum of INR 9,702 crores, encompassing an area of 22.4 lakh hectares[10]. About 13 lakh farmers have benefitted from these schemes. However, there is still a large percentage of area and farmers who are yet to be covered under these schemes.

[10]https://pmfby.gov.in/pdf/2018-19.pdf


Technical Interventions
Physical Interventions
In-field Practices
Cropping-related
Institutional Interventions
Climate Information Services
Social Safety Nets
Crop Insurance
Innovative Solutions
Insurance with 'no claims' process
Payment for ecosystem services
Public-private partnership for agroforestry
Forecast-based financing for social protection

7. Resilience Options for Buffering Climate Shocks

Adaptation strategies to cope with climate risks range from farmers switching to crops that withstand climate variations, to changing sowing time, using hybrid varieties, etc. Strategies and techniques to promote water harvesting are useful for bridging short-term dry spells. However, in order to decrease risks to rainfed agriculture, investment in water management is needed.

The rationale for promoting investment in rainfed agriculture is made compelling by

- Current low yields of rainfed crops, offering potential to improve productivity.
- Large dependence of small and marginal farmers on rainfed agriculture. In Karnataka, the number of small and marginal farmers according to Agricultural Census (2015–16) is about 70 lakhs, spanning an area of 52 lakh hectares (~43% of agricultural land in Karnataka).
    - Improving productivity in rainfed areas is a way of improving livelihoods and supporting the poor.
- Depleting groundwater resources, as a combined result of prolonged, multi-year drought and intensive extraction (Wada et al., 2010; Famiglietti, 2014).
- High cost of developing and promoting large-scale irrigation, with likely adverse environmental and social impacts.
- Erosive nature of current coping strategies in response to climate or other income shocks.
    - Sale of assets, shift to non-agricultural employment, migration (Munshi and Rosenzweig, 2016; Blakeslee et al., 2018) are some such strategies.

In this chapter, strategies to build resilience in rainfed agricultural systems are presented in two parts. In the first part, on-farm and community-level interventions are described considering the districts and climate risks projected. The second part presents institutional interventions and innovations for climate resilience, which act as generic strategies for building overall resilience of the agriculture sector in Karnataka.

7.1. On-Farm and Community-Scale Interventions

Climate projections for Karnataka districts and the analysis of projected temperature and rainfall in conjunction with crop-climate thresholds show that high temperature, dry spells, and high-intensity rainfall events leading to floods would pose risks to agriculture. In some districts, the risks are multiple, depending on the crops grown and the sensitivity of these crops to climatic aberrations. There is, therefore, a need to formulate strategies for addressing multiple risks in the districts growing maize, sorghum, and groundnut. It is evident from Table 12 that the predominant risk of climate change during the projected period is the occurrence of heavy rainfall events during different stages of growth of maize, sorghum, and groundnut, grown in many districts, spanning multiple agro-climatic zones.

Table 12: Mapping of climate risks to rainfed crops at different crop phenophases, districts, and agro-climatic zones

	Climate risks—rainfall and crop phenophase	Districts	Agro-climatic zones
Maize	Higher rainfall during all phases	Dharwad	Northern Dry Zone, Northern Transition Zone, Hilly Zone
	Higher rainfall during sowing phase	Chamarajanagar	Southern Dry Zone
	Higher rainfall during sowing and grain-formation phases	Belagavi, Chikballapur, Davanagere, Haveri	Northern Transition Zone, Hilly Zone, Northern Dry Zone, Eastern Dry Zone. Central Dry Zone, Southern Transition Zone
	Higher rainfall during sowing, germination and grain-formation phases	Shivamogga	Southern Transition Zone, Hilly Zone
	Lower rainfall during all phases except grain formation when heavy rainfall is projected	Bangalore (Rural), Chikkamagaluru, Chitradurga, Hassan, Kolar, Koppal, Mandya, Mysore, Tumkur	Eastern Dry Zone, Central Dry Zone, Southern Transition Zone, Hilly Zone, Southern Dry Zone, Hilly Zone, Eastern Dry Zone, Northern Dry Zone
Sorghum	Optimum or slightly higher rainfall	Bagalkote, Belagavi, Bidar, Dharwad, Gadag, Kalaburagi, Haveri, Koppal, Raichur, Yadgir	Northern Dry Zone, Northern Transition Zone, Hilly Zone, North Eastern Transition Zone, North Eastern Dry Zone
Groundnut	Higher rainfall during all phases	Chikkamagaluru, Ramanagara, Udupi, Yadgir	Central Dry Zone, Southern Transition Zone, Hilly Zone, Eastern Dry Zone, Coastal Zone, North Eastern Dry Zone
	Higher rainfall at all growth stages except pod-filling phase	Chamarajanagar, Gadag, Chikballapur, Dharwad, Bagalkote, Belgaum	Southern Dry Zone, Northern Dry Zone, Northern Transition Zone, Eastern Dry Zone, Hilly Zone
	Higher rainfall during all phases except flowering and pegging phase when lower rainfall is projected	Bengaluru (Rural), Hassan, Kolar, Koppal, Tumakuru	Eastern Dry Zone, Central Dry Zone, Southern Dry Zone, Southern Transition Zone Hilly Zone, Northern Dry Zone, Central Dry Zone
	Higher rainfall during sowing and germination phases, and lower rainfall during flowering and pegging, and pod-filling phases projected	Davanagere	Northern Dry Zone, Central Dry Zone and Southern Transition Zone

Management of agricultural farms, particularly those under rainfed conditions, is designed for optimising crop yields. This involves the use of incoming moisture (through rains) as efficiently as possible; utilisation of the growing season to the maximum extent possible; supplying nutrients; and removal of weeds, diseases, and insects that compete with the crop for resources such as light, water, and nutrients. In rainfed systems, capture, conservation, and utilisation of rainwater is a must for realising optimum crop yields. Alternatively, during heavy rainfall, there is a need for measures to store the excess water for use later, as well as to avoid erosion and run-off.

Physical Interventions

Rainwater harvesting and conservation requires implementation of mechanisms to divert surplus water to storage structures, which could be used for meeting the critical irrigation requirements of crops during crucial phases of growth. Life-saving irrigation is a must in regions where rainfed agriculture is predominantly practised. In districts with relatively high rainfall, strategies to conserve as much rainwater as possible and to harvest surplus water for life-saving irrigation should be promoted. This could lead to enhanced cropping intensity and help maximise returns from harvested water. In addition, there is a need for promoting approaches to increase water-use efficiency by arresting losses so as to maximise returns from every drop of harvested water. Some such interventions are as follows:

- **Contour bunding:** This is a technique widely recommended for low-rainfall areas, with a slope of up to 6% and permeable soils. Bunds are simple earthen embankments of varying lengths and heights, constructed across the slope. When constructed along the contour of the area, they are called contour bunds and when a gradation is provided, they are called graded bunds. Bunding checks free flow of run-off water, impounds rainwater in the inter-bund space, increases its infiltration, and thereby improves soil moisture. Levelling of the inter-bund space is essential to ensure a uniform spread of water and to avoid water stagnation in patches.

- **Contour farming:** Ploughing and conducting all other agricultural operations along the contour (across the slope) reduces soil erosion and run-off. This practice fits all the dry regions of Karnataka which receive rainfall up to 1000 mm and have 4% slope. Practically, it is often difficult to establish all crop rows on the true contour because of non-uniform slopes in most of the fields. In order to establish row directions, adjusted contours are laid out at one or more elevations in the field. In certain situations, it is desirable to provide a small slope along the row, to prevent run-off from a large storm breaking over the small ridges formed during contour cultivation.

- **Broad bed furrow system:** In medium to deep black soils (Vertisols) of Northern Karnataka, with 700–1300 mm rainfall and up to 5% slope, a raised land configuration 'broad bed and furrow' (BBF) system has been found satisfactory to attain in-situ soil and water conservation and proper drainage. The raised bed portion acts as an in-situ bund to conserve more moisture and ensures soil stability. The shallow furrows provide good surface drainage to promote aeration in the seedbed and root zone, preventing water logging of crops on the bed.

- **Conservation furrow:** In red (Alfisol) soil regions of Karnataka, receiving 400–900 mm rainfall and having slope up to 4%, conservation furrow with contour cultivation is a simple, low-cost, in-situ soil and water conservation practice.

- **Ridges and furrows:** It is a recommended soil and water conservation technique for black and red soils of Karnataka. In widely spaced crops with a row spacing above 60 cm (for maize, sunflower, chilli, castor, pigeon pea, etc.), placing the inter-row soil in the crop rows forms ridges and furrows. These ridges serve the dual role of improving infiltration and safe disposal of excess rainwater.

- **Farm ponds:** Storage structures that can provide life-saving irrigation to overcome moisture stress in rainfed agriculture systems. These are proven to increase yields by 15–40% (Rajeshwari et al., 2007).

- **Check dams:** Masonry check dams are permanent structures effectively used for controlling gully erosion, water harvesting, and groundwater recharging. These structures are preferred at sites where the velocity of run-off water flow in gullies/streams is very high and a stable structure is needed to withstand the difficult conditions. In the districts where heavy rainfall events are projected to increase, these structures could be built for both conserving soil and for safely draining excess rainwater without damaging the crops.

Zero-Budget Natural Farming (ZBNF) is a low-input, climate-resilient model of agriculture promoted in Karnataka. ZBNF was proposed in Karnataka during 2018, with a budget of INR 50 crores. During the first phase, the programme was proposed to be implemented on a pilot basis in all the 10 agro-climatic zones of the state. ZBNF has resilient features to cushion against rising temperature and shrinking moisture. In Karnataka, the aim is to bring around 5% of the total cultivable area under ZBNF over a period of five years.

In-field Practices

There are several agronomic practices that could be adopted for improving water conservation in rainfed systems. They range from reduced or no tilling, mulching, cover cropping to promotion of intercropping and agroforestry. When flooding is a risk, several strategies to cope with flood damage are implemented, such as mulching or cover-cropping ploughed soil; planting trees and hedges around fields to reduce run-off; constructing dykes and irrigation channels to control the flow of water onto crops; improving drainage through raised beds, ridges, or mounds; planting early-maturing crops to avoid the flooding season in flood-prone areas; and planting flood-tolerant crops.

- **Mulching:** It is widely practiced for reducing soil erosion and for increasing infiltration and moisture retention in soils. Mulching has a positive impact on germination of seedlings, leading to deep rooting and better crop yield (Venkateswarlu, 2010; Blanco Canqui et al., 2006). Gan et al. (2013) and Li et al. (2013) suggested mulching as an option for increasing 'crop yield per drop and bag' by modifying soil temperature, reducing evaporation and erosion, and reducing weed infestation. Taraz (2018) stressed the need for mulching in regions projected to experience high temperatures as well as those that experience temperature extremes regularly. Mulching is advantageous in both red and black soil areas and in districts receiving rainfall up to 1500 mm. Mulching with crop wastes/weeds, pebbles, etc. can be practised in all the soil types. Sand mulching is advantageous in black soil areas of northern parts of Karnataka.

- **Reduced tillage or no tillage:** It helps to increase the amount of water in the soil and decrease soil erosion. It may also increase the number and variety of life forms in and on the soil, which increases soil fertility and thereby crop yields (Saha et al. 2010).

- **Cover cropping:** This involves incorporation of a large quantity of plant biomass, especially of leguminous crops, into the soil. Biological measures of erosion control involving use of cover crops provide ground cover to protect the soil from the impact of raindrops and decrease the velocity and carrying capacity of overland flow.
- **Managed aquifer recharge:** The excessive use of groundwater as a resource has led to overexploitation, creating additional depleted storage. This additional storage capacity could be used to capture excess monsoon run-off during high-intensity rainfall episodes, making the water available during dry spells and thus mitigating both flood and drought hazards. Managed aquifer recharge is one of the techniques which can be used to harness rainwater (Alam et al. 2020).

Cropping-related Measures

In addition to the above agronomic practices, certain cropping-related changes or measures could also be undertaken to cope with projected climate risks in the districts of Karnataka.

Change in time of sowing: Studies have established that adjusting sowing date is a cost-effective adaptation option for maize (Abbas et al 2017). Experiments done on sorghum show that varying sowing dates can affect the grain yields, and modelling approaches can be adopted to identify the ideal week for sowing (Karhale et al, 2014). The proper time of sowing exerts a distinguished effect on growth and eventually on the yield of groundnut. It was observed that changing the sowing window can help groundnut escape the period of moisture stress (Raagavalli et al. 2019), which is likely in certain districts as projected.

Climate-resilient varieties: Climate-resilient crop varieties are key to future food security in rainfed areas. They are tolerant to varying climate scenarios and hence provide a practical and sustainable adaptation option for farmers. Various Indian Council of Agriculture Research (ICAR) institutes and state agricultural universities are making concerted efforts to develop high-yielding varieties of different crops with enhanced tolerance to delayed monsoon and drought over the years. The climate projections for the districts of Karnataka indicate an increase in the number of high-intensity rainfall events. However, this does not rule out the possibility of extended dry spells, if not drought, in these districts. Therefore, the adoption of climate-resilient varieties of crops is an adaptation option.

Resilient intercropping: In rainfed and dry regions of southern Karnataka, sole cropping is not much remunerative in the present scenario of climate change. Intercropping provides insurance against the vagaries of climate, modifies soil environment, improves moisture and radiation use, ensures better weed control, reduces disease and pest incidence, and on the whole increases and stabilises productivity.

Crop diversification: Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm considering the different returns from value-added crops with complementary marketing opportunities. Crop diversification is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production-related activities on various crops and to lessen risk and losses due to climate change.

7.2. Institutional Interventions

In addition to the various physical and biological interventions, there is a need for institutional interventions that are required for building long-term resilience. These include strengthening of climate information and agromet advisory services, as well as increasing the penetration of crop insurance and social safety nets.

7.2.1. Climate Information Services for Resilient Agriculture

Climate information includes information related to a continuum of time scales such as the current time, next few days or weeks, the cropping season, and the next decade. Information at these different scales are required for the farmers to aid climate-sensitive decision-making. However, for this information to be of value and use, it must match the time horizon of a particular decision. The most important time scales for decision-making in rainfed agriculture range from a few days to the following season.

To be useful, raw climate information must be translated into value-added climate information that is relevant to rainfed agriculture with estimates of sowing conditions, crop phenological stage, soil water content, soil temperature, crop water stress, (supplemental) irrigation requirements, and pest and disease risks (World Bank, 2010). Agromet advisories are such value-added products that consider the current and future weather, soil moisture, crop type, crop climate thresholds, and crop status. Such agromet advisories help farmers to buffer climate shocks and realise normal crop yields with no or minimal losses.

Currently, agromet advisories are provided through collaborative efforts of agricultural universities and Karnataka State Natural Disaster Management Centre (KSNDMC) through Grameen Krishi Mausam Seva Centres and the district-level agromet units of the Indian Meteorological Department.

Identifying the time horizon of climate-sensitive decisions and mapping annually made decisions onto a decision calendar are useful initial steps when identifying climate information needs and opportunities to improve climate information services (World Bank, 2010).

Here, we discuss some of the weather-based agriculture programmes, which are under implementation and can be expanded or replicated in the state.

i) **Village-based rain gauge:** Insufficient or excessive rainfall that is poorly timed can reduce plant health and the ability to produce high yield. Crops are also more likely to suffer from insect and disease damage under these conditions. Using rain gauges can enable farmers to keep a record of actual rainfall season by season, which will reflect changing rainfall patterns over time. CARE's Adaptation Learning Programme (ALP) with their partner organisation Presbyterian Agricultural Station–Garu (PAS-G) works to help vulnerable households enhance their abilities to adapt to climate change in Sub-Saharan Africa, to address the extreme changes in precipitation. ALP installed a rain gauge in the Farfar community to measure the amount of rainfall. They trained community members to take readings and write them on a tally card and to then pour out the water from the gauge to allow for accurate daily measurements. Every month, the data is sent to PAS-G, where a copy is kept on file and then forwarded to the Meteo Regional Office through Ghana's Ministry of Food and Agriculture (MOFA) for analysis and weather forecasting. The purpose of the rain gauge is to help determine the amount and distribution of annual rainfall and monitor changes over the long term. The feedback information from rainfall monitoring helps in planning for future, by guiding which crops can be sown and when. It also helps communities to become more sensitised to climate change, which will help them adapt effectively and face uncertainties.

ii) **Automatic weather stations (AWSs):** An AWS is a system that automatically records and transmits the observations recorded by using measuring instruments. Skymet Weather Services has built one of the world's largest networks of automated weather stations in India and has also enlisted corporate clients and public–private partnerships (PPP) to help farmers predict and prepare for extreme weather variations. It is expected that advances in digital technology and artificial intelligence can help farmers mitigate the severe impacts of climate change and prepare for worst-case scenarios[11].

iii) **Weather-based agro advisory:** Response farming tools such 'Automated Agro Advisory Service' (AAS) help farmers to get timely weather-based agro advisories to make necessary decisions for the next few days of farm operations. To cope with the impacts of climate change, agricultural scientists in state agricultural universities and ICAR are working to develop new technologies. These technologies are being developed to provide farmers with weather-based technical inputs on time, which will help them in managing weather-based anomalies and maintain their crops' productivity. Both central and state governments, including the Karnataka government, have such programmes. However, there is a need to expand the scope of these programmes to penetrate all the districts of Karnataka.

7.2.2. Crop Insurance

Crop insurance is a form of risk management, or rather a risk-sharing strategy, that helps farmers cope with climate risks. These include forms of crop insurance that protect farmers from the impacts of poor weather, thus mitigating risk. The Pradhan Mantri Fasal Bima Yojana (PMFBY) is one such scheme which covers all crops, as well as loanee and non-loanee farmers; is area-based; and recommends the use of technology. According to the Pocket Book of Agricultural Statistics (2019), the area insured under all crop insurance schemes in Karnataka during 2018–19 is 22.19 lakh hectares. This is only 18.48% of the total area under agriculture.

An effective crop insurance system is a critical part of a strategy to cushion income losses for farmers, provide finance inputs for agricultural production in the next planting season after a drought or flood, and deepen the penetration of agricultural credit for investment to boost agricultural productivity. There is, therefore, a need to increase the penetration of crop insurance. This could be achieved through mandatory awareness programmes on the benefits of crop insurance to be broadcast on radio and television, or spread through campaigns or word of mouth (Rai, 2019). There also is a need to make eligible women farmers, tenant farmers, and sharecroppers for crop insurance. Most importantly, the time taken for settlement of claims has to be strictly adhered to, as delays in release of claims will unsettle the farmers[12].

7.2.3. Social Safety Nets Through MGNREGA

The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) was ranked as the world's largest public works programme (World Bank, 2015), providing social security and

[11]https://ensia.com/features/india-weather-stations-farms-climate-resilience/
[12]https://www.thehindu.com/news/national/karnataka/delay-in-release-of-crop-insurance-claims-unsettles-farmers/article32061505.ece

leading to rural development across India. Enhancement of livelihood security of rural households by providing at least 100 days of guaranteed wage employment during the financial year to every household, whose adult members volunteer to do unskilled manual work, is the main goal of MGNREGA. Studies have demonstrated that MGNREGA provides environmental and climate vulnerability reduction benefits (Esteves et al., 2013).

MGNREGA could be tailored to provide social protection in the context of climate change if certain principles are incorporated into the programme. These principles are

- **Recognise uncertainty** in climate and changing frequency and intensity of shocks
- **Avoid maladaptation** by taking into consideration climate change projections in planning and design of activities so as to not only foster coping capacity in the short term but also build resilience in the long term. This is possible by
    - Selection of activities (termed 'works' under MGNREGA) that can address a flood or drought scenario at the district level.
    - Designing assets such as soil water conservation and irrigation to adapt to the projected climatic conditions, such as flooding events or moisture-deficit conditions.
    - Allocation of funds to districts and fixing of wage rates at the district level based on rainfall, drought, and flood projections.
- **Adjust programmes to context** as interventions need to be tailored to specific needs and vulnerability contexts. This would be possible only if planning, design, and implementation are science based.

7.3. Innovation Needed for Buffering Climate Risks and Shocks

In addition to the various time-tested and established physical and biological interventions for increasing the resilience of rainfed agriculture systems and institutional mechanisms to enable famers to utilise information and schemes that help cope with climate risks and shocks, there is a need for innovation in tackling issues faced by rainfed agriculture. Here we outline some innovative mechanisms that have been piloted by different institutions in different countries to address issues related to food and nutrition security, and climate adaptation.

Crop Insurance with No 'Claims' Process

A variant of the weather-based insurance scheme is the innovative Weather Index Insurance (WII)—a relatively new type of financial risk transfer product, which could help overcome some of the problems with traditional insurance schemes (IFAD, 2010; Barnett and Mahul, 2007). WII has been piloted in Kenya and India. This insurance scheme, unlike traditional crop insurance schemes wherein compensation is offered for loss that can be verified at the end of the growing season, clears claims based on the realisation of an objectively measured weather variable such as rainfall that is correlated with production losses (Musshof et al., 2011).

Kilimo Salama (Swahili term meaning 'safe farming') is an agricultural insurance programme launched in Kenya. This insurance scheme has been designed specifically for smallholders, helping farmers cope with climate change and devastating weather shocks in Kenya. Kilimo

Salama is a partnership between Syngenta Foundation, the Kenyan insurance company UAP, and Swiss Re Corporate Solutions. WII uses weather data from satellites and automated weather stations as a proxy to estimate farmers' harvest situation. At the end of each growing season, the collected weather data is automatically compared to an index of historical weather data, and if the rainfall, for example, is lower or above average, insurance pay out that the company owes to client farmers is calculated and sent. There is no claims process involved in this[13].

There is a need to bring in such innovations that promote use of technologies and financial instruments to help better manage risk in rainfed farming systems.

Payment for Ecosystem Services

Payment for Ecosystem Services (PES) related to water management assumes that activities in one part of a watershed may have implications for other parts of the watershed. For example, upstream adoption of soil and water management techniques are likely to reduce soil erosion and sedimentation in downstream water bodies, benefiting the downstream farmers. Such activities generate positive externalities, giving an opportunity for monetising and formulating schemes for payment (World Bank, 2009). Many of the soil and water management techniques provide many non-hydrological services, including carbon benefits from organic or non-tillage farming. Soils with increased carbon stocks have higher water retention capacity. Some projects implemented by the World Bank in Kenya have included payment for soil carbon enhancement as a strategy for promoting soil conservation measures on a pilot basis.

Public–Private Partnership for Agroforestry

Agroforestry is promoted worldwide as a climate adaptation strategy to smoothen climate shocks and ensure stable income to farmers. In many of the African countries, public–private partnerships are being promoted in agroforestry. One such successful case of public–private partnership for agroforestry has been demonstrated in Peru, where 20,000 farmers who produce organic high-quality cocoa in agroforestry systems on 58,000 hectares are supported through a public–private partnership[14]. There is a need to explore such partnerships for promoting agroforestry in rainfed areas, as agroforestry is an effective adaptation option that helps buffer loss of income from annual crops through produce and income flow from perennial tree crops (Duguma et al., 2014). It is also a climate change mitigation option (Murthy et al., 2013) that potentially could be accounted towards India's Nationally Determined Contribution Goals under the Paris Agreement.

Forecast-Based Financing for Social Protection

A financial mechanism that is put together by anticipating hazards—based on forecasts if properly linked with social protection systems such as MGNREGA—can help buffer climate-related shocks, and can help cope and manage climate risks in a proactive and effective way (Coughlan de Perez et al., 2015). Such a mechanism has been piloted by World Food Programme through the Food Security Climate Resilience Facility wherein early action is taken by: (i) a set of pre-agreed triggers (or danger levels); (ii) pre-defined actions to be taken when those triggers are met, and (iii) a financing mechanism to automatically fund them (RCCC and GRC 2017).

[13]https://www.syngentafoundation.org/agricultural-insurance-kenya
[14]https://initiative20x20.org/news/brazil-and-peru-trade-expertise-cocoa-agroforestry-first-ever-exchange

8. Way Forward

The government of India recently announced that it is planning to re-evaluate crop planting across the country to align agricultural practices with changes in climate and rainfall patterns. This requires a better understanding of the risks posed by climate change to agriculture in general, and more importantly for different crops at the state or district level. This study is an effort in that direction.

Risks of climate change have been analysed for only the three dominant rainfed crops—maize, sorghum, and groundnut—grown in Karnataka. There is a need to expand this analysis to all the rainfed crops grown in Karnataka. There is also a need for more information on actual yield losses due to variability and climate change. Further, changes in rainfall will need to be looked at in conjunction with other physiographic characteristics such as soil quality and slope to quantify the risks of climate change in the districts of Karnataka. However, on the basis of changes in temperature and rainfall projected for the short-term period of 2030s (2021–2050), several strategies could be implemented at the district level, considering the crops and projected risks due to climate change in the projected period.

Taking into consideration the climate risks identified in this study, adaptation strategies could be implemented. Many of the suggested strategies are 'win-win' options and could be implemented to build the resilience of rainfed agriculture systems. Some such strategies include physical interventions such as contour bunding, check dams and farm ponds; in-field practices such as mulching, cover cropping, and aquifer recharge, and crop related measures including crop diversification, agroforestry and intercropping.

The adoption of climate-resilient strategies for rainfed agriculture in the state will help buffer losses and avoid setbacks in agriculture production. Moreover, the implementation of long-term strategies that build resilience of agriculture systems will help bring crop productivity at par with the highest productivity recorded for those crops in India under rainfed conditions.

9. References

Abbas, G., Ahmad, S., Ahmad, A., Nasim, W., Fatima, Z., Hussain, S., ... & Boote, K. J. (2017). Quantification the impacts of climate change and crop management on phenology of maize-based cropping system in Punjab, Pakistan. Agricultural and Forest Meteorology, 247, 42-55.

Acharyya K (2019, November 08). Excess rain during 2019 monsoon damaged 32 lakh hectares of agricultural land in 12 states, says Skymet report. *Firstpost*. Retrieved from https://www.firstpost.com/india/excess-rain-during-2019-monsoon-damaged-32-lakh-hectares-of-agricultural-land-in-12-states-says-skymet-report-7623571.html

Alam, M. F., Pavelic, P., Sharma, N., & Sikka, A. (2020). Managed Aquifer Recharge of Monsoon Runoff Using Village Ponds: Performance Assessment of a Pilot Trial in the Ramganga Basin, India. Water, 12(4), 1028.Assefa, Y., Staggenborg, S. A., & Prasad, V. P. (2010). Grain sorghum water requirement and responses to drought stress: A review. Crop Management, 9(1), 1-11.

Attri, S. D., & Rathore, L. S. (2003). Simulation of impact of projected climate change on wheat in India. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 23(6), 693-705.*

Barnett BJ, Mahul O. Weather index insurance for agriculture and rural areas in lower-income countries. Am J Agric Econ. 2007; 89(5):1241–7. 13.

Birthal, P. S., Khan, T., Negi, D. S., & Agarwal, S. (2014). Impact of climate change on yields of major food crops in India: Implications for food security. Agricultural Economics Research Review, 27(2), 145-155.

Blakeslee, David S., and Ram Fishman. 2018. “Weather Shocks, Agriculture, and Crime: Evidence from India.” Journal of Human Resources 53: 750–82.

Blanco-Canqui H., R. Lal, W. M. Post and L. B. Owens. 2006. “Corn growth, and grain and biomass yield shortly after stover removal from no-till in Ohio.” Agron. J. 98: 1128–1136.

Boomiraj, K., Marimuthu, S., Wani, S. P., Ravikumar, S., and Tani, S. (2012). Vulnerability assessment of kharif rainfed sorghum to climate change in SAT regions of India. Journal of Agrometeorology, 14(1), 2-8.

Brooks, A., & Farquhar, G. D. (1985). Effect of temperature on the CO 2/O 2 specificity of ribulose-1, 5-bisphosphate carboxylase/oxygenase and the rate of respiration in the light. Planta, 165(3), 397-406.

Cairns, J. E., Sonder, K., Zaidi, P. H., Verhulst, N., Mahuku, G., Babu, R., ... & Rashid, Z. (2012). Maize production in a changing climate: impacts, adaptation, and mitigation strategies. In *Advances in agronomy* (Vol. 114, pp. 1-58). Academic Press.

Cakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research*, *89*(1), 1-16.

Challinor, A. J., Slingo, J. M., Wheeler, T. R., Craufurd, P. Q., & Grimes, D. I. F. (2003). Toward a combined seasonal weather and crop productivity forecasting system: determination of the working spatial scale. Journal of Applied Meteorology, 42(2), 175-192.

Chatterjee, A. (1998). *Simulating the impact of increase in Carbon Dioxide and temperature on growth and yield of Maize and Sorghum* (Doctoral dissertation, M. Sc. thesis, Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi).

Cicchino, M., Edreira, J. R., Uribelarrea, M., & Otegui, M. E. (2010). Heat stress in field-grown maize: Response of physiological determinants of grain yield. *Crop Science*, *50*(4), 1438-1448.

Denmead, O. T., & Shaw, R. H. (1960). The Effects of Soil Moisture Stress at Different Stages of Growth on the Development and Yield of Corn 1. *Agronomy Journal*, *52*(5), 272-274.

Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmer's Welfare, Ministry of Agriculture and Farmer's Welfare, Retrieved from https://eands.dacnet.nic.in/

Duguma, L.A., Minang, P.A. & van Noordwijk, M. 2014. Climate Change Mitigation and Adaptation in the Land Use Sector: From Complementarity to Synergy. Environmental Management 54, 420–432, https://doi.org/10.1007/s00267-014-0331-x.

E. Coughlan de Perez, B. van den Hurk, M. K. van Aalst, B. Jongman, T. Klose, and P. Suarez 2015. Forecast-based financing: an approach for catalyzing humanitarian action based on extreme weather and climate forecasts, Nat. Hazards Earth Syst. Sci., 15, 895–904, 2015, https://doi.org/10.5194/nhess-15-895-2015

Endo, M., Tsuchiya, T., Hamada, K., Kawamura, S., Yano, K., Ohshima, M., ... & Kawagishi-Kobayashi, M. (2009). High temperatures cause male sterility in rice plants with transcriptional alterations during pollen development. *Plant and Cell Physiology*, *50*(11), 1911-1922.

Esteves, T., Rao, K. V., Sinha, B., Roy, S. S., Rao, B., Jha, S., Singh, A. B., Vishal, P., Nitasha, S., Rao, S., Murthy, I. K., Sharma, R., Porsche, I., Basu, K. and Ravindranath, N. H. 2013, 'Agricultural and livelihood vulnerability reduction through the MGNREGA', Economic and Political Weekly, vol. 48, no. 52, pp. 94-103.

Famiglietti, James S. 2014. "The Global Groundwater Crisis." Nature Climate Change 4 (11): 945–48.

Fuhrer, J. (2003). Agroecosystem responses to combinations of elevated CO2, ozone, and global climate change. *Agriculture, Ecosystems & Environment*, *97*(1-3), 1-20.

Gadgil, S., Abrol, Y. P., & Seshagiri Rao, P. R. (1999). On growth and fluctuation of Indian foodgrain production. *Current Science*, *76*(4), 548-556.

Gan, Y. T. et al. Ridge-Furrow Mulching Systems-An Innovative Technique for Boosting Crop Productivity in Semiarid Rain-Fed Environments. Advances in Agronomy, Vol 118 118, 429–476, 10.1016/B978-0-12-405942-9.00007-4 (2013).

GoI, 2011, Census of India, 2011, Registrar General & Census Commissioner, Ministry of Home Affairs, retrieved by https://www.censusindia.gov.in/2011Census/pes/Pesreport.pdf

GoI, 2019, Agricultural Census, 2015-16, Agriculture Census Division Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare Government of India, Retrieved from http://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf

GoI, 2019. Pocket Book of Agricultural Statistics 2019, Ministry of Agriculture & Farmers Welfare, Directorate of Economics and Statistics, Government of India, Retrieved from - https://eands.dacnet.nic.in/PDF/Pocket%20Book%202019.pdf

GoI, 2020, Economic Survey of India, 2020, Ministry of Finance Department of Economic Affairs, retrieved from https://www.indiabudget.gov.in/economicsurvey/doc/echapter.pdf.

GoK, 2019, Economic Survey of Karnataka, 2018-19, Planning, Programme Monitoring and Statistics Department, retrieved from https://karnataka.gov.in/storage/pdf-files/ESR%202018-19%20English.pdf

Grant, R. F., Jackson, B. S., Kiniry, J. R., & Arkin, G. F. (1989). Water deficit timing effects on yield components in maize. *Agronomy journal*, *81*(1), 61-65.

Guiteras, R. (2009). The impact of climate change on Indian agriculture. *Manuscript, Department of Economics, University of Maryland, College Park, Maryland*.

Holaday, A. S., Martindale, W., Alred, R., Brooks, A. L., & Leegood, R. C. (1992). Changes in activities of enzymes of carbon metabolism in leaves during exposure of plants to low temperature. *Plant Physiology*, *98*(3), 1105-1114.

Horie, T., Matsui, T., Nakagawa, H., & Omasa, K. (1996). Effects of elevated CO 2 and global climate change on rice yield in Japan. In *Climate change and plants in East Asia* (pp. 39-56). Springer, Tokyo.

http://agritech.tnau.ac.in/agriculture/millets_sorghum.html, accessed on 8 July 2020.

http://agropedia.iitk.ac.in/content/growth-groundnut-plant#:~:text=Normally%2060%2D80%20days%20are,development%20declines%20during%20pod%20filling., accessed on 9 July 2020.

http://www.icrisat.org/Timelines/Bhoochetana/pub/2013_2.pdf

http://www.icrisat.org/Timelines/Bhoochetana/pub/2013_2.pdf , accessed on 2 June 2020.

https://e-krishiuasb.karnataka.gov.in/ItemDetails.aspx?depID=1&subDepID=3&cropID=1#, accessed on 9 July 2020.

https://grdc.com.au/__data/assets/pdf_file/0030/370596/GrowNote-Sorghum-North-04-Physiology.pdf, accessed on 8 July 2020.

https://initiative20x20.org/news/brazil-and-peru-trade-expertise-cocoa-agroforestry-first-ever-exchange

https://www.syngentafoundation.org/agricultural-insurance-kenya

ICRISAT, 2013, Bhoochetana, retrieved from IFAD. The potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods. Rome: International Fund for Agricultural Development and World Food Program; 2010.

Impe D, Reitz J, Köpnick C, Rolletschek H, Börner A, Senula A and Nagel M (2020) Assessment of Pollen Viability for Wheat. Front. Plant Sci. 10:1588. doi: 10.3389/fpls.2019.01588.

Jacoby, H., Rabassa, M., and Skouas, E. (2011). Distributional implications of climate change in India. The World Bank.

Jamanal, S. K., Natikar, K. V., Halakatti, S. V. (2019) A Study on Farmers Knowledge about Crop Insurance Schemes in Northern Karnataka.

Jonathan Woetzel, Dickon Pinner, Hamid Samandari, Hauke Engel, Mekala Krishnan, Brodie Boland, and Carter Powis, 2020. Climate risk and response – Physical Hazards and Socioeconomic impacts, McKinsey Global Institute, January 2020.

Jones, R. J., Quattar, S., & Crookston, R. K. (1984). Thermal Environment During Endosperm Cell Division and Grain Filling in Maize: Effects on Kernel Growth and Development in Vitro 1. *Crop Science*, *24*(1), 133-137.

Jian Xu, Wei Lan, Yanfeng Li, Wen-Chieh Cheng, Jun Yuan, Qinghai Tan, "Evaporation-Induced Water and Solute Coupled Transport in Saline Loess Columns in Closed and Open Systems", Geofluids, vol. 2019, Article ID 3781410, 26 pages, 2019. https://doi.org/10.1155/2019/3781410.

Kalra, N., Chakraborty, D., Ramesh, P. R., Jolly, M., & Sharma, P. K. (2007). Impacts of climate change in India: Agricultural Impacts. Final Report, Joint Indo-UK Programme of Ministry of Environment, 32.

Karhale, M. B., Jaybhaye, P. R., Asewar, B. V., & Shinde, P. B. (2014). Effect of different sowing dates on growth and yield of kharif sorghum hybrids. J Agric Vet Sci, 12(7), 2319-2380.

Kiniry, J. R., & Musser, R. L. (1988). Response of kernel weight of sorghum to environment early and late in grain filling. Agronomy Journal, 80(4), 606-610.

Kozlowski TT, Pallardy SG (1984) Effects of flooding on water, carbohydrate and mineral relations. In: Flooding Plant Growth Kozlowski pp: 165–193.

Kramer PJ, Boyer JS (1995) Water Relations of Plants and Soils. Academic Press, New York.

Krishna Kumar, K., Rupa Kumar, K., Ashrit, R. G., Deshpande, N. R., & Hansen, J. W. (2004). Climate impacts on Indian agriculture. International Journal of Climatology: A Journal of the Royal Meteorological Society, 24(11), 1375-1393.

KSNDMC (2017) Drought Vulnerability Assessment in Karnataka (A Composite Index: using Climate, Soil, Crop Cover and Livelihood components) KSNDMC. Bengaluru, 114p.

Kulshrestha, S. M. (2002). Climate variability and India's agriculture. *Meghdoot*, *3*, 2-3.

Kumar KS, Parikh J. 1998. Climate Change Impacts on Indian Agriculture: The Ricardian Approach. In Measuring the Impact of Climate Change on Indian Agriculture, (eds). Dinar A, Mendelsohn R, Evenson R, Parikh J, Sanghi A, Kumar K, McKinsey J, Lonergan S. Technical Paper 402, World Bank: Washington, DC.

Li, S. X., Wang, Z. H., Li, S. Q., Gao, Y. & Tian, X. H. Effect of plastic sheet mulch, wheat straw mulch and maize growth on water loss by evaporation in dryland areas of China. Agricultural Water Management 116, 39–49, 10.1016/j.agwat.2012.10.004 (2013).

Luhunga, P. M. (2017). Assessment of the impacts of climate change on maize production in the Southern and Western Highlands Sub-agro Ecological Zones of Tanzania. *Frontiers in Environmental Science*, *5*, 51.

Madhusudhana, B. (2013). A survey on area, production and productivity of groundnut crop in India. *IOSR journal of Economics and Finance*, *1*(3), 1-7.

Makoto Endo, Tohru Tsuchiya, Kazuki Hamada, Shingo Kawamura, Kentaro Yano, Masahiro Ohshima, Atsushi Higashitani, Masao Watanabe and Makiko Kawagishi-Kobayashi, 2009. High Temperatures Cause Male Sterility in Rice Plants with Transcriptional Alterations During Pollen Development, Plant Cell Physiol. 50(11): 1911–1922 (2009) doi:10.1093/pcp/pcp135, available online at www.pcp.oxfordjournals.org.

Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: a review. *Climatic Change*, *78*(2-4), 445-478.

Martin, B.A. (Pioneer Hi-Bred International, Inc., Johnston, IA); Cerwick, S.F.; Reding, L.D. (1991). Physiological basis for inhibition of maize seed germination by flooding, *Crop Sci* 31:1052-1057.

Mohamed, H. A. (1984). *Varietal differences in the temperature responses of germination and crop establishment* (Doctoral dissertation, University of Nottingham).

Muchow, R. C. (1989). Comparative productivity of maize, sorghum and pearl millet in a semi-arid tropical environment II. Effect of water deficits. *Field Crops Research*, *20*(3), 207-219.

Munshi, Kaivan, and Mark Rosenzweig. 2016. "Networks and Misallocation: Insurance, Migration, and the Rural-Urban Wage Gap." American Economic Review 106 (1): 46–98.

Murari Kamal, Mahato Sandeep, Jayaraman, Thiagarajan and Swaminathan Madhura (2019). Extreme Temperatures and Crop Yields in Karnataka, India.

Murthy IK, Gupta M, Tomar S, Munsi M, and Tiwari R. (2013) Carbon Sequestration Potential of Agroforestry Systems in India. J Earth Sci Climate Change 4:131. doi: 10.4172/2157-7617.1000131.

Musshof O, Odening M, Xu W. Management of climate risks in agriculture: will weather derivatives permeate? Appl Econ. 2011;43(9):1067–77.

Nageswara Rao, R. C., L. J. Reddy, V. K. Mehan, S. N. Nigam, and D. McDonald, 1992: Drought research on groundnut at ICRISAT. In: S. N. Nigam, ed. Groundnut – A Global Perspective. Proc. International Workshop, p. 455. ICRISAT Center, Andhra Pradesh, India, 25–29 November 1991

Pandey, V., Karande, B. I., & Mote, B. M. (2016). Impact and management of extreme weather events in Groundnut production in India. Indian Journal of Natural Sciences, 7(39), 11824-11833.

Pandit, M., Sah, R. P., Chakraborty, M., Prasad, K., Chakraborty, M. K., Tudu, V., & Rana, M. (2018). Gene action and combining ability for dual purpose traits in maize (Zea mays L.) under water deficit stress prevailing in eastern India. *Range Management and Agroforestry*, *39*(1), 29-37.

Pandya, P. A., Mashru, H. H., Patel, R. J., & Rank, H. D. (2019) Rainfall variations and its correlation with groundnut productivity.

Prasad, P. V., Boote, K. J., & Allen Jr, L. H. (2006). Adverse high temperature effects on pollen viability, seed-set, seed yield and harvest index of grain-sorghum [Sorghum bicolor (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. *Agricultural and forest meteorology*, *139*(3-4), 237-251.

Prasad, P. V., Craufurd, P. Q., & Summerfield, R. J. (2000). Effect of high air and soil temperature on dry matter production, pod yield and yield components of groundnut. *Plant and soil*, *222*(1-2), 231-239.

Raagavali, K., Soumya, T., Veeranna, H., Nataraju, S., & Narayanswamy, H (2019). Effect of sowing windows on growth and yield of groundnut (Arachis hypogaea L.) genotypes. Int. J. Curr. Microbiol. App. Sci 8(3): 59-67

Raghavan, K., Jayanarayanan, S., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (Eds.), 2020. Assessment of Climate Change over the Indian Region. A Report of the Ministry of Earth Sciences (MoES) (1st ed), Government of India, Springer Singapore, Springer Nature.

Rajeshwari, Desai, B. L. Patil, L. B. Kunnal, H. Jayashree and H. Basavaraj. 2007. “Impact assessment of farm-ponds in Dharwad district of Karnataka.” Karnataka Journal of Agricultural Sciences 20(2): 426–427.

Rao PV, Subba Rao IV, Reddy PR (1986) Influence of water stress at different stages on growth and productivity of groundnut (Arachis hypogea L.). The Andhra Agric. J. 33, 48-52.

Rao, V. U. M., Rao, S. A., Chandran, M. S., Kaur, P., Kumar, P. V., Rao, B. B., ... & Rao, C. S. (2015). *District level crop weather calendars of major crops in India*. ICAR-Central Research Institute for Dryland Agriculture.

Rathore, T. R., Warsi, M. Z. K., Singh, N. N., & Vasal, S. K. (1998, February). Production of maize under excess soil moisture (waterlogging) conditions. In *Proceedings of the 2nd Asian Regional Maize Workshop PACARD. Laos Banos, Phillipines* (p. 23).

RCCC and GRC (2017) Manual for Forecast Based Financing, Red Cross, Red Crescent Climate Centre and German Red Cross.

Reddy, T. Y., Reddy, V. R., & Anbumozhi, V. (2003). Physiological responses of groundnut (Arachis hypogaea L.) to drought stress and its amelioration: a review. Acta agronomica hungarica, 51(2), 205-227.

Revadekar, J. V., & Preethi, B. (2012). Statistical analysis of the relationship between summer monsoon precipitation extremes and foodgrain yield over India. *International Journal of Climatology*, *32*(3), 419-429.

Reyna, N., B. Cornelious, J. G. Shannon, and C. H. Sneller, 2003. “Evaluation of a QTL for waterlogging tolerance in Southern Soybean Germplasm,” Crop Science, vol. 43, no. 6, pp. 2077–2082, 2003.

Reynolds, M. P., Pierre, C. S., Saad, A. S., Vargas, M., & Condon, A. G. (2007). Evaluating potential genetic gains in Wheat associated with stress-adaptive trait expression in elite genetic resources under drought and heat stress. *Crop Science*, 47, S-172.

Ruchbah Rai, 2019. Pradhan Mantri Fasal Bima Yojana: An Assessment of India’s Crop Insurance Scheme, ORF Issue Brief No. 296, May 2019, Observer Research Foundation.

Saha S., Chakraborty D., Sharma A. R., Tomar R. K., Bhadraray S., Sen U., Behera U. K., Purakayastha T. J., Garg R. N., and Kalra N. 2010. “Effect of tillage and residue management on soil physical properties and crop productivity in maize (Zea mays)–Indian mustard (Brassica juncea) system.” *Indian Journal of Agricultural Sciences* 80(8):679–85.

Sahu, D. D., Patra, B. K., & Patoliya, B. M. (2004). Effect of sowing time and rainfall distribution on groundnut yield.

Sanghi, A., & Mendelsohn, R. (2008). The impacts of global warming on farmers in Brazil and India. *Global Environmental Change*, *18*(4), 655-665.

Sarkar J, Thapliyal V. 2003. Forecasting wheat yield over Uttar Pradesh using agrometeorological model. Journal of Maharashtra Agricultural University 28(3): 299302.

Sarkar J. 2005. Agricultural drought in India during Monsoon – 2002. Journal of Maharashtra Agricultural University 30(2): 204–206.

Schlenker, W., & Roberts, M. J. (2008). *Estimating the impact of climate change on crop yields: The importance of nonlinear temperature effects* (No. w13799). National Bureau of Economic Research.

Scott, H. D., J. De Angulo, M. B. Daniels, and L. S. Wood, "Flood duration effects on soybean growth and yield," Agronomy Journal, vol. 81, no. 2, pp. 631–636, 1989.

Selvaraju, R. (2003). Impact of El Niño–southern oscillation on Indian foodgrain production. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *23*(2), 187-206.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Shanker S. (2019, June 14), 88.6% Of Karnataka's Area Under Drought As Govt Admits Design Flaw in Water Schemes. *India Spend*. Retrieved from https://www.indiaspend.com/88-6-of-karnatakas-area-under-drought-as-govt-admits-design-flaw-in-water-schemes/

Shiva Prasad, C.R., Reddy, R.S., Sehgal, J. and Velayutham, M, 1998. Soils of Karnataka for optimizing land use. NBSS Publications 47, p. 15.

Singh, S., Kattarkandi, B., Deka, S., & Choudhary, R. (2010). Impact of climatic variability and climate change on maize productivity in north India. *Current Advances in Agricultural Sciences (An International Journal)*, *2*(1), 5-9.

Swamy, H. M., Lokesh, G. B., & Deepthi, B. V. (2017). Productivity and Sustainability of Maize under Climate Change Scenario in Karnataka. *Research Journal of Agricultural Sciences*, *8*(4), 875-878.

Taraz Vis, 2018. http://barrett.dyson.cornell.edu/NEUDC/paper_287.pdf

Thiyagarajan, G., Ranghaswami, M. V., Rajakumar, D., & Kumaraperumal, R. (2010). Deficit irrigation effects on groundnut (Arachis hypogaea L.) with micro-sprinklers. *Madras Agricultural Journal*, *97*(1-3), 40-2.

Vara Prasad, P. V., Boote, K. J., Hartwell Allen Jr, L., & Thomas, J. M. (2003). Super‐optimal temperatures are detrimental to peanut (Arachis hypogaea L.) reproductive processes and yield at both ambient and elevated carbon dioxide. Global Change Biology, 9(12), 1775-1787.

Varma IJ, Das HP, Kore PA, Balasubramanian R. 2007. A study on 'Peak Rainfall Period 'and its agricultural implication on crops grown in dry farming region of India. Mausam 58(4): 580–582.

Varshneya, M. C., Sabale, R. N., Bote, N. L., Salunke, S. S., More, D. B., & Thanedar, P. V. (2004). Response of CERES sorghum model for different agroclimatic conditions. J Agrometeorol, 6(1), 119-124.

Venkatesh, H., H. S. Shivaramu, M. B. Rajegowda and VUM Rao. 2016. Agroclimatic Atlas of Karnataka. UAS, Dharwad.

Venkateswarlu, J. 2010. Rainfed Agriculture in India: Research and Development Scenario. New Delhi: Indian Council of Agricultural Research.

Wada, Yoshihide, Ludovicus P. H. van Beek, Cheryl M. van Kempen, Josef W. T. M. Reckman, Slavek Vasak, and Marc F. P. Bierkens. 2010. "Global Depletion of Groundwater Resources." Geophysical Research Letters 37 (20).

Wani SP, Sarvesh KV, Krishnappa K, Dharmarajan BK and Deepaja SM (eds.) 2012. Bhoochetana: Mission to Boost Productivity of Rainfed Agriculture through Science-led Interventions in Karnataka. Retrieved from http://oar.icrisat.org/5925/

World Bank, 2009. Harvesting Agricultural Carbon in Sub-Saharan Africa: A Potential Triple-Win. World Bank Policy Brief (draft). Washington, DC: World Bank.

World Bank, 2010. Improving Water Management in Rainfed Agriculture: Issues and Options in Water-Constrained Production Systems.

World Bank. 2015. The State of Social Safety Nets 2015. Washington, DC: World Bank. doi:10.1596/978-1-4648-0543-1. License: Creative Commons Attribution CC BY 3.0 IGO.

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., ... & Durand, J. L. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, *114*(35), 9326-9331.

10. Appendix

Appendix 1: List of CORDEX models used in this study for climate change projections

CORDEX Simulation	RCM	GCM Boundary Condition
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	SMHI-RCA4	CNRM
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	SMHI-RCA4	GFDL
IPSL-CM5A-MR_SMHI-RCA4	SMHI-RCA4	IPSL-CM5A
MIROC-MIROC5_SMHI-RCA4	SMHI-RCA4	MIRCO
MPI-M-MPI-ESM-LR_SMHI-RCA4	SMHI-RCA4	MPI-M
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	IITM–RegCM4-4	CNRM
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	IITM–RegCM4-4	GFDL
IPSL-CM5A-MR_SMHI-RCA4	IITM–RegCM4-4	IPSL-CM5A
MIROC-MIROC5_SMHI-RCA4	IITM–RegCM4-4	MIROC
MPI-M-MPI-ESM-LR_SMHI-RCA4	IITM–RegCM4-4	MPI-M
CCma-CanESM2	IITM–RegCM4-4	CCMA
CSIRO-QCCCE-CSIRO-Mk3-6-0	IITM–RegCM4-4	CSIRO
NOAA-GFDL/GFDL-ESM2M	IITM–RegCM4-4	GFDL-ESM2M
MPI-M-MPI-ESM-LR	IITM–RegCM4-4	MPI-M
MOHC-HadGEM2-ES	IITM–RegCM4-4	HadGEM2

(*Source: CORDEX South Asia, IITM Pune (RCP 8.5); RCM: SMHI-RCA4 (Rossby Centre Regional Atmospheric Model V. 4, Swedish Meteorological and Hydrological Institute*)

Appendix 2: Physical and financial targets and achievements under the Rainfed Area Development Programme in Karnataka

District	Physical (ha) Target	Physical (ha) Achievement	Financial (in INR) Target	Financial (in INR) Achievement
Bagalkot	204.00	166.87	56,28,516	39,69,671
Ballari	364.00	274.72	1,36,65,000	97,14,000
Belagavi	1,036.00	1,042.72	3,88,40,000	2,22,85,631
Bidar	440.00	211.00	1,21,02,000	62,78,250
Chikballapur	710.22	499.00	1,63,26,000	81,18,300
Chitradurga	589.00	253.17	1,71,83,180	1,04,81,066
Davanagere	196.00	197.00	60,44,000	56,47,060
Koppal	101.00	49.64	52,26,000	27,96,308
Mandya	252.00	128.30	1,68,62,000	1,05,55,832
Raichur	73.00	50.00	21,03,000	12,50,000
Ramanagara	467.00	558.15	2,05,15,800	1,17,25,949
Yadgir	400.00	131.00	44,11,000	28,51,000

Appendix 3: Optimum climate thresholds for maize

Std week	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
T_{max} (°C)	36.2	36.4	35.0	34.3	33.4	33.2	33.5	33.5	33.3	33.5	32.9	32.9	33.4	33.6	33.5	32.3
T_{min} (°C)	22.0	22.0	21.7	21.9	21.9	21.6	21.8	21.8	21.4	21.0	19.2	22.3	23.8	23.4	19.2	15.2
Rain (mm/w)	37	63	66	89	61	108	74	66	86	41.7	12	23	7	5	-	-

Appendix 4: Optimum climate thresholds for sorghum

Std Week	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
T_{max} (°C)	30	30	31	32	29	30	30	30	30	31	29	30	30	29	28
T_{min} (°C)	20	21	22	22	20	20	19	18	17	16	16	14	14	13	13
Rain (mm/w)	32	45	49	40	24	14	7	5	7	4	1	3	1	0	1

Appendix 5: Optimum climate thresholds for groundnut

Std week	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
T_{max} (°C)	30.3	29.2	29.1	29	28.8	28.3	28.0	27.8	27.6	27.5	27.5	27.7	27.9	28.1	28.2	28.1	28.1	27.9
T_{min} (°C)	19.7	19.5	19.3	19.2	19.1	19.1	19.1	19.0	18.8	18.9	18.9	18.8	18.7	18.8	18.8	18.9	18.8	18.7
Rain (mm/w)	22	24	20	10	8	18	25	25	26	31	24	30	35	21	43	50	53	43

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY AND POLICY

Bengaluru

No. 18 & 19, 10th Cross, Mayura Street, Papanna Layout,
Nagashettyhalli (RMV II Stage), Bengaluru-560094
Karnataka, India

Noida

1st Floor, Tower-A, Smartworks Corporate Park, Sector-125,
Noida-201 303, Uttar Pradesh, India

Email: cpe@cstep.in