Syed Sheraz Mahdi *Editor*

Climate Change and Agriculture in India: Impact and Adaptation

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In memory of my beloved late father, Syed Mahdi Shah, to whom my desire to serve utmost remained a desire only

Preface

Climate change is perhaps the most serious environmental threat to fight against hunger, malnutrition, disease and poverty, mainly through its impact on agricultural productivity. Agriculture is a climate-sensitive sector and is also a sector that provides livelihood for more than 60% of Indians. Warming due to climate change is now reality as evident from the significant increase in the CO_2 concentration (410.88 ppm as on June, 2018) which has caused most of the warming and has contributed the most to climate change. Yet again, year 2016 and 2017 set a global heat record for the third year in a row. A record El Nino lasting from 2015 into 2016 played a role in further pushing the planet's temperature higher. The rising temperatures will adversely affect the world's food production and India would be the hardest hit. There are reports of shifting in the sowing time and length of growing seasons geographically, which would alter planting and harvesting dates of crops and varieties currently used in a particular area. It is estimated that crop production loss in India by 2100 AD could be 10–40% despite the beneficial effects of higher CO_2 on crop growth. The impact of climate change on water availability will be particularly severe for India. About 54% of India's groundwater wells are decreasing with 16% of them decreasing by more than one meter per year. Dynamic of pests and diseases will be significantly altered leading to the emergence of new patterns of pests and diseases which will affect crops yield.

No doubt, Indian farmers have evolved many coping mechanisms over the years, but these have been fallen short of an effective response strategy in dealing with recurrent and intense forms of extreme climatic events on the one hand and gradual changes in climate like rise in surface temperatures, changes in rainfall patterns, increases in evapo-transpiration rates and degrading soil moisture conditions on the other. Region wise climate change adaptation and mitigation options have been identified as important strategies to safeguard food production.

To this end, this book ***Climate Change and Agriculture in India: Impact and Adaptation*** provides the most recent understanding about climate change and its effects on agriculture in India. Further in-depth research is showcased regarding important allied sectors such as horticulture and fisheries and examines the effect of climate change on different cereal crops. The individual chapters discuss the different mitigation strategies for climate change impacts and detail abiotic and biotic stresses in relation to climate change. The book provides an insight into environmentally safe and modern technologies approaches such as nanotechnology, utilization of underutilized crops and breeding climate resilient crops under a changing climate. This book provides a solid foundation for the discussion of climate resilience in agricultural systems under both temperate and subtropical conditions of India and the requirements to keep improving agricultural production.

I am grateful to Dr. A.K. Singh, Vice Chancellor, BAU, Sabour, for providing necessary support, guidance and encouragement in compiling and editing this first edition of the book. The encouragement, support and guidance received from Dr. R.K. Sohane, Director Agriculture Extension Education, BAU, Sabour, and Dr. R.P. Sharma, Associate Dean-cum-Principal, BAC, Sabour, is sincerely acknowledged. I express sincere thanks to all the authors who had contributed in time and sharing their knowledge.

I firmly believe that this publication will be highly useful, in one way or other, for researchers, academicians, extension workers, policy makers, planners, officials in development institutions/agencies, producers, farmers and students of the agriculture and allied sciences.

Khudwani, Anantnag, Kashmir, J & K, India
June 12, 2018

Editor

S. Sheraz Mahdi

Introduction

Due to increase in anthropogenic activities, global temperatures have shown a warming trend of 0.87°Cover the period 1880–2015. Annual surface air temperatures over India also have shown increasing trends of similar magnitude during the period 1901–2016, making 2016 the warmest year in the period of instrumental data. Warmer temperature during the monsoon season (June-September, +0.72°C above average) and the post monsoon season (October-December, +1.1°C above average) mainly contributed to the warmer annual temperature. Climate change is now reality as evident from the significant increase in the CO_2 concentration (408.84 ppm as on June 2017) which has caused most of the warming and has contributed the most to climate change. Two drought years in south central India created panic and for the first time in the history and special trains were put in place to provide drinking water. Climate Change and its extremes are increasingly one of the most serious national security threats, which will have significant impacts on agriculture, natural resources, ecosystem and biodiversity. At the same time, it is likely to trigger food insecurity, human migration, economic and social depression, environmental and political crisis, thereby affecting national development. Although, scientific reports have amply proved that future food production is highly vulnerable to climate change. But, an important source of uncertainty in anticipating the effects of climate change on agriculture is limited understanding of crop responses to extremely weather events. This uncertainty partly reflects the relative lack of observations of crop behavior in farmers' field under extreme heat or cold. Crop yield increases have been slowed and may go into decline as the region runs out of natural resources. Therefore, regular assessments to understand the science of earth's changing climate, and its consequences; primarily driven by global warming, which in turn is highly extensive, complicated, and uncertain, is a scientific challenge of enormous importance to society. The summary of the recent IPCC's fifth assessment report (IPCC 2015) has again a stark warning on how climate change is threatening the South Asia, but report has also shown the way out to combat rampant climate change. India needs to develop a regional strategy for adapting to climate change and its variability in order to ensure food and ecological sustainability. Recognizing the importance of science issues that need to be addressed to deal with climate change, new approaches and policy interventions are desperately needed to enable and encourage smallholder farmers to adopt new technologies and practices under more uncertain and extreme climatic conditions for a resilient agricultural production system. No doubt, Indian farmers have evolved many coping mechanisms over the years, but these have been fallen short of an effective response strategy in dealing with recurrent and intense forms of extreme climatic events on one hand and gradual changes in climate like rise in surface temperatures, changes in rainfall patterns, increases in evapo-transpiration rates and degrading soil moisture conditions on the other. Region wise climate change adaptation and mitigation options have been identified as important strategies to safeguard food production.

Through this book we have bought together a series of chapters that provide scientific insights to possible implications of climate changes for different important types of crop and fisheries systems, and a discussion of options for adaptive and mitigative management. The book provides recent understanding about the climate change and its effects on agriculture. It also includes information regarding important sector like horticulture and fisheries. It examines the effect of climate change on different cereal crops and discusses different mitigation strategies for climate change effects. Details about the abiotic and biotic stresses in relation to climate change are also discussed. It also presents environmentally safe and recent technologies approaches such as nanotechnology and utilization of underutilized crops under changing climate. The information about climate change trends and crop scenario of temperate and cold arid region of Ladakh, Kashmir has been also discussed in last two chapters. This volume provides a solid foundation for the discussion of climate resilience in agricultural systems and the requirements to keep improving agricultural production.

The book is an excellent resource for researchers, instructors, students in agriculture, horticulture, environmental science, other allied subjects and policymakers.

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Contents

List of Figures

List of Tables

The original version of this book was revised: The author group of the chapters 18 and 19 have now been restored as in the original submission. The correction to this chapter is available at https://doi.org/10.1007/978-3-319-90086-5_21

Chapter 1
Future Changes in Rainfall and Temperature Under Emission Scenarios over India for Rice and Wheat Production

P. Parth Sarthi

Abstract Indian Summer Monsoon (IMS) prevails during June–July-August-September (JJAS) and 80% of the annual precipitation is received during JJAS. The spatial and temporal variability of ISMR and surface temperature has been influencing agriculture and water resources. The changes in earth's surface temperature is affecting the patterns of weather and climate and influencing the agriculture. The Coupled Model Inter comparison Project 5 (CMIP5) models output data is generally of higher resolution with different emission experiments and therefore rainfall and surface temperature over India is analyzed under CMIP5 which may be used for agricultural purposes.

The Indian Summer Monsoon Rainfall (ISMR) in simulation of BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM), CESM1(WACCM), and MPI-ESM-MR for the period of 2006–2050 under RCPs 4.5 and 8.5 at 99% confidence shows possibility of excessrainfall over homogeneous monsoon regions of NWI, NEI, WCI and PI, while deficit rainfall over NWI, NEI, WCI, CNI and PI. At 99% and 95% confidence levels, deficit rainfall is found over CNI, NWI and PI. The CMIP5 model GISS-E2-H, BCC-CSM1.1 m and GISS-E2-H-CC for Tmax; GFDL-CM3, MRI-CGM3 and MRI-ESM1 for Tmin; and CESM1 (CAM5) for T under Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the period of 2021–2055 shows possible significant warming of 0.5°C–0.7°C at 99% confidence level over homogeneous temperature regions of NC, NW, and WC. The warming of 0.2°C–0.5°C might be possible at other locations.

These future projections may be used in crop simulation models which may assist adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies.

Keywords Rainfall · Temperature · Future projections and GCMs

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1.1 Introduction

The summer monsoon season in India lasts during June-July-August-September (JJAS) (Rao 1976) and 80% of the annual rainfall occurs during JJAS. The Indian Summer Monsoon Rainfall (ISMR) spatial and temporal variability has been largely influencing agriculture and water resources. As well as, rapid increase in earth's surface temperature is affecting the patterns of weather and consequently influencing the agriculture production.

Under warming conditions, ISMR simulated in different Global and Regional Climate Models have been studied by various researchers; however, uncertainties exist in the regional climate projections due to biasness in the global climate models (Meehl and Washington 1993; Lal et al. 1994, 1995; Rupa Kumar and Ashrit 2001; May 2004; Kripalani et al. 2003; Rupa Kumar et al. 2002, 2003). The variability of ISMR has great importance over the Gangetic plain for agriculture, but it is poorly simulated in many climate models (Lal et al. 2001; Rupa Kumar and Ashrit 2001; Rupa Kumar et al. 2003)., Kripalani et al. (2007a) suggested significant increase in mean monsoon precipitation of 8% and possible extension of the monsoon period, in doubling of CO_2 experiment of Coupled Model Inter Comparison Project Phase 3 (CMIP3). Further, Kripalani et al. (2007b) applied t test and F ratio and suggested possible significant changes in future rainfall from −0.6% for CNRM-CM3 to 14% for ECHO-G and UKMO HadCM3 for East Asian monsoon. Menon et al. (2013a, b) suggested increase in all-India summer monsoon rainfall (AISMR) per degree change in temperature of about 2.3% K − 1, which is similar to the projected increase in global mean precipitation per degree change in temperature in CMIP3. Sarthi et al. (2012) suggested, under A2, B1 and A1B experiments of CMIP3, a future projected change in spatial distribution of ISMR which shows deficit and excess of rainfall in Hadley Centre Global Environment Model version 1 (HadGEM1), European Centre Hamburg Model version 5 (ECHAM5), and Model for Interdisciplinary Research on Climate (MIROC) (Hires) over parts of western and eastern coast of India. Multi-models average of CMIP5 simulations, less uncertainty in CMIP5 projections of rainfall and temperature.

The global mean surface air temperature has been increased by 0.60°C in 20th century experiment of Intergovernmental Panel on Climate Change (IPCC)'s Third Assessment Report (AR3), while as per IPCC's Fourth Assessment Report (AR4), it is estimated to have increased by 0.74°C and could rise up to 1.1°C–6.4°C during twenty-first century depending on a range of possible scenarios (IPCC 2007). In IPCC's Fifth Assessment Report (AR5), increment in temperature are largely due to anthropogenic emissions (IPCC 2014). In IPCC (2014), increase in global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to increase in the range of 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5) in CMIP5. Lal et al. (2001), Rupa Kumar et al. (2003, 2013), and Pattnayak et al. (2015) have analyzed projected surface temperature in various coordinated climate models experiments such as CMIP3 and CMIP5.

Lal et al. (2001) has been suggested projected mean warming of 1.0°C–1.4°C and 2.2°C–2.8°C by 2020 and 2050, respectively over the Indian subcontinent (IPCC, 2014). In 21st century, increase in temperature is particularly conspicuous after the 2040s over India and suggested an increase in Tmin (up to 4°C) all over the country, which might be more in Northeast India (Rupa Kumar et al. 2003).Overall increase in surface temperature by 4.8°C, 3.6°C and 2.2°C in A2, A1B, and B1 emission scenarios, may be possible at the end of 21st century experiment of CMIP3. Extremes in Tmax and Tmin are also expected to increase over the West-Central India in different scenarios (Rupa Kumar et al. 2013). Pattnayak et al. (2015) have analyzed the six CMIP5 model's namely GFDL-CM3, GFDL-ESM2M, GFDL-ESM2G, HadGEM2-AO, HadGEM2-CC and HadGEM2-ES in RCPs 4.5 and 8.5, which are able to capture spatial distribution of temperature with an increasing trend over most of the regions over India. Chaturvedi et al. (2012) worked on multi-model and multiscenario temperature projections over India for the period of 1860–2099 using CMIP5 under RCPs 6.0 and 8.5 scenarios, it is found that mean warming in India is likely to be in the range of 1.7–2°C by 2030s and 3.3–8 4.8°C by 2080s relative to preindustrial times.

Under World Climate Research Programme (WCRP),Working Group on Coupled Modelling (WGCM), Climate models are integrtaed out for past, present and future climate under differerent emission scenarios in Coupled Model Inter comparison Project 5 (CMIP5) and simulated rainfall and surface temperature area analyzed for agriculture purposes in this paper Section 1.1 deals with Introduction and literature survey; data and methodology is in Sect. 1.2. Results and discussion is placed in Sect. 1.2 while conclusions are in Sect. 1.4.

1.2 Data and Models

The gridded observed rainfall of India Meteorological Department (IMD) at resolution of 1°×1° during 1961–1999 and observed rainfall of Global Precipitation Climatology Project (GPCP) at resolution of 2.5°× 2.5° during 1979–1999 is considered for validating the model's performance. Table 1.1 and 1.2 shows list of CMIP5 models considered under RCP 4.5 and 8.5 experiments for analysis of rainfall and surface temperature T, Tmax (for March, April, May) and Tmin (December, January, February). RCPs 4.5 and 8.5 experiments are very likely that world will follow these mild and high emission scenarios in future time periods. The simulation of a Historical experiment in CMIP5 is equivalent to 20th century experiment (20C3M) of CMIP3; models are integrated from 1850 to 2012 with external forcing changing with time. The external forcing includes GHGs, the solar constant, volcanic activity, ozone, and aerosols.

For rainfall, the period of historical experiment is 1961–2005 and for future project is 2006–2050; for surface temperature, the period for historical experiment is 1971–2005 and for future project is 2021–2055.

Table 1.1 List of CMIP5 models their surface resolution and available RCPs experiment for rainfall analysis

Serials No.	Models	Surface Resolution	RCP 4.5	RCP 8.5
1	BCCCSM 1.1(m)	320 × 160	√	√
2	CCSM4	288 × 192	√	√
3	CESM1(CAM5)	288 × 192	√	√
4	CESM1 (BGC)	288 × 192	√	√
5	CESM1 (WACCM)	144 × 96		√
6	MPI-ESM-MR	192 × 96	√	√
7	CESM1 (FASTCHEM)	288 × 192		

Table 1.2 List of CMIP5 models their surface resolution and available RCPs experiment for T, Tmax, and Tmin

	Models	Surface Resolution	RCP 4.5	RCP 8.5
T	BCCCSM 1.1(m)	320 × 160	√	√
Tmax	GISS-E2-H-CC	144 × 90	√	√
	BCCCSM1.1(m)	320 × 160	√	√
	GISS-E2-H-CC	144 × 90	√	√
Tmin	GFDL-CM3	144 × 90	√	√
	MRI-CGCM3	120 × 120	√	√
	MRI-ESM1	120 × 120	√	

1.3 Results and Discussions

Fig. 1.1 shows homogeneous monsoon regions namely North West India (NWI), Central Northeast India (CNI), North East India (NEI), West Central India (WCI), Peninsular India (PI) and Hilly Regions (HR). Fig. 1.2 depicts Temperature homogeneous regions namely North East (NE), North West (NW), North Central (NC), East Coast (EC), Peninsula India (IP), Western Himalaya (WH), West Central (WC) of India. To analyze the reduced uncertainty in future projection of rainfall and temperature, students T test at 99% and 95% confidence levels is applied on the projected values.

A large number of CMIP5 models under Historical experiment is evaluated with observed rainfall of IMD and GPCP (Fig. not shown) and only BCC-CSM1.1(m), CCSM4, CESM1(BGC), CESM1(CAM5), CESM1(FASTCHEM), CESM1 (WACCM), and MPI-ESM-MR performed well and therefore used for analyzing future projections of ISMR in June-July-August-September (JJAS) under RCPs 4.5 and 8.5 emission scenarios. The spatial distribution of future projected percentage changes in JJAS (mm/month) rainfall during 2006–2050 in RCPs of 4.5 and 8.5 of BCC-CSM1.1 (m),CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (WACCM), CESM1 (FASTCHEM) and MPI-ESM-MR with respect to Historical experiment (1961–2005) is shown in Figs. 1.3a–k at 99% and 95% confidence levels using student t-test. In Figs. 1.3a–b, an excess of 5–25% rainfall at 99% and 95%

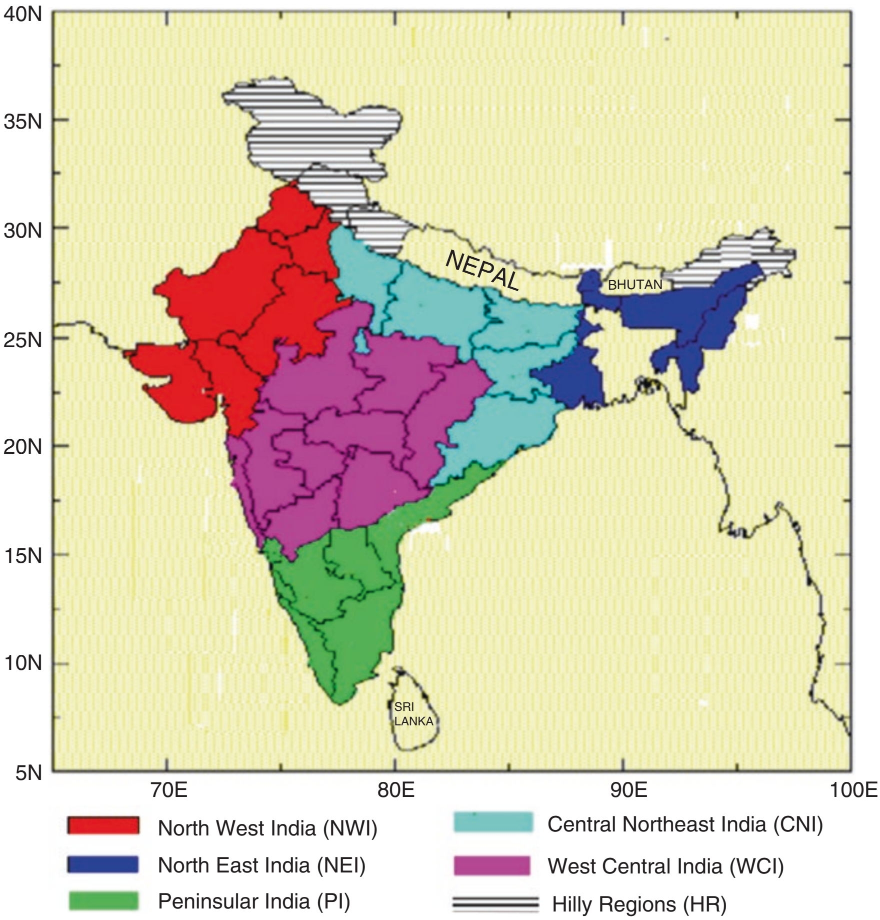

Fig. 1.1 Homogeneous monsoon regions of India (Source: India Institute of Tropical Meteorology, Pune, India)

confidence levels may be possible over the parts of NWI, Gangetic plain of CNI and PI. Figs. 1.3c–d shows possibility of 5–15% excess rainfall at 99% and 95% confidence levels over Western Ghat, parts of WCI and Gangetic plain of CNI, in simulations of CCSM4. In CESM1 (CAM5) simulations (Figs. 1.3e–f), 5–15% deficit rainfall at 99% and 95% confidence levels may be possible over the Gangetic plain of CNI and 5% deficit rainfall at 95% confidence over PI. Excess rainfall of 5–15% at 99% and 95% confidence levels may be possible over parts of CNI and PI in CESM1 (BGC) (Figs. 1.3g–h). 5–10% deficit rainfall at 99% confidence level over NWI is simulated in both RCPs. In MPI-ESM-MR simulations (Figs. 1.3i–j), 10–15% excess rainfall at 99% and 95% confidence levels may be possible over WCI, while 5–10% deficit rainfall over parts of NWI and CNI. In Fig. 1.3k, CESM1 (WACCM) shows, 10–15% excess rainfall at 99% confidence level over parts of

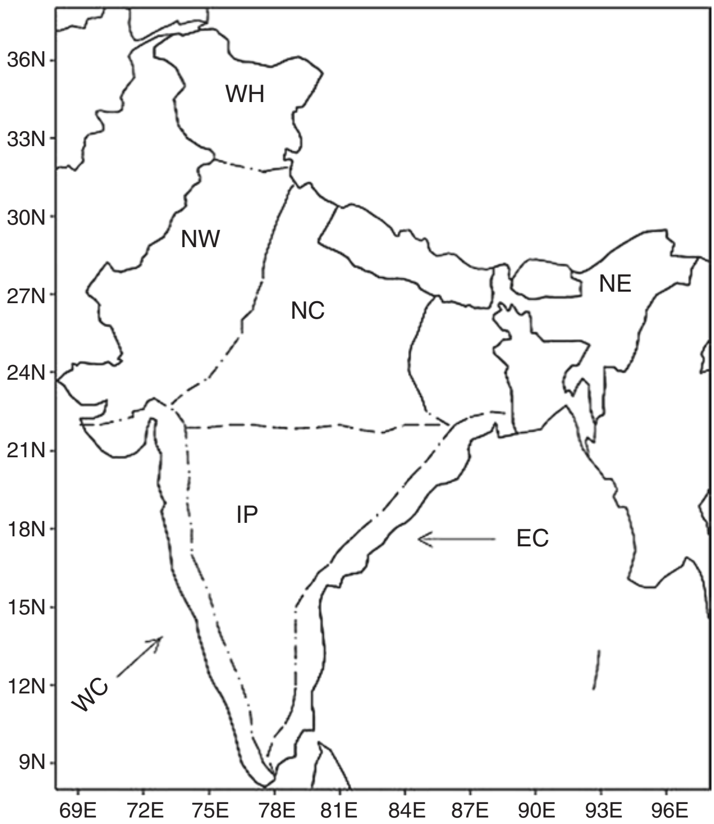

Fig. 1.2 Temperature Homogeneous Regions of India (Source: IITM, Pune, India)
NE – North East **NW** – North West
NC – North Central **EC** – East Coast
IP – Peninsula India **WH** – Western Himalaya **WC** – West Central

NEI and PI. Out of seven models, six models shows possibility of excess rainfall in JJAS at 99% and 95% confidence levels in future time periods over rice production regions of CNI and PI. If distribution of rainfall within JJAS is taking place equaly in months of june, july, august and september, then it would be favourable for production of rice. Further analysis of rainfall variability within rainy months is important over these regions.

In simulating surface temperature, models evaluation shows that model CESM1 (CAM5) for T, GISS-E2-H, BCC-CSM1.1 m, and GISS-E2-H-CC for Tmax and GFDL-CM3, MRI-CGCM3, and MRI-ESM1 for Tmin are relatively better performing than other models. Figs. 1.4a–n shows future projected changes in Tmax, Tmin and T during 2021–2055 under RCPs 4.5 and 8.5 with respect to Historical experiment (1971–2005). Student's t-test at 99% and 95% confidence levels is

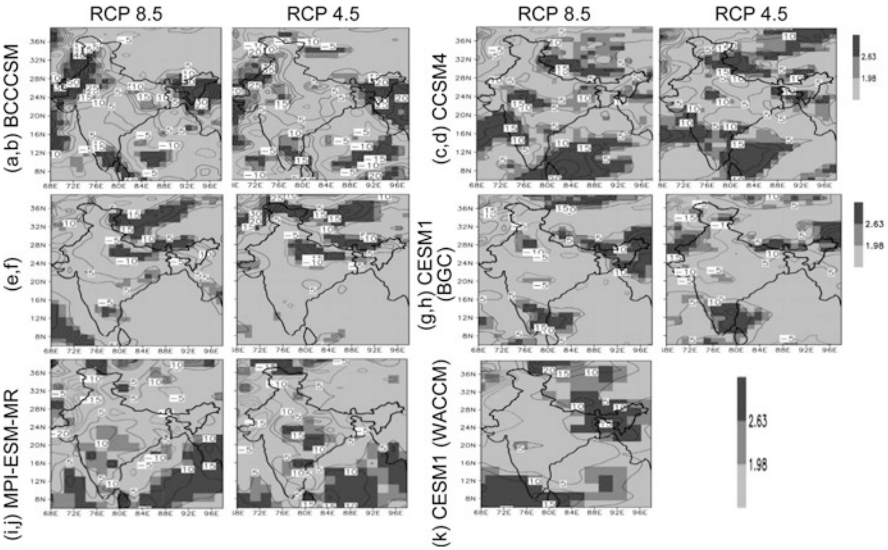

Fig. 1.3 (a–k) Percentage change in JJAS rainfall (mm/ day) for the period of 2006–2050 under RCPs 4.5 and 8.5 with respect to Historical experiment for the period of 1961–2005 at 99% confidence level (in dark blackish grey color) and at 95% confidence level (in masked with light grey color) at student's t test

applied to know the significance of future projected changes. In Figs. 1.4a–n, 99% and 95% confidence levels are masked with dark gray and medium gray color respectively, while non-significant area is masked with light gray color. GISS-E2-H, GISS-E2-H-CC projected Tmax (Figs. 1.4c–f) shows possibility of 0.3°C–0.4°C warming over NW and NC and 0.6°C–0.7°C over NW and the Gangetic plain under RCPs 4.5 and 8.5. The model BCC-CSM1.1 m (Figs. 1.4a–b) shows possible warming of 0.4°C–0.5°C at 99% confidence level over the entire region of India except over the central west region while 0.25°C–0.45°C over southern India at 99% confidence level. In Figs. 1.4g–l, GFDL-CM3, MRI-CGCM3, and MRI-ESM1 simulated Tmin in RCPs 4.5 and 8.5 shows possible warming of 0.3°C–0.7°C over major parts of India, but more warming is seen over northwest and southeast part at 99% confidence level while 0.4°C–0.6°C at 95% confidence level is depicted over whole India. In simulation of CESM1(CAM5), future projected T in RCPs 4.5 and 8.5 (Fig. 1.4m–n) shows a significant warming of 0.4°C–0.5°C over NC and the Gangetic plain at 99% confidence level, and the same magnitude of warming at 95% confidence level may be possible over whole India except WC and EC. The projected inrecase in Tmin over over noinfrthwest and other parts of India may not be supportive for wheat production and diseases may be possible in wheat grains. It would be important to understand the variability of Tmin within December, January and February and its relations to the wheat production.

Further, the significant projected change of rainfall and temperature in CMIP5 models may be used as inputs to Crop simulation models over the Gangetic plain

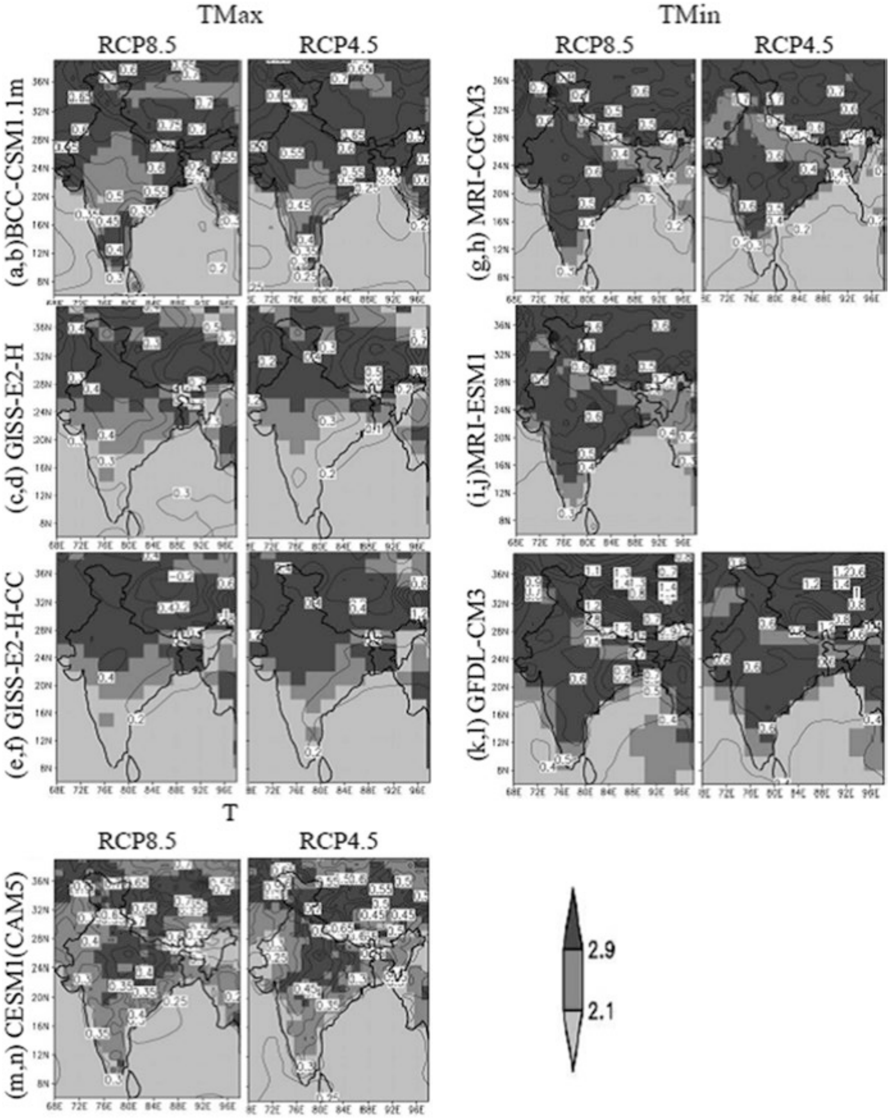

Fig. 1.4 **(a–n)** Future Projected Changes in Tmax, Tmin, and T (°C) for the period of 2021–2055 under RCP 4.5 and 8.5 with respect to Historical experiment for the period of 1971–2005. (Regions with statistically significant at 99% (cut off t value ≧ 2.9) confidence level (masked with dark grey color) and is 95% (cut off t value equals to 2.1) confidence level (masked with medium grey color) on two-tailed student's t test). The light grey shade shows the area with confidence lesser than 95%

which is more scientific approach to study the impact of climate change on agricultural production. Such study may help in framing adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies which may reduce impacts of climate change.

1.4 Conclusions

These seven (7) models namely BCC-CSM1.1 (m), CCSM4, CESM1 (BGC), CESM1 (CAM5), CESM1 (FASTCHEM), CESM1 (WACCM), and MPI-ESM-MR simulated future projected percentage changes in JJAS rainfall for the period of 2006–2050 under RCPs 4.5 and 8.5 at 99% confidence level is analyzed which shows possibility of excess rainfall over homogeneous monsoon regions of NWI, NEI, WCI, CNI and PI. CMIP5 models GISS-E2-H, BCC-CSM1.1 m and GISS-E2-H-CC for Tmax; GFDL-CM3, MRI-CGM3 and MRI-ESM1 for Tmin; and CESM1 (CAM5) for T are close to observation for the period of 1961–2005. In RCPs 4.5 and 8.5 experiments for the period of 2021–2055 with respect to historical experiment for the period of 1961–2005, significant warming of 0.5°C–0.7°C at 99% confidence level may be possible over homogeneous temperature regions of NC, NW, and WC. The changes of 0.2°C–0.5°C might be possible at other locations.

These future projections of rainfall and Tmin may be used in assessment of rice and wheat production and assist adaptation to climate changethrough changes in farming practices, cropping patterns, and use of new technologies.

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