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Research Article

Regional Variability in Projected Temperature and Rainfall in Indian Punjab – A Case Study using the IPSL-CM5A-MR Modeled Scenario-wise Changes

JATINDER KAUR*, PRABHJYOT-KAUR, SHIVANI KOTHIYAL AND S.S. SANDHU

Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana-141004, Punjab

ABSTRACT

Projected changes in climatic entities are guided by the local topographic features of the region. With this objective the present study was conducted by analyzing the projected temperature and rainfall under four representative concentration pathways (RCPs) as simulated by IPSL-CM5A-MR model for seven locations lying in undulating mountainous terrain with humid (UMTH) climate (Ballowal Saunkhri), plain region with sub-humid (PSH) climate (Amritsar, Ludhiana, Patiala), plain region with semi-arid (PSA) climate (Bathinda) and plain region with arid (PA) climate (Abohar, Faridkot). The temperature and rainfall data and their anomalies from the baseline (1970-2015) were analyzed for three time slices i.e. Early (ETS-: 2020-2045); Mid (MTS-: 2045-2070) and Late (LTS-: 2070-2095). In general, the temperature is predicted to increase in all four study areas with a peak increase projected under RCP 8.5. In Punjab state under RCP 2.6, 4.5, 6.0 and 8.5 scenarios by the end of 21st century, the maximum temperature (Tmax) would increase by +0.1 to +1.4, +0.1 to +2.8, -0.2 to +2.8 and +0.4 to +4.9°C and the minimum temperature (Tmin) by -1.9 to +3.1, -1.1 to +4.7, -1.8 to 4.8 and -1.2 to +7.3°C, respectively, while the rainfall (RF) would decrease by 592, 540, 572 and 565 mm, respectively as compared to baseline 1970-2015. The increase in Tmax and Tmin and decrease in RF from their respective baseline (1970-2015) ranges revealed that amongst all the regions, there would be a peak increase/decrease in UMTH followed by PSH, PSA and PA in decreasing order. Consequently, the growth and yield of agricultural crops would be severely affected and suitable adaptive measures would be needed to offset the adverse effects of changes in climatic parameters.

Key words: Climate projection, IPSL-CM5A-MR model, Rainfall, RCPs, Temperature, Punjab

Introduction

The earth's average temperature has increased by 1^{o}C since the preindustrial time period due to a growing increase in the concentration of greenhouse gases (GHGs) in the atmosphere (Dibike and Coulibaly, 2005; Feng *et al.,* 2014; Bekele *et al.,* 2019). These changes in the climate system at the global level have the ability to change the local climate and these in turn speed up the hydrological process (Kim *et al.,* 2011; Thomas *et al.,* 2018; Bekele *et al.,* 2019) which have a direct bearing on agricultural entities. The major drivers of climate change are the alterations in socio-economic conditions, technology, land use, energy consumption, and emission of GHG and finally the pollution of environmental resources. Climate change in the future will depend on the GHG emission trajectories resulting from socio-economic changes. In 2007, IPCC (Intergovernmental Panel on Climate Change) superseded the earlier SRES (Special Report on Emission Scenarios) (IPCC, 2000) by RCPs (Representative Concentration Pathways) which

*Corresponding author,
Email: jkbrar7@gmail.com

were later used in the IPCC Assessment Report Five (AR5) (IPCC, 2014). So, the four RCP scenarios give a picture of the future with adaptations/mitigation strategies being followed in the decreasing order from maximum (RCP 2.6) to less (RCP 4.5) to least (RCP 6.0) and finally none (RCP 8.5) led changes in temperature and rainfall.

The temperature and rainfall are two key weather factors that have a significant impact on crop germination/emergence, growth, reproduction, and yield as well as agriculture production (IPCC, 2007). In Punjab, agriculture generally depends on the South-West monsoon which affects the length of crop growth period; cropping pattern, farming profits etc. (Venkateswarlu *et al.,* 2012; Barlow *et al.,* 2015). Any anomaly in the seasonal rainfall as well as heat/cold waves has a direct impact on the population that depends on agriculture for their survival. In the future, with the increasing concentration of GHGs, the frequency of natural disasters is projected to escalate. To develop suitable adaptive measures, it becomes necessary to project the future climate in advance so as to deal with such natural disasters. The extremes of temperature and rainfall are better understood and can be evaluated with the help of climate models. General Circulation Models (GCMs) are the most commonly used tools for studying changes in the climate system for present and future by climate scenarios at global as well as regional scales. For instance, the influences of the unpredictable climate have been documented globally by several scientists, and hence to understand these changes in the future, particularly on regional scales, is needed for the development of suitable adaptations and mitigation strategies/measures (Szersynski and Urry, 2010; Bouwer, 2011; Met Office Hadley Centre 2011). Keeping this in view, the current study was undertaken with the objective to project the climate change at regional level as simulated by IPSL-CM5A-MR model under four RCPs for three time periods during the 21st century in Punjab, India.

Material and Methods

Location details and methodology

In this study seven locations covering undulating mountainous terrain with humid (UMTH) climate which represents the *kandi* region of Punjab (Ballowal Saunkhri 30°07′ N 76°23′ E 355 a.m.s.l.), plain region with sub-humid (PSH) climate (Amritsar 31°37′ N, 74°53′ E 231 a.m.s.l; Ludhiana 30°56′ N 75°48′ E 247 a.m.s.l; Patiala 30°20′ N, 76°28′ E 251 a.m.s.l.), plain region with semi-arid (PSA) climate (Bathinda 30°12′ N, 74°57′ E 211 a.m.s.l.) and plain region with arid (PA) climate (Abohar 30°58′ N, 74°36′ E 177 a.m.s.l, Faridkot 30°40′ N, 74°45′ E 204 a.m.s.l.) in Punjab state were selected (Fig. 1).

Daily meteorological data of maximum temperature (Tmax), minimum temperature (Tmin), and rainfall (RF) was downscaled from the IPSL-CM5A-MR model accessible at the website *http://gismap.ciat.cgiar.org/MarkSimGCM/* for these seven locations. The available historical weather database records were compared with the simulated weather data of the IPSL-CM5A-MR model developed by Pierre-Simon Laplace Institute. IPSL CM5A LR had two variants: a medium resolution configuration, IPSL CM5A MR, and an experimental version, IPSL CM5B LR, based on a new version of the atmospheric physics (Hourdin *et al.*, 2013). The resolution of the atmospheric model was 96 × 95 points in longitude and latitude in the LR configuration, and 144 × 143 in the MR configuration. Both versions had 39 layers in the vertical. The daily data on RF for the baseline period (1970-2015) and projected data for three time slices ETS (2020-2045), MTS (2045-2070) and LTS (2070-2095) under four scenarios (RCPs 2.6, 4.5, 6.0 and 8.5) was then corrected by the "Difference method" as defined by Kaur *et al.* (2021). In an earlier study, Kaur *et al.* (2020) compared the different bias correction methods and reported that after bias correction at a monthly scale, RMSE (Root Mean Square Error) of Tmax decreased from 4.57-3.70% and for RF from 8.28-7.54%. The RMSE of Tmin indicated that there was no need for bias correction because the model data was very similar to the observed data. The corrected data were then evaluated annually for three time slices ETS (2020-2045), MTS (2045-2070), and LTS (2070-2095) during the 21st century under four RCPs scenarios (RCP 2.6, 4.5, 6.0, and 8.5) by comparing it with baseline data (1970-2015) to evaluate the projected changes in the future time period *w.r.t.* historic time era (1970-2015) for four regions (UMTH, PSH, PSA, and PA).

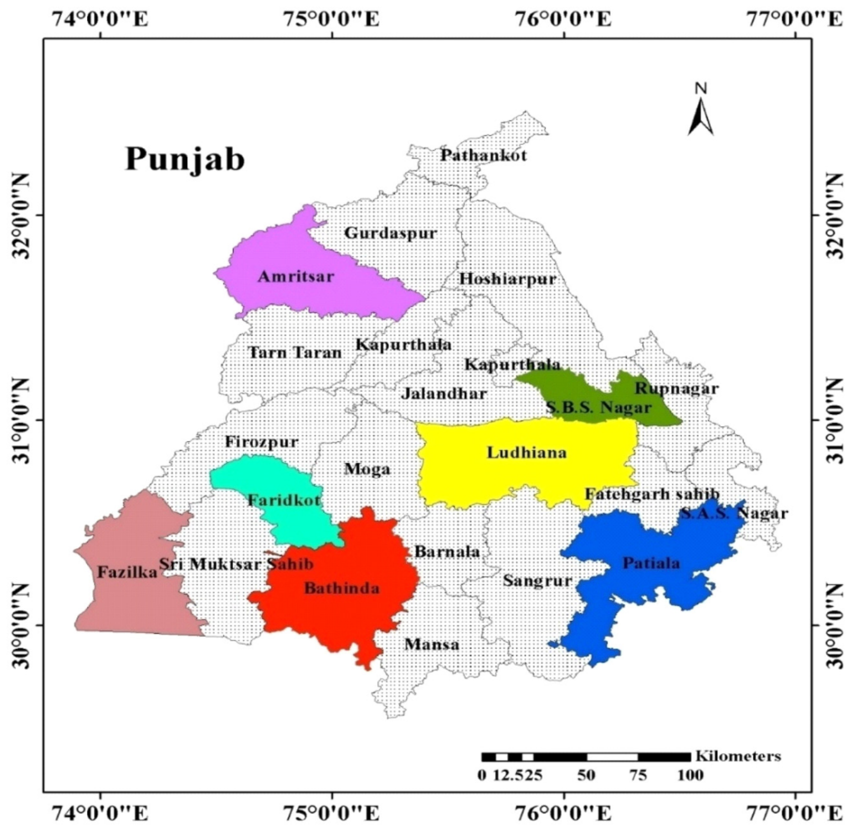

Fig. 1. Location map of study area

Representative Concentration Pathway (RCP)

As per the fifth Assessment Report given by IPCC (IPCC, 2014) the description of four RCPs which indicate various climate futures depending on the volume of GHGs emitted are given in Table 1. The four pathways include a very stringent mitigation scenario (RCP 2.6), two intermediate stabilization scenarios (RCP 4.5 and RCP 6.0), and one pessimistic scenario with high GHG emissions (RCP 8.5). During ETS, MTS, and LTS, respectively the Tmax may increase by +0.1 to +1.4, +0.1 to +2.8, -0.2 to +2.8 and +0.4 to +4.9^{o}C; Tmin may increase by -1.9 to +3.1, -1.1 to +4.7, -1.8 to 4.8 and -1.2 to

Table 1. Explanation of Representative Concentration Pathways (RCPs)

RCPs	Explanation	Variability	Developed by
RCP 2.6	Radiative forcings level reaches a value around 3.1 W/m^2 in mid-centuries.	Least	IMAGE modelling team of the Netherlands Environmental Assessment Agency
RCP 4.5	Radiative forcings is stabilized before 2100. The emissions peak around 2040 and then decline.	More	Mini CAM modelling team at the Pacific Northwest National Laborator"-s Joint Global Change Research Institute
RCP 6.0	Radiative forcing is stabilized after 2100. The emissions peak around 2080 and then decline.	More	AIM modelling team at the National Institute for Environmental Studies, Japan
RCP 8.5	It is categorized by rising GHGs throughout the 21st century.	Peak	MESSAGE modelling team and the IIASA Integrated Assessment Framework at the International Institute for Applied Systems Analysis (IIASA), Austria

+7.3°C and RF may decrease by 592, 540, 572 and 565 mm in UMTH, PSH, PSA, and PA (Table 2).

Results and Discussion

Variations in maximum temperature (Tmax)

The daily Tmax (Figs. 2 a-f) data for seven locations lying in UMTH, PSH, PSA and PA were examined to work out the deviations on annual basis for three time slices ETS (2020-2045), MTS (2045-2070) and LTS (2070-2095) under four RCPs emission scenarios.

The projections of Tmax anomalies for three time slices ETS (2020-2045), MTS (2045-2070) and LTS (2070-2095) ranged from 0.1 to 1.1; 0.5 to 1.4 and 0.4 to 1.1°C under RCP 2.6 scenario; from 0.1 to 1.1; 1.0 to 2.0 and 1.6 to 2.8°C under RCP 4.5 scenario, from -0.2 to +0.7; 0.6 to 1.7 and 1.8 to

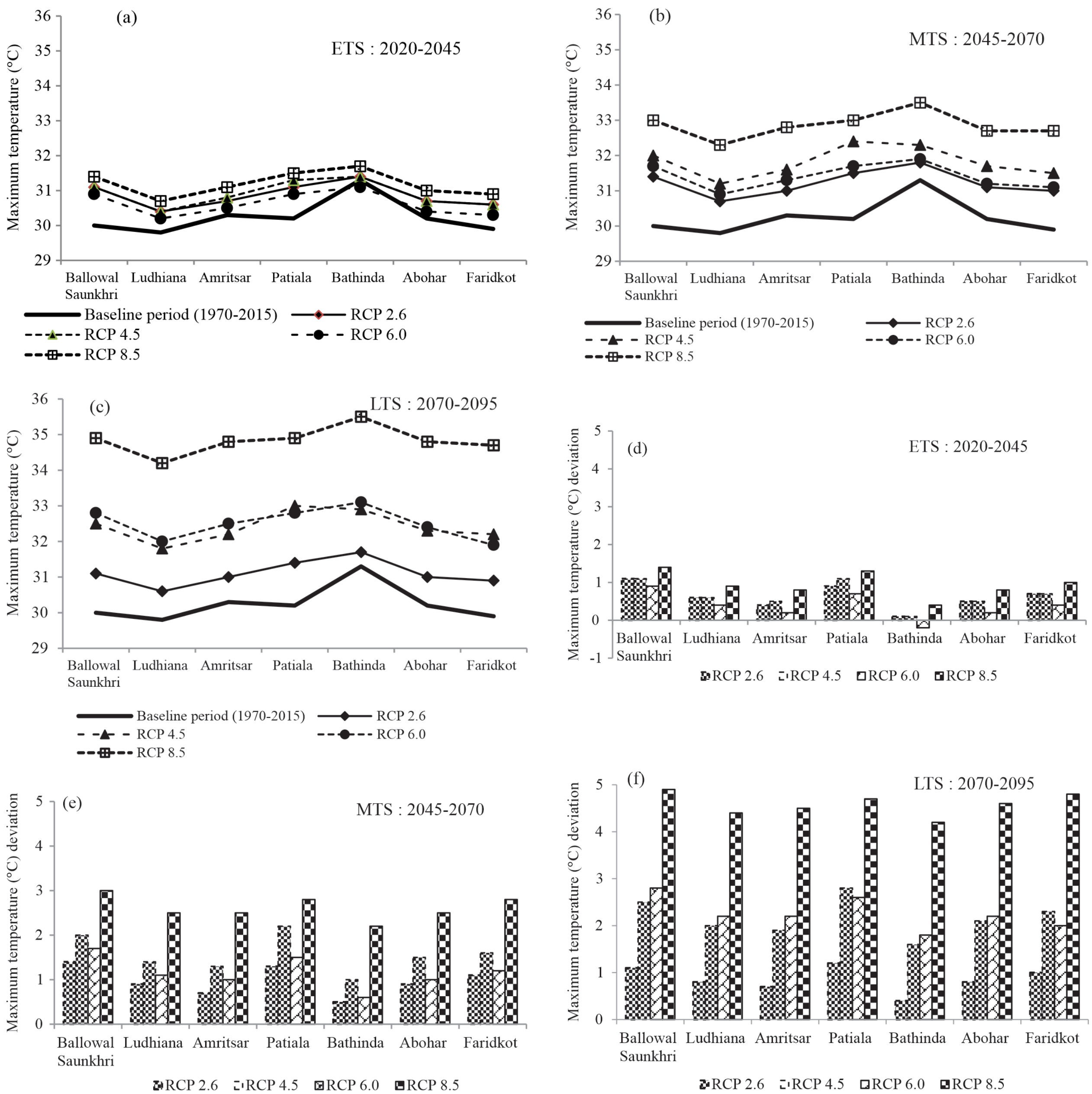

Fig. 2. Simulated maximum temperature and their deviations (°C) (a–f) from the baseline by IPSL-CM5A-MR model at different locations in Punjab (India) under four RCP scenarios at different time slices

Table 2. Simulated temperature and rainfall projections by IPSL-CM5A-MR model and baseline data (1970-2015) in Punjab (India) under four RCP scenarios during different time slices

Region	Baseline period (1970-2015)	RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
		ETS	MTS	LTS	ETS	MTS	LTS	ETS	MTS	LTS	ETS	MTS	LTS
Maximum temperature (°C)													
Punjab	(29.8-31.3)	30.4-31.4	30.7-31.8	30.6-31.7	30.4-31.4	31.2-32.4	31.8-33.0	30.2-31.1	30.9-31.9	31.9-33.1	30.7-31.7	32.3-33.5	34.2-35.5
Undulating mountainous terrain	(30.0)	31.1	31.4	31.1	31.1	32	32.5	30.9	31.7	32.8	31.4	33.0	34.9
Plain region with sub-humid climate	(29.8-30.3)	30.4-31.1	30.7-31.5	30.6-31.4	30.4-31.3	31.2-32.4	31.8-33.0	30.2-30.9	30.9-31.7	32.0-32.8	30.7-31.5	32.3-33.0	34.2-34.9
Plain region with semi-arid climate	(31.3)	31.4	31.8	31.7	31.4	32.3	32.9	31.1	31.9	33.1	31.7	33.5	35.5
Plain region with arid climate	(29.9-30.2)	30.6-30.7	31.0-31.1	30.9-31.0	30.6-30.7	31.5-31.7	32.2-32.3	30.3-30.4	31.1-31.2	31.9-32.4	30.9-31.0	32.7	34.7-34.8
Minimum temperature (°C)													
Punjab	(15.5-20.3)	17.9-19.0	18.5-19.5	18.6-19.6	18.7-19.9	19.4-21.1	19.8-21.5	18.0-19.2	18.8-20.1	20.2-21.3	18.7-19.7	20.4-21.7	22.8-23.9
Undulating mountainous terrain	(16.2)	18.6	19.1	19.2	19.4	20.3	20.9	18.8	19.7	21.0	19.3	21.1	23.5
Plain region with sub-humid climate	(15.5-17.6)	17.9-19.0	18.5-19.5	18.6-19.6	18.7-19.9	19.4-21.1	19.8-21.5	18.0-19.2	18.8-20.1	20.2-21.3	18.7-19.7	20.4-21.7	22.8-23.9
Plain region with semi-arid climate	(16.9)	18.6	19.0	19.1	19.3	20.1	20.6	18.6	19.3	20.6	19.2	20.8	23.0
Plain region with arid climate	(17.6-20.3)	18.4-18.6	19.0-19.1	19.1-19.1	19.2-19.3	20.0-20.2	20.5-20.7	18.5-18.6	19.3-19.5	20.6-20.8	19.1-19.3	20.8-20.9	23.0
Rainfall (mm)													
Punjab	(323-1049)	389-594	337-596	327-582	377-596	333-642	341-677	383-601	343-637	380-756	340-583	357-716	329-697
Undulating mountainous terrain	(1049)	527	502	457	509	548	522	477	517	611	484	584	589
Plain region with sub-humid climate	(722-774)	503-594	515-596	511-582	588-596	559-642	615-668	521-601	605-637	643-756	523-583	627-716	628-697
Plain region with semi-arid climate	(517)	405	375	393	428	394	417	400	415	442	438	412	395
Plain region with arid climate	(323-468)	390-394	363-386	327-379	377-415	333-394	341-386	383-385	343-417	380-443	340-418	357-427	369-379

2.8°C under RCP 6.0 scenario and from 0.4 to 1.4; 2.2 to 3.0 and 4.2 to 4.9°C under RCP 8.5 scenario. The bar graphs in Fig. 2 (a-f) clearly indicate that the difference among the predictions under four emission scenarios is considerably large. The predictions under RCP 8.5 were, though, considerably greater than the other three RCP emission scenarios. In general, the bar graphs show Tmax anomaly for the three time periods is minimum (-0.2°C) during 2020-2045 for Bathinda having the PSA climate under RCP 6.0 and was maximum (4.9°C) for Ballowal Saunkhri having UMTH climate during 2070-2095 under RCP 8.5 scenario.

According to the SRES scenarios, India's temperature would rise by 2.9°C (B2) and 4.1°C (A2) in 2080's as compared to 1980's (Kumar *et al*., 2006). For the A1B scenario, Kumar *et al.* (2010) predicted a warming of 3.5 to 4.3°C during the same time period. According to Sarkar *et al.* (2015), the summer maximum temperature was expected to rise by 0.1 to 0.2 (2011-2030); 1.1 to 1.5 (2046-2065), and nearby 3°C (2080-2099) respectively. In an earlier study for Punjab state, Prabhjyot-Kaur *et al.* (2017) reported that during the end of 21st century PRECIS model predicted an increase in the Tmax from 2.0-2.2°C at agroclimatic zone-II (Ballowal Saunkhri), from 0.4-5.8°C at agroclimatic zone-III (Amritsar, Jalandhar, Ludhiana and Patiala) and between 0.5 to 4.0° Catagroclimatic zone-V (Bathinda) under A1B scenario. Later, Kaur J and Prabhjyot-Kaur (2020) used Ensemble model to evaluate the changes in maximum temperature and reported an increase of 0.5-1.0°C during mid-century (2020-2049) and by 1.2-2.4°C during end-century (2066-2095) from the observed data of 45 years (1970-2015). Kaur *et al.* (2022) reported an increase in maximum temperature during spring season by 2.1°C and during autumn season by 1.8°C during mid-century (2020–2049) for Ludhiana station falling in agroclimatic zone-III of Punjab state. For the Indian region, Chaturvedi *et al.* (2012) predicted an increase in temperature from 1.7 to 2°C during 2030's (RCP 6.0) and by 3.3 to 4.8°C during 2080's (RCP 8.5) from the baseline period (1961 to 1990). Later Krishnan *et al.* (2020) reported an increase in Tmax under RCP 4.5 and 8.5 scenarios from 1.7-3.7 and 2.3-4.7°C in the mid-century and from 2.2-4.3 and 3.7-6.1°C in the end-century, respectively. For the coastal parts of India, Vijayakumar *et al.* (2021) have reported an increase in maximum temperature during near, mid, and late centuries, respectively from 0.61 to 0.66, 0.68 to 0.72 and 1.35 to 1.55°C under RCP 4.5 and 1.79 to 1.97, 1.73 to 2.01 and 3.08 to 3.44°C under RCP 8.5 scenario. So the results of the present study are in concurrence with earlier findings for the Punjab state as well as for other parts of the country.

Minimum temperature (Tmin) deviation from baseline period (1970-2015)

The daily Tmin (Figs. 3 a-f) data for seven locations lying in UMTH, PSH, PSA and PA were examined to work out the deviations on annual basis for three time slices ETS (2020-2045), MTS (2045-2070) and LTS (2070-2095) under four RCPs emission scenarios.

The projections of Tmin anomalies for three time periods; ETS (2020-2045), MTS (2045-2070), and LTS (2070-2095) ranged from -1.9 to 2.4; -1.3 to 3.0 and -1.2 to 3.1°C under RCP 2.6 scenario; from -1.1 to 3.2; -0.3 to 4.1 and 0.2 to 4.7°C under RCP 4.5 scenario, from -1.8 to 2.6; -1.0 to 3.5 and 0.3 to 4.8°C under RCP 6.0 scenario and from -1.2 to 3.1; 0.5 to 4.9 and 2.7 to 7.3°C under RCP 8.5 scenario. The data in Fig. 3 (a-f) clearly indicate that the difference among the predictions under several emission scenarios is considerably large. However, the predictions under RCP 8.5 were considerably greater than the other three RCPs emission scenarios. In general, the bar graphs show Tmin anomaly for the three time periods is minimum (-1.9°C) during 2020-2045 for Faridkot having the PA climate under RCP 2.6 and was maximum (7.3°C) for Amritsar and Ballowal Saunkhri having PSH and UMTH climate during 2070-2095 under RCP 8.5 scenario.

Sarkar *et al.* (2015) reported an increase in winter Tmin by 0.6 to 1°C during 2011-2030; ~ 3°C during 2046-2065 and 5°C during 2080-2099 for the Indian subcontinent. In a previous study for Punjab state, Prabhjyot-Kaur *et al.* (2017) found that during end of 21st century, PRECIS model predicted an increase in the Tmin from 3.3-5.4°C within agroclimatic zone-II (Ballowal Saunkhri), 2.5-7.4°C within agro-climatic zone-III (Amritsar, Jalandhar, Ludhiana and Patiala) and 4.7-7.7°C within agroclimatic zone-V

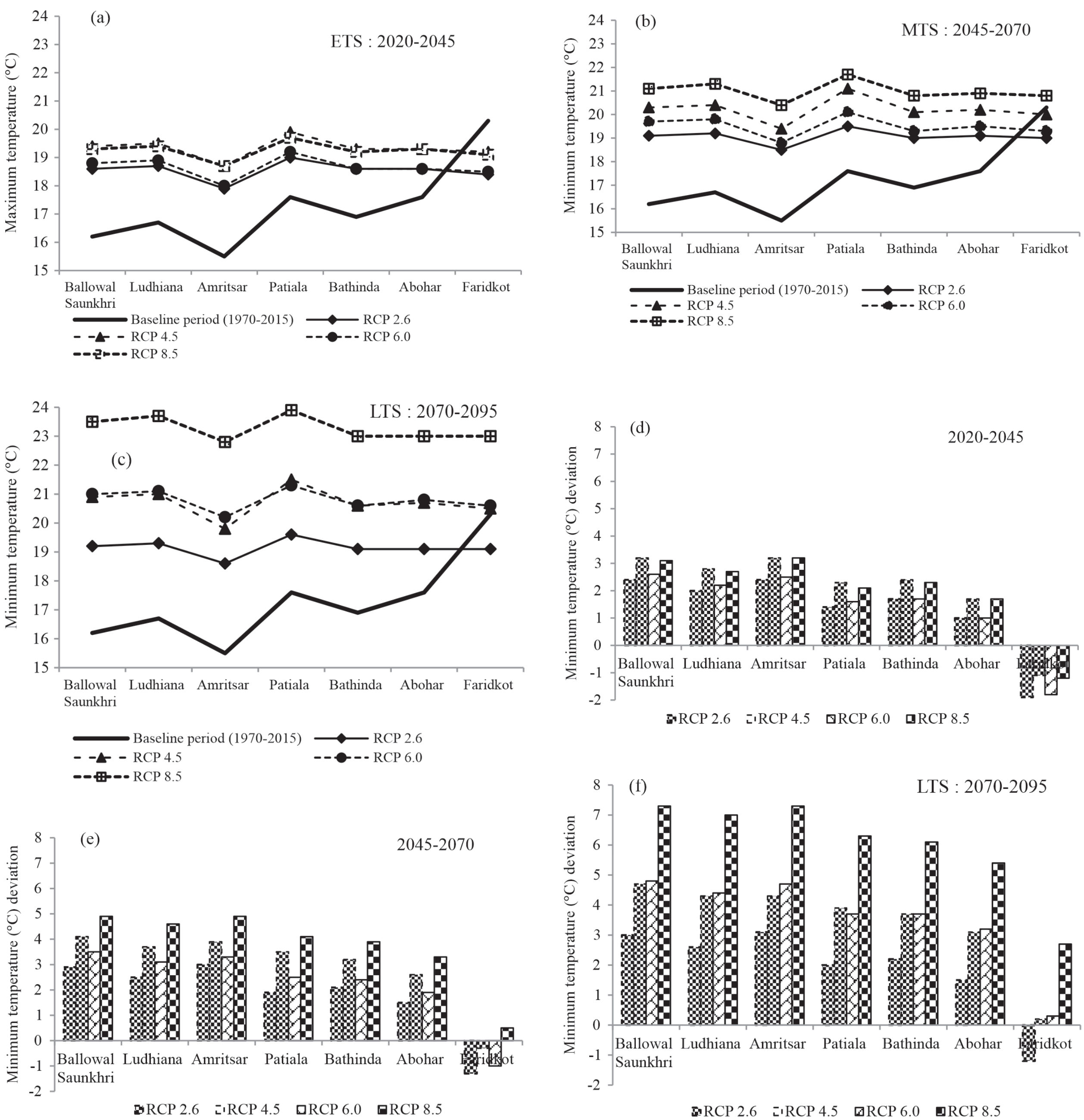

Fig. 3. Simulated minimum temperature and their deviations (°C) (a-f) from the baseline by IPSL-CM5A-MR model at different locations in Punjab (India) under four RCP scenarios at different time slices

(Bathinda) of Punjab state under A1B scenario of climate change. Later, Kaur J and Prabhjyot-Kaur (2020) used Ensemble model to evaluate the changes in minimum temperature and reported an increase by 15.5 to 20.3°C (baseline period) to 17.6 to 18.9°C under RCP 2.6, 17.9 to 19.2°C under RCP 4.5, 17.7 to 18.9°C under RCP 6.0 and 18.1 to 19.4°C under RCP 8.5 scenario during the mid-century and from 17.8 to 19.1°C under RCP 2.6, 19.0 to 20.2°C under RCP 4.5, 19.2 to 20.5°C under RCP 6.0 and 21.1 to 22.4°C under RCP 8.5 scenario during the end-century. Kaur *et al.* (2021) employed the CSIRO-Mk 3-6-0 model to evaluate the temperature data and predicted a rise in Tmin in Punjab state on annual, *kharif* and *rabi* season basis by 1.1-3.1, 0.1-4.8 and 0.3-1.8°C, respectively during the mid-century and

0.4-6.6, 0.5-6.3 and 0.0-5.5°C, respectively during the end-century. Kaur *et al.* (2020) reported an increase in minimum temperature from 15.5 to 20.3°C (baseline period) to 17.6 to 18.9°C (RCP 2.6); 17.9 to 19.2°C (RCP 4.5); 17.7 to 18.9°C (RCP 6.0) and 18.1 to 19.4°C (RCP 8.5) scenario by the MC (mid-century). Similarly, an increase in minimum temperature from 17.8 to 19.1°C (RCP 2.6); 19.0 to 20.2°C (RCP 4.5); 19.2 to 20.5°C (RCP 6.0) and 21.1 to 22.4°C (RCP 8.5) scenario by the EC (end-century).

Rainfall (RF) deviation from baseline period (1970-2015)

The daily RF (Figs. 4 a-f) data for seven locations lying in UMTH, PSH, PSA and PA were examined to work out the deviations on annual basis for three time slices ETS (2020-2045), MTS (2045-2070) and LTS (2070-2095) under four RCPs emission scenarios.

The projections of RF anomalies for three time periods ETS (2020-2045), MTS (2045-2070), and LTS (2070-2095) ranged from +67 to -522 mm; +40 to -547 mm and +4 to -592 mm under RCP 2.6 scenario; from +54 to -540 mm; +10 to -501 mm and +18 to -527 mm under RCP 4.5 scenario, from +62 to -572 mm; +20 to -532 mm and +57 to -438 mm under RCP 6.0 scenario and from +17 to -565 mm; +34 to -465 mm and +46 to -460 mm under RCP 8.5 scenario. In general, the bar graphs in Fig. 4 (a-f) clearly indicate that the difference amongst the predictions under several emission scenarios is considerably large. The predictions under RCP 8.5 were, though, considerably greater than the other three RCPs emission scenarios. The bar graphs shows RF anomaly for the three time periods is minimum (67mm) during 2020-2045 for Abohar having PA climate under RCP 2.6 and was maximum (-592 mm) for Ballowal Saunkhri having UMTH climate during 2070-2095 under RCP 2.6 scenario.

According to Kumar *et al.* (2006) there are predictions of noticeable increase in rainfall after 2040s for India. In another study, Guhathakurta *et al.* (2011) observed that in many areas of central and northern India the extreme rainfall events are diminishing but they are increasing in East, North-East and Peninsular India. Chaturvedi *et al.* (2012) reported that intensification in rain is projected by 4-5% during 2030's; 6-14% during 2080's as compared to the baseline (1961-1990) period. In the future, rainfall predicted by seven GCMs showed an increase of 9 to 17% from baseline period (Sarkar *et al*., 2015). However, Dar *et al*. (2019) reported that the HADGEM2-ES model predicted a decline in rainfall during mid and end-century by 12.8 and 11.8%, respectively under RCP 4.5 scenario but an upsurge in rainfall by 20 and 33%, respectively under RCP8.5 scenario for Ludhiana (Punjab). Later during 2020, Kaur and Prabhjyot-Kaur reported that the precipitation is not only expected to decline in three agroclimatic zones of the Punjab state but its spatio-temporal distribution may also become more inconsistent. Similarly, Kaur *et al.* (2020) evaluated the Ensemble model data and reported that the *kharif* (May-October) season precipitation is projected to decline by 28.7 to 39.2% during the early time period (2020-2050), 31.1 to 56.8% during the mid-time period (2051-70) and 32.1 to 63.9% during the late time period (2071-2095) while the *rabi* (November-March) season precipitation is also projected to vary by -6.3 to 23.1% during the early time period (2020-2050), -12.7 to 7.9 during the mid time period (2051-70) and -15.6 to 7.1 during the late time period (2071-2095) in Punjab state. Kaur *et al.* (2021) employed the CSIRO-Mk 3-6-0 model and reported that the annual, *kharif* and *rabi* seasons rainfall are predicted to decline in Punjab state as compared to baseline period (1970-2015) by 33-554, 20-443 and 20-110 mm during the mid-century and by 3-610, 14-506 and 17-107 mm during the end-century. Kingra *et al*. (2017) reported that the decreasing rainfall during *kharif* and *rabi* seasons from north-east to south-west regions of Punjab. Similar trends were also reported by Kaur *et al*. (2019). A recent study by Kaur *et al.* (2021) reported that the average RF of 405 mm observed during the Present Time Slice (PTS) for the Sirhind Canal Tract (Punjab) is predicted to decline by 22.4% (RCP 4.5) and 17.2% (RCP 6.0) during the mid-century (2020-2050) and by 4.7% (RCP 4.5) and 18.0% (RCP 6.0) during the end-century (2065-2095). For the coastal parts of the country, Vijayakumar *et al.* (2021) reported a change in annual mean rainfall during 2011-39 (near-term), 2040-69 (mid-term), and 2070-99 (late-term) time period by 0.1 to 2.2, -0.3 to 0.7 and 1.5 to 3.2%,

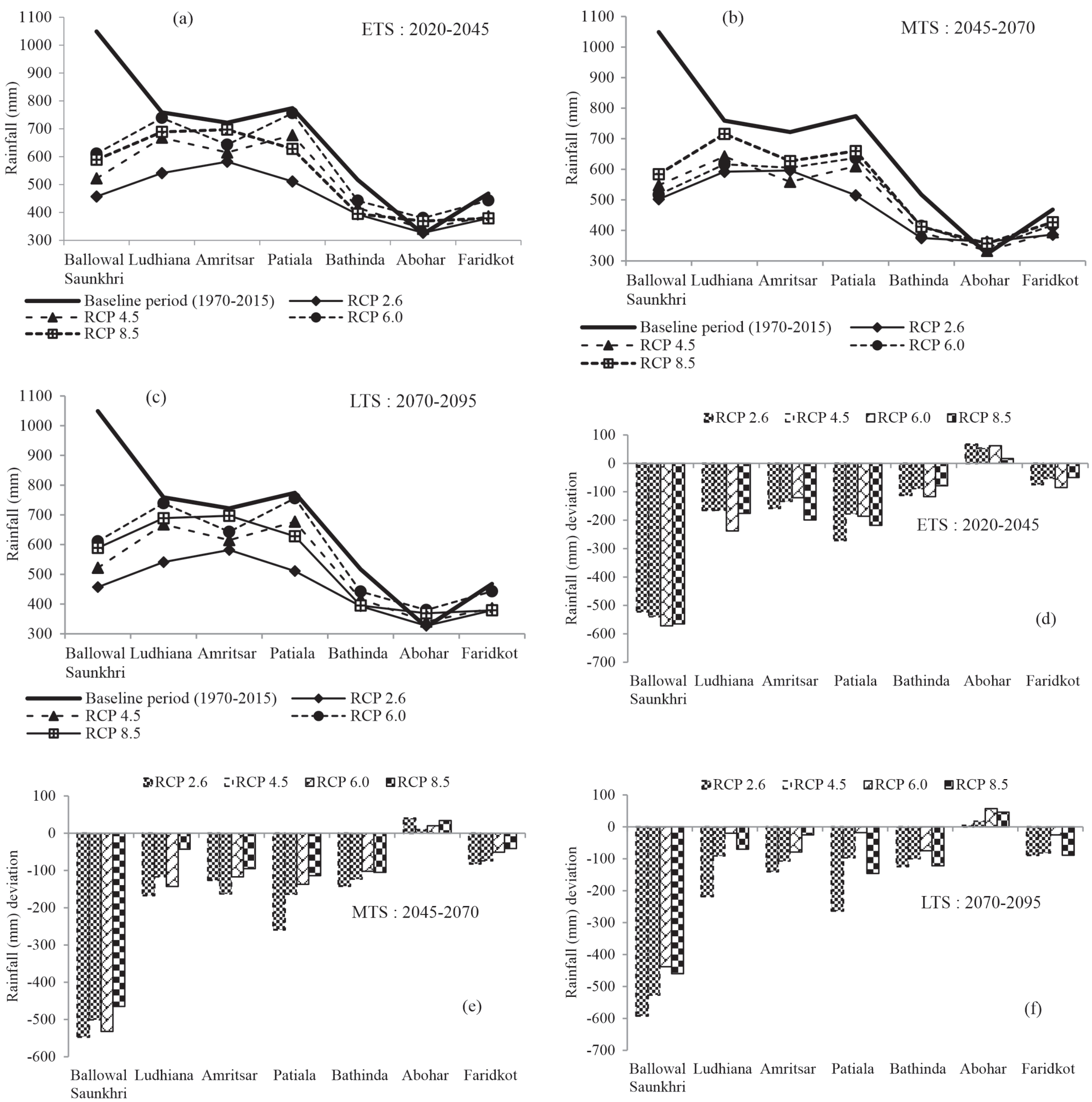

Fig. 4. Simulated rainfall and their deviations (mm) (a–f) from the baseline by IPSL-CM5A-MR model at different locations in Punjab (India) under four RCP scenarios at different time slices

respectively under RCP 4.5 scenario and from 3.6 to 7.9, 3.7 to 6.6 and 8.5 to 14%, respectively under RCP 8.5 scenario.

Region wise variations in temperature and climate

The analysis of the data indicates that in Punjab state the Tmax would increase from baseline range of 29.8-31.3^{o}C upto 30.4-31.7 (RCP 2.6), 30.4-33.0 (RCP 4.5), 30.2-33.1 (RCP 6.0) and 30.7-35.5^{o}C (RCP 8.5) (Table 2). But this increase would be more in the UMTH, i.e. by 1.1-1.4^{o}C under the least emission scenario (RCP2.6) to 1.4 -3.9^{o}C under peak emission scenario (RCP 8.5) and least in the PA, i.e. by 0.6-1.1^{o}C under least emission scenario (RCP2.6) to 0.9-4.6^{o}C under peak emission scenario (RCP 8.5).

Similarly, the Tmin would invariably increase from baseline range of 15.5-20.3 °C to 17.9-19.6 (RCP 2.6), 18.7-21.5 (RCP 4.5), 18.0-21.3 (RCP 6.0) and 18.7-23.9°C (RCP 8.5). Under the least emission scenario (RCP2.6), there would be a slight decrease in the upper limit (20.3°C) of Tmin by 1.0-1.7°C in PA but in the other three regions there would be an overall increase in Tmin under all the scenarios. The RF indicates a decline in the upper range of rainfall in the state from baseline values of 1049 mm to 484-589 mm in UMTH, 774 mm to 594-697 mm in PSH, 517 mm to 375-442 mm in PSA and 468 mm to 385-443 mm in PA. So overall the Tmax and Tmin would increase and RF would decrease from their baseline ranges in all the regions with peak increase / decrease in UMTH followed by PSH, PSA, and PA in decreasing order.

Conclusions

The IPSL-CM5A-MR model projections indicate a substantial warming along with declining rainfall under four RCPs based scenarios considered in this research. However, large variability in the predictions of Tmax, Tmin and RF abnormalities for three time periods; ETS (2020-2045), MTS (2045-2070), and LTS (2070-2095) within RCPs reveals that in the future, climate of Punjab may become hotter and drier. This pattern would be more severe in the UMTH followed by PSH, PSA, and PA in decreasing order. Since under RCP 8.5 scenario, the GHGs are assumed to continuously rise, it projects the highest increase in temperature and major variability and decline in RF for three time periods as compared to RCP 2.6 (least pessimistic) and stabilization scenarios, *i.e.*, RCP 4.5 and RCP 6.0. The comparison of Tmax and Tmin reveals that an increase in Tmin tends to be higher than Tmax. This suggests that the diurnal temperature range (DTR) would be reduced and from plant physiology point of view it is not ideal for growth and development of crop plants. The expected surge in temperature could have a negative effect on Punjab's agriculture production both in the short and long term. Since the decline in RF changes the hydrological cycle of the region, it results in an increased risk of extreme events. In the present study the climate change projections depicted study for the Punjab state provide a scientific support for the sustainable management of water resources in as the economy of the state is primarily dependent on the agriculture sector.

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References

Barlow, K.M., Christy, B.P., O'leary, G.J., Riffkin, P.A. and Nuttall, J.G. 2015. Simulating the impact of extreme heat and frost events on wheat crop production: a review. *Field Crops Research* **171**: 109-119.

Bekele, D., Alamirew, T., Kebede, A., Zeleke, G. and Melesse, A.M. 2019. Modeling climate change impact on the hydrology of Keleta watershed in the awash river basin, Ethiopia. *Environ Modeling Assess* **24**: 95-107.

Bouwer, L.M. 2011. Have disaster losses increased due to anthropogenic climate change? *Bulletin of the American Meteorological Society* doi:10.1175/2010BAMS3092.1.

Chaturvedi, R.K., Joshi, J., Jayaraman, M., Bala, G. and Ravindranath, N.H. 2012. Multi-model climate change projections for India under representative concentration pathways. *Current Science* **103**: 791-802.

Dar, M.U.D., Aggarwal, R. and Kaur, S. 2019. Climate predictions for Ludhiana district of Indian Punjab under RCP 4.5 and RCP 8.5. *International Journal of Environment and Climate Change* **9**: 128-141.

Dibike, Y.B. and Coulibaly, P. 2005. Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of Hydrology* **307**: 145-163.

Feng, S., Hu, Q., Huang, W., Ho, C.H., Li, R. and Tang, Z. 2014. Projected climate regime shift under future global warming from multi-model, multi-scenario CMIP5 simulations. *Global Planetary Change* **112**: 41-52.

Guhathakurta, P., Sreejith, O.P. and Menon, P.A. 2011. Impact of climate change on extreme rainfall events and flood risk in India. *Journal of Earth System Science* **120**: 359-73.

Hourdin, F., Grandpeix, J.Y., Rio C., Bony S., Jam A., Cheruy F., Rochetin N., Fairhead L., Idelkadi A., Musat L., Dufresne J.L., Lahellec A., Lefebvre M.P. and Roehrig R. 2013. LMDZ5B: The atmospheric component of the IPSL climate model with revisited parameterizations for clouds and convection. *Climate Dynamics* **40**: 2193-2222.

IPCC, 2000. Emissions scenarios. A Special Report of WG III of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC, 2007. Climate change: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change, (eds. Pachauri R.K. and Reisinger A) Geneva, Switzerland, pp. 104.

IPCC, 2013. The physical science basis contribution of working Group I to the fifth assessment report of the Intergovernmental Panel on climate change, edited by Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 1535 pp https://doi.org/10. 1017/CBO97811074153 24.

IPCC, 2014. Summary for Policymakers. In: Climate change: Impacts, adaptation, and vulnerability. part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change (eds. Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi. K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., Mac, C.S., Mastrandrea, P.R. and White, L.L.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, 1-32.

Kaur, J. and Prabhjyot-Kaur. 2020. Annual, seasonal and monthly projected changes in meteorological parameters under RCP based emission scenarios at Ludhiana (Punjab). *Agricultural Research Journal* **57**: 861-868.

Kaur, J., Prabhjyot-Kaur. and Kaur, S. 2020. Climate change predictions by ensemble model in different agroclimatic zones of Punjab, India. *Journal of Agricultural Physics* **20**: 231-242.

Kaur, J., Prabhjyot-Kaur. and Kaur, S. 2021. Comparison of statistical procedures for bias removal in temperature, solar radiation and rainfall data predicted by CSIRO-MK3-6-0 model in Punjab. *Agricultural Research Journal* **58**: 200-206.

Kaur, J., Prabhjyot-Kaur and Kaur, S. 2021. Projected changes in temperature and rainfall during 21st century simulated by CSIRO- Mk-3-6-0 model under RCP based scenarios in Punjab. *Mausam* **72**: 649-660.

Kaur, J., Prabhjyot-Kaur and Kothiyal, S. 2022. Futuristic changes in monthly meteorological parameters as simulated by four GCMs under four emission based scenarios at Ludhiana, Punjab. *Arabian Journal of Geosciences* **15**: 906. https://doi.org/10.1007/s12517-022-10199-y.

Kaur, N. and Prabhjyot-Kaur. 2020. Statistical analysis of projected climate data under diverse scenarios for *Kandi* region of Punjab. *Journal of Agricultural Physics* **20**: 199-207.

Kaur, N., Kaur, S., Prabhjyot-Kaur and Aggarwal, R. 2021. Impact of climate change on groundwater levels in Sirhind canal tract of Punjab, India. *Groundwater for Sustainable Development* **15***:*100670. https://doi.org/10.1016/j.gsd.2021.100670.

Kaur, S., Kingra, P.K., Setia, R. and Singh, S.P. 2019. Comparative analysis of rice productivity of three agroclimatic zones of Punjab. *Agricultural Research Journal* **56**: 49-55.

Kim, B.S., Kim, B.K. and Kwon, H.H. 2011. Assessment of the impact of climate change on the flow regime of the Han river basin using indicators of hydrologic alteration. *Hydrological Processes* **25**: 691-704.

Kingra, P.K., Setia, R., Singh, S., Kaur, J., Kaur, S., Singh, S.P., Kukal, S.S. and Pateriya, B. 2017. Climatic variability and its characterization over Punjab, India. *Journal of Agrometeorology* **19**: 46-250.

Krishnan, R., Ganaseelan, C., Sanjay, J., Swapna, P., Dhara, C., Sabin, T.P., Jadhav, J., Sandeep, N., Choudhary, A.D., Singh, M., Mujumdar, M., Parekh, A., Tewari, A., Mehajan, R., Chopra, R., Joshi, A., Nagarajan, A., Nivsarkar, M., Rajeevan, M., Collins, M. and Niyogi, D. 2020. Introduction to climate change over the Indian region. In:

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (eds) Assessment of climate change over the Indian region. Springer, Singapore. https://doi.org/10.1007/978-981-15-4327-2_1

Kumar, K., Kamla, K., Rajagopalan, B. and Hoerling, M.P. 2010. The once and future pulse of Indian monsoonal climate. *Climate Dynamics* **36**: 2159-70.

Kumar, R., Sahai, A.K., Kumar, K.K., Patwardhan, S.K., Mishra, P.K., Revadekar, J.V., Kamala, K. and Pant, G.B. 2006. High resolution climate change scenarios for India for the 21st century. *Current Science* **90**: 334-45.

Mahmood, R. and Babel, M.S. 2013. Evaluation of SDSM developed by annual and monthly sub-models for downscaling temperature and precipitation in the Jhelum basin, Pakistan and India. *Theoretical and Applied Climatology* **113**: 27-44.

Met Office Hadley Centre (MOHC). 2011. Climate: Observations, projections and impacts. Developed at the request department of energy and climate change by met office Hadleycentre, The University of Nottingham, Walker Institute, Centre for Ecology and Hydrology, University of Leads and Tydall Centre.

Prabhjyot-Kaur, Kaur, N. and Singh, H. 2017. PRECIS-model simulated changes in climatic parameters under various scenarios in different agro-climatic zones of Punjab. *Mausam* **68**: 139-148.

Sarkar, J., Chicholikar, J.R. and Rathore, L.S. 2015. Predicting future changes in temperature and precipitation in arid climate of Kutch, Gujarat: analyses based on LARS-WG model. *Current Science* **109**: 2084.

Szerszynski, B. and Urry, J. 2010. Changing climates: Introduction. *Theory, Culture Society* doi:10.1177/ 0263276409362091.

Thomas, T., Goyal, S., Goyal, V.C. and Kale, R.V. 2018. Water availability under changing climate scenario in Ur river basin. In: climate change impacts. Springer, Singapore, pp. 213-229.

Venkateswarlu, B. and Prasad, J.V.N.S. 2012. Carrying capacity of Indian agriculture: issues related to rainfed farming. *Current Science* **102**: 882-888.

Vijayakumar, S., Nayak, A.K., Ramaraj, A.P., Swain, C.K., Geethalakshmi, V., Pazhanivelan, S., Tripathi, R., Sudarmanian, N.S. 2021. Rainfall and temperature projections and their impact assessment using CMIP5 models under different RCP scenarios for the eastern coastal region of India. *Current Science* **121**: 2doi: 10.18520/cs/v121/i2/222-232.

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