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A critical assessment of changes in climate predicted by four GCMs under different RCP scenarios in Punjab (India)

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सार – चार सामान्य परिसंचरण मॉडल अर्थात् CSIRO-Mk3-6-0, FIO-ESM, IPSL-CM5A-MR और चार RCP (प्रतिनिधि एकाग्रता पथ) परिदृश्यों के तहत एन्सेम्बल मॉडल से प्राप्त अनुमानित तापमान, वर्षा और सौर विकिरण का वार्षिक आधार पर पंजाब के चार कृषि जलवायविक क्षेत्र का विश्लेषण किया गया। त्रुटिपूर्ण डेटा में निहित पूर्वाग्रह को अधिकतम तापमान, वर्षा का मासिक पैमाने पर और सौर विकिरण को दैनिक पैमाने पर अंतर विधि द्वारा ठीक किया गया। सामान्यतः भविष्य में तापमान के रैखिक रूप से बढ़ने की संभावना है जबकि चार आरसीपी परिदृश्यों के तहत सौर विकिरण और वर्षा में कमी हो सकती है। चार मॉडलों में, CSIRO-Mk3-6-0 द्वारा अधिकतम तापमान इस शताब्दी के मध्य/अंत के दौरान बेसलाइन से 0.5 से 1.2/1.6 से 2.6 °C तक बढ़ने का पूर्वानुमान दिया गया है और न्यूनतम तापमान शताब्दी के मध्य/अंत के दौरान बेसलाइन से 1.1 से 2.6/2.7 से क्रमशः 4.1 °C तक तक बढ़ने पूर्वानुमान दिया गया है। IPSL-CM5A-MR मॉडल द्वारा इसके घटते क्रम का अनुमान है। CSIRO-Mk3-6-0 के चार मॉडलों द्वारा अनुमानित सौर विकिरण शताब्दी के मध्य/अंत के दौरान आधार रेखा से 0.5 से 1.1/0.3 से 1.2 W/m² और शताब्दी के मध्य/अंत के दौरान वर्षा में 96 से 558/59 से 530 मिमी तक कमी होने का पूर्वानुमान दिया गया है। FIO-ESM मॉडल द्वारा भी इसी क्रम में वर्षा में कमी होने का अनुमान दिया गया है। चार आरसीपी परिदृश्यों के तहत चार मॉडलों द्वारा उच्चतम/न्यूनतम अधिकतम तापमान क्रमशः 32.9 °C (बठिंडा) / 30.5 °C (लुधियाना), उच्चतम / निम्नतम न्यूनतम तापमान 20.8 °C (पटियाला) / 17.9 °C (अमृतसर), उच्चतम / निम्नतम सौर विकिरण 15.9 W/m² (अमृतसर और बठिंडा) / 14.9 W/m² (अमृतसर) और उच्चतम/न्यूनतम वर्षा क्रमशः 659 मिमी (अमृतसर) / 346 मिमी (अबोहर) के पूर्वानुमान दिए गए।

ABSTRACT. The projected temperature, rainfall and solar radiation derived from four General Circulation Models namely CSIRO-Mk3-6-0, FIO-ESM, IPSL-CM5A-MR and Ensemble model under four RCP (Representative Concentration Pathways) scenarios were analyzed on annual basis for four agro-climatic zones of Punjab. The inherent bias in the simulated data was corrected by the difference method at monthly scale for maximum temperature, rainfall and at daily scale for solar radiation. In general, the temperatures are expected to increase linearly in future while the solar radiation and rainfall would decrease under the four RCP scenarios. Amongst the four models, the maximum temperature is predicted to increase from the baseline during mid/end century by 0.5 to 1.2/1.6 to 2.6 °C and minimum temperature is predicted to increase from the baseline during mid/end century by 1.1 to 2.6/2.7 to 4.1 °C by CSIRO-Mk3-6-0, respectively followed by IPSL-CM5A-MR model in decreasing order. The solar radiation predicted by four models is predicted to decrease from baseline during mid/end century by 0.5 to 1.1/0.3 to 1.2 W/m² and rainfall during mid/end century by 96 to 558/59 to 530 mm by CSIRO-Mk3-6-0, respectively followed by FIO-ESM model in decreasing order. The highest/lowest maximum temperatures were predicted by four models under four RCP scenarios were 32.9 °C (Bathinda)/30.5 °C (Ludhiana), highest/lowest minimum temperature were 20.8 °C (Patiala)/17.9 °C (Amritsar), highest/lowest solar radiation 15.9 W/m² (Amritsar and Bathinda)/14.9 W/m² (Amritsar) and highest/lowest rainfall 659 mm (Amritsar)/346 mm (Abohar), respectively.

Key words – CSIRO-Mk3-6-0, FIO-ESM, IPSL-CM5A-MR, Ensemble model, Punjab, meteorological parameters, RCPs.

1. Introduction

General circulation models (GCMs) are a powerful tool to give an insight of the future climates. Earlier studies by Kumar *et al.*, (2006) simulated the regional climate of India by using PRECIS for the baseline (1961-1990) as well as long-term (2071-2100) climatology model and projected a temperature rise of 2.9 °C under the

B2 scenario and 4.1 °C for A2 scenario of SRES in 2080s relative to 1970s. Chaturvedi *et al.*, (2012) used the CMIP5 climate projections for India and observed that there may be a great uncertainty in precipitation projections. However, temperature is likely to increase 3-4 °C under the Representative Concentration Pathways (RCP) 8.5 by the end of 21st century. Dar *et al.*, (2019) revealed that climate change presents critical threats to world food security and water resources. In their study, a Global Climate Model HAD GEM2-ES under RCPs 4.5 and 8.5 was utilized for climate prediction. The study spanned 46 years of baseline (1970-2015) as well as two future periods', *i.e.*, mid-century (MC) of 2020-2050 and end-century (EC) of 2060-2090. The outcomes demonstrated that under RCP 4.5 by MC the temperature would increase by 1.56 °C and precipitation would reduce by 98 mm. The corresponding magnitude would be 3.11 °C and 90 mm in EC. But under RCP 8.5 the increase in temperature and decrease in precipitation was 2.75 °C and 153 mm, separately in MC and the corresponding values in EC was 5.46 °C and 251 mm, respectively.

Climate change is a risk to the survival of mankind as it has substantial impact on the environment, crop production, water resources, and livestock production (Araya *et al.*, 2015). Over the last century, earth has experienced changes in climate due to increase in temperature and CO_2 concentration as a result of anthropogenic factors including changes in land use pattern (Islam and Sikka, 2010) and emission of greenhouse gases (GHG) from industrial as well as agriculture sector (Rozenweig and Hillel, 1998). Climate change has expected effects on physical, biological and socio-economic processes. Present and future climate change information at local, regional and global scales is required to develop national as well as international level adaptation and mitigation strategies (Xu *et al.*, 2010; Miao *et al.*, 2011). At regional scale, Prabhjyot-Kaur *et al.*, (2017) used PRECIS (Providing Regional Climates for Impacts Studies) model and predicted that by the end of 21st century there may be rise in the maximum temperature by 2.0 to 2.2 °C, minimum temperature by 3.3 to 5.4 °C and rainfall by 33 to 66%, respectively in agro-climatic zone II; by 0.4 to 5.8 °C, 2.5 to 7.4 °C and 3 to 62%, respectively in agro-climatic zone III; and by 0.5 to 4.0 °C, 4.7 to 7.7 °C and 58 to 69%, respectively in agro-climatic zone V of the state.

The general circulation model (GCM) has steadily become a prime tool for climate change research (IPCC, 2007). Driven by different radiative forcings, GCMs can simulate present-day climate and project future climate conditions under different scenarios (IPCC, 1990; Li *et al.*, 2011; McAfee *et al.*, 2011; Xu *et al.*, 2011; Miao *et al.*, 2013; Ou *et al.*, 2013). Climate projections for the

Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) are made using the newly developed Representative Concentration Pathways (RCPs) under the Coupled Model Inter-comparison Project 5 (CMIP5). It is often desired to have an accurate assessment of future climate. Bias correction of outputs from the GCMs is a necessary step and useful approach for obtaining high resolution and detailed climate simulations that can be used in the development of effective adaptation strategies at regional and sub-regional scale. This approach is based on the assumption that large-scale weather exhibits a strong influence on local-scale weather but, in general, disregards any reverse effects from local scales upon global scales (Hewitson and Crane, 1996; Benestad *et al.*, 2007). Wide range of 21st century RCP scenarios allow us to see the impact of different magnitudes of anthropogenic forcing, as well as the response of the climate system simulated with different model representations. The credibility of the future simulations depends on how the climate model reproduces the preindustrial, historical, and current conditions, processes, and sensitivities. All climatic projections involve an inevitable degree of uncertainty but still a considerably large number of scientific studies conclude that under RCP 8.5 global warming will overshoot 2 °C and may rise up to 6 °C by the year 2100 (Friedlingstein *et al.*, 2014; Betts *et al.*, 2016). The Fifth Assessment Report (AR5) of the IPCC (2014) critically analyzed the expected severe impact of a warming of 1 to 2 °C above pre-industrial levels on many facets of life. The present study was conducted to assess the changes in temperature and rainfall as simulated by different models under four RCPs scenarios at annual time scales at different locations in Punjab. This information may help in planning future research needs as well as drafting policy for the agriculture of tomorrow.

2. Materials and method

2.1. *Site description and model data used*

Data for meteorological parameters like maximum and minimum temperature, solar radiation and rainfall were derived at daily interval under four RCPs scenarios from weather generator available at the site http://gismap.ciat.cgiar.org/MarkSimGCM/ using the CSIRO-Mk3-6-0, FIO-ESM, GISS-E2-R and IPSL-CM5A-MR model for four agro-climatic zones of Punjab. Though seventeen models are available over the weather generator site, but these four models were selected on the basis of earlier study conducted by Kaur *et al.*, (2020). The study was carried out for Ballowal Saunkhri (30° 07′ N 76° 23′ E 355 a.m.s.l) in Zone II, 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.) in
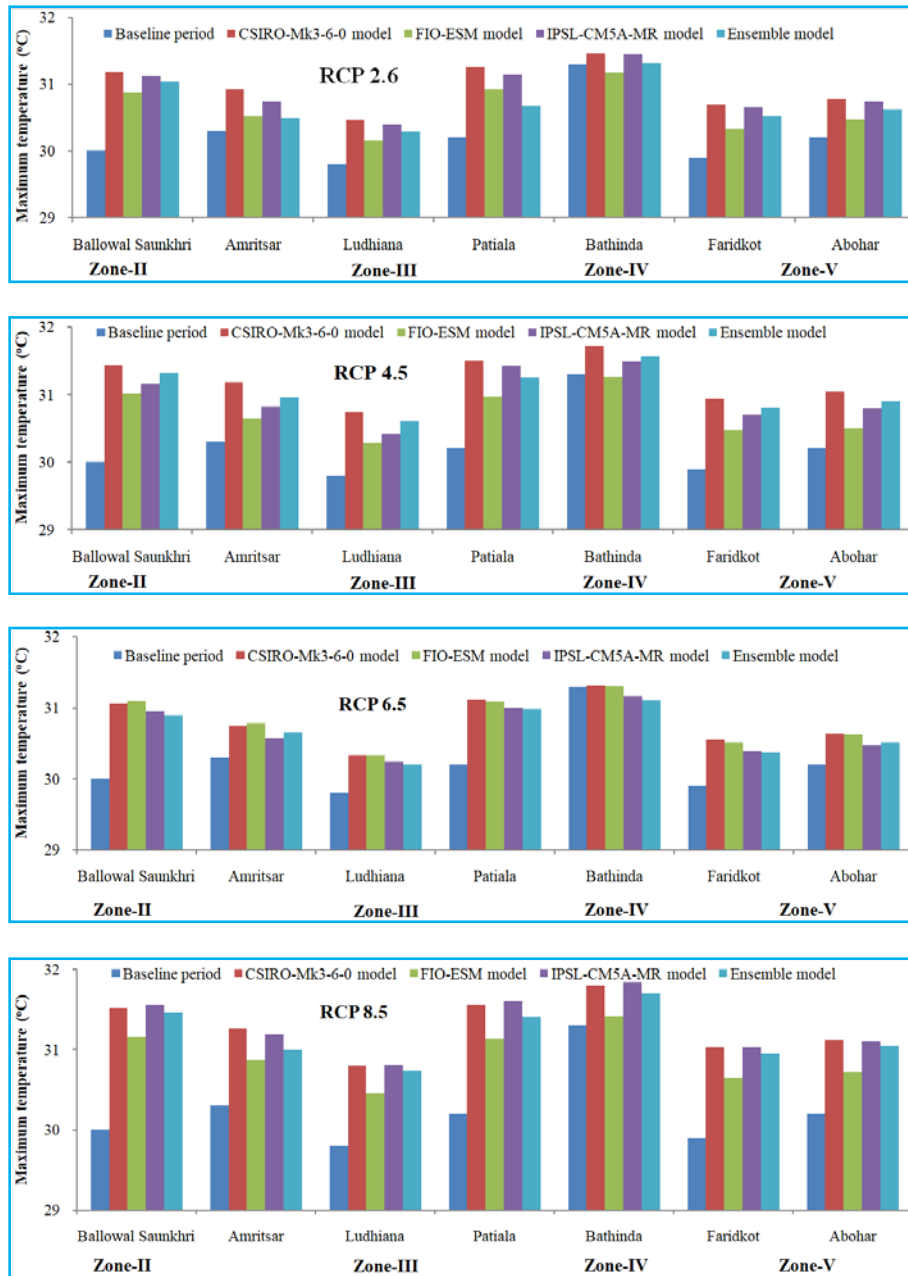
Fig. 1. Annual maximum temperature (°C) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during mid-century (2020-49)

Zone III, Bathinda (30° 12′ N, 74° 57′ E 211 a.m.s.l.), Faridkot (30° 40′ N, 74° 45′ E 204 a.m.s.l.) in Zone IV and Abohar (30° 58′ N, 74° 36′ E 177 a.m.s.l.) in Zone V at four agro-climatic zones of Punjab. The bias correction in the modeled data was done as described by Kaur *et al.,* (2021) at daily time scale for solar radiation which reduced the Root Mean Square Error (RMSE) in the data from 7.28 to 3.54%; at monthly scale for maximum temperature which reduced the RMSE in the data from

4.57 to 3.70% and for rainfall which reduced the RMSE in the data from 8.28 to 7.54%. Minimum temperature data with a RMSE of 3.71% was used as such without any bias removal since the simulated data was very close to observed values.

The observed daily weather data for baseline period of 8 years (2010-2017) on temperature, solar radiation and rainfall recorded at the agro meteorological observatory,
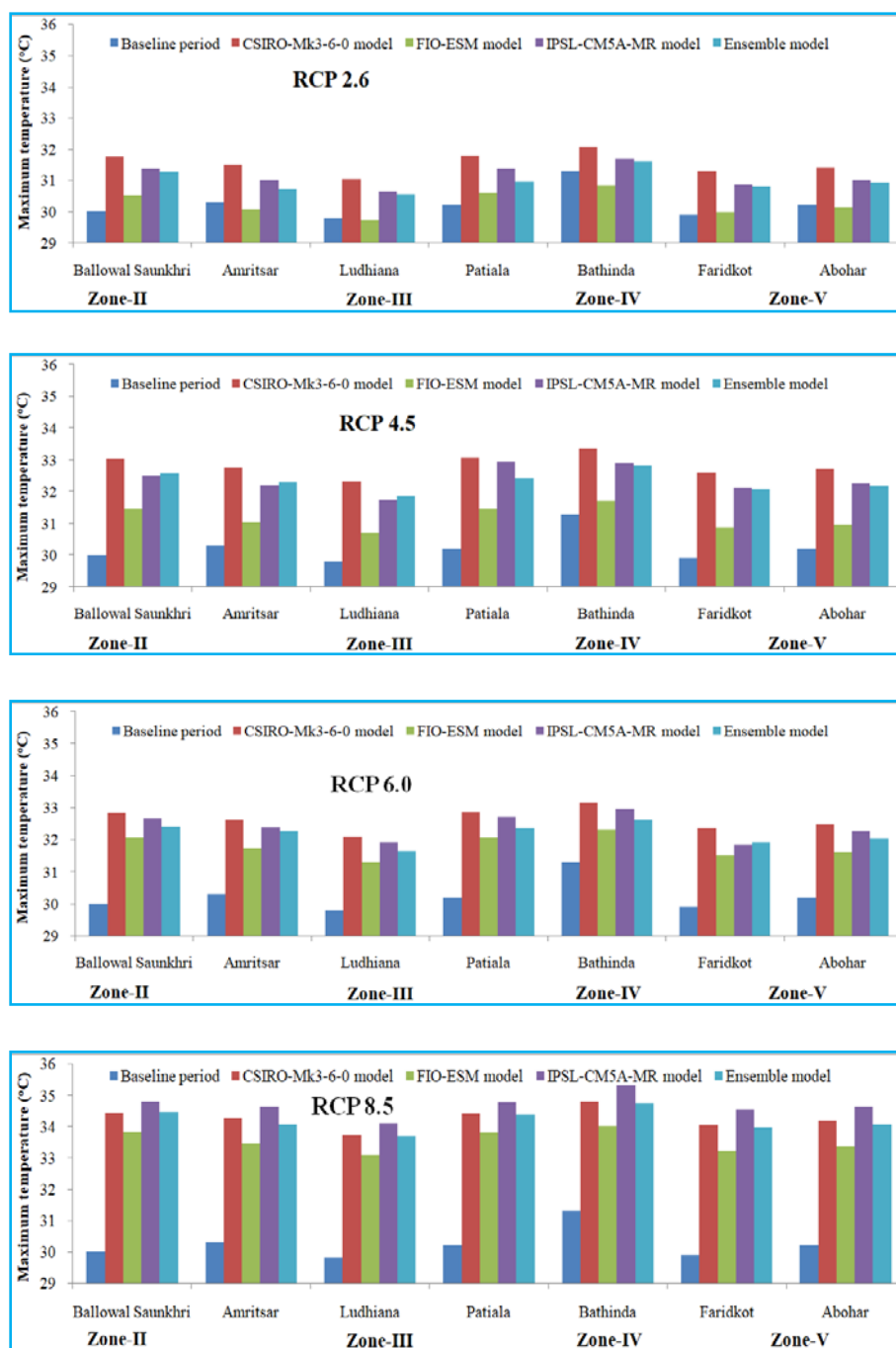
Fig. 2. Annual maximum temperature (°C) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during end-century (2066-95)

Punjab Agricultural University Ludhiana was used for calibration for 6 years (2010-2015) and 2 years (2016-2017) for validation.

In difference method of bias removal first daily difference between model data (X_{model}) and observed data (X_{obs}) of meteorological parameters (*e.g.*, temperature, rainfall and solar radiation) for each Julian day (365 days) averaged over 6 years (2010-15) was used. These were taken as a "Daily Correction Factor". Then these correction factors were subtracted from the modeled uncorrected ($X_{modeluncorr}$) data so that the model corrected
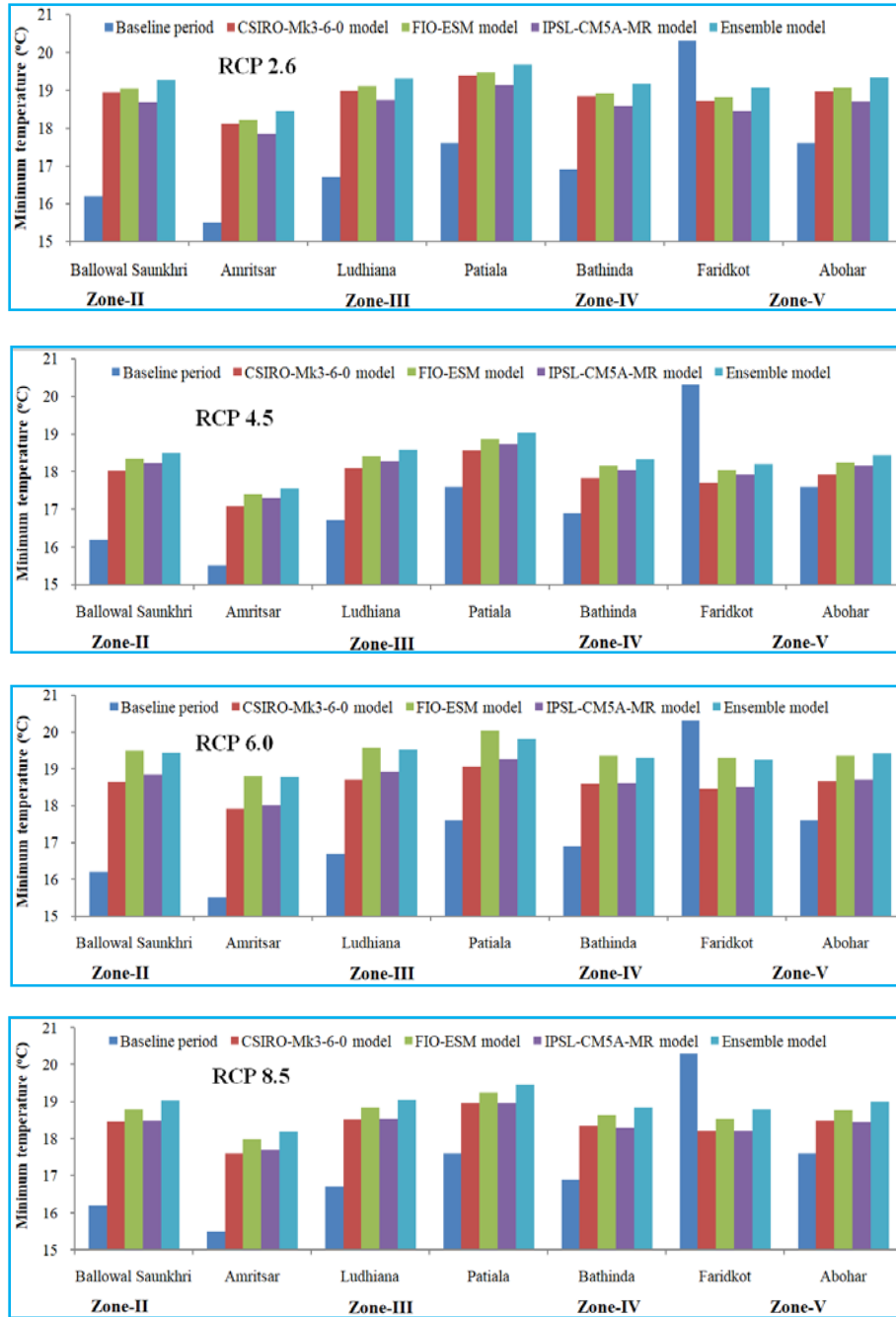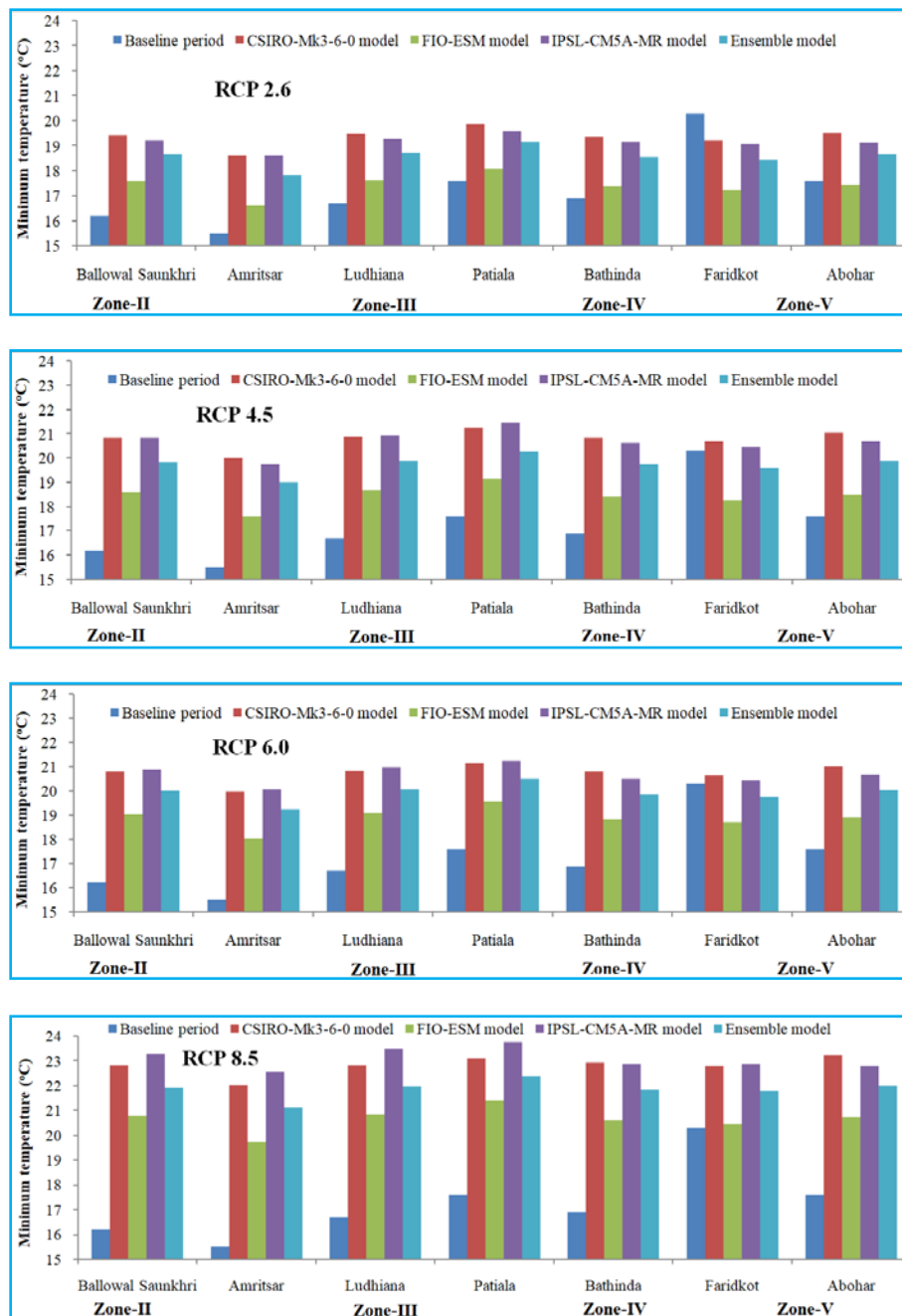
Fig. 3. Annual minimum temperature (°C) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during mid-century (2020-49)

($X_{modelcorr}$) data comes closer to the actual data (Kaur *et al.*, 2021). The formula for difference method of bias removal is given as under:

$$X_{modelcorr} = X_{modeluncorr} - (X_{model} - X_{obs})$$

$X_{modeluncorr}$ = Daily modelled average of 6 years

$X_{modelcorr}$ = Daily corrected modelled average of 6 years

X_{model} = Daily modeled value

X_{obs} = Daily observed value

Fig. 4. Annual minimum temperature (°C) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during end-century (2066-95)

3. Results and discussion

3.1. *Bias removal in simulated temperature, rainfall and solar radiation data*

The model simulated data for 2016-2017 was subjected to bias removal by Difference and Leander and Buishand methods on daily, monthly and annual time scales (Table 2). The RMSE value of 4.57% in the Tmax was reduced by difference method to 2.70, 3.70 and 3.82% at daily, monthly and annual time scale, respectively and by Leander and Buishand method to 4.80 and 3.80% at monthly and annual time scale. In case of Tmin the RMSE was reduced/ increased by difference
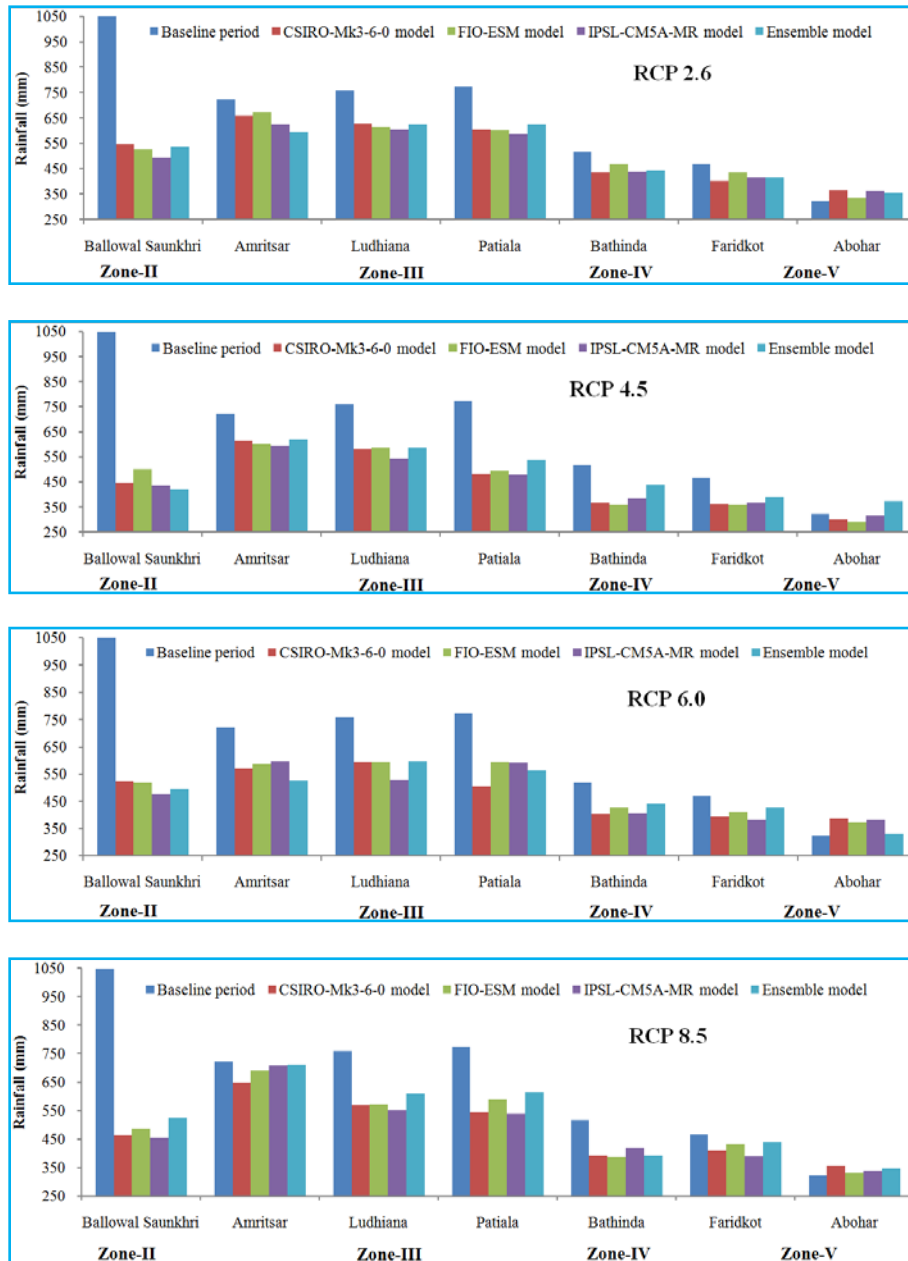
Fig. 5. Annual rainfall (mm) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during mid-century (2020-49)

method to 2.00, 3.28 and 3.75% at daily, monthly and annual time scale respectively and by Leander and Buishand method to 3.18 and 3.59% at monthly and annual time scale. For the RF data the RMSE value of 8.28% was reduced at daily, monthly and annual time scale by difference method to 7.56, 7.54 and 7.95%, respectively and by modified difference method to 6.79, 7.98 and 8.28%, respectively from the simulated values. In case of SR, the RMSE value of 7.28% in the model data was reduced by difference method to 3.54, 6.62 and

6.56% at daily, monthly and annual time scale, respectively.

3.2. *Changes in maximum temperature*

The simulated data using all models under all RCP-based scenarios indicated that annual maximum temperature will elevate from the baseline temperature for both mid-century (2020-2049) and end-century (2066-2095) at all locations (Figs. 1 and 2).
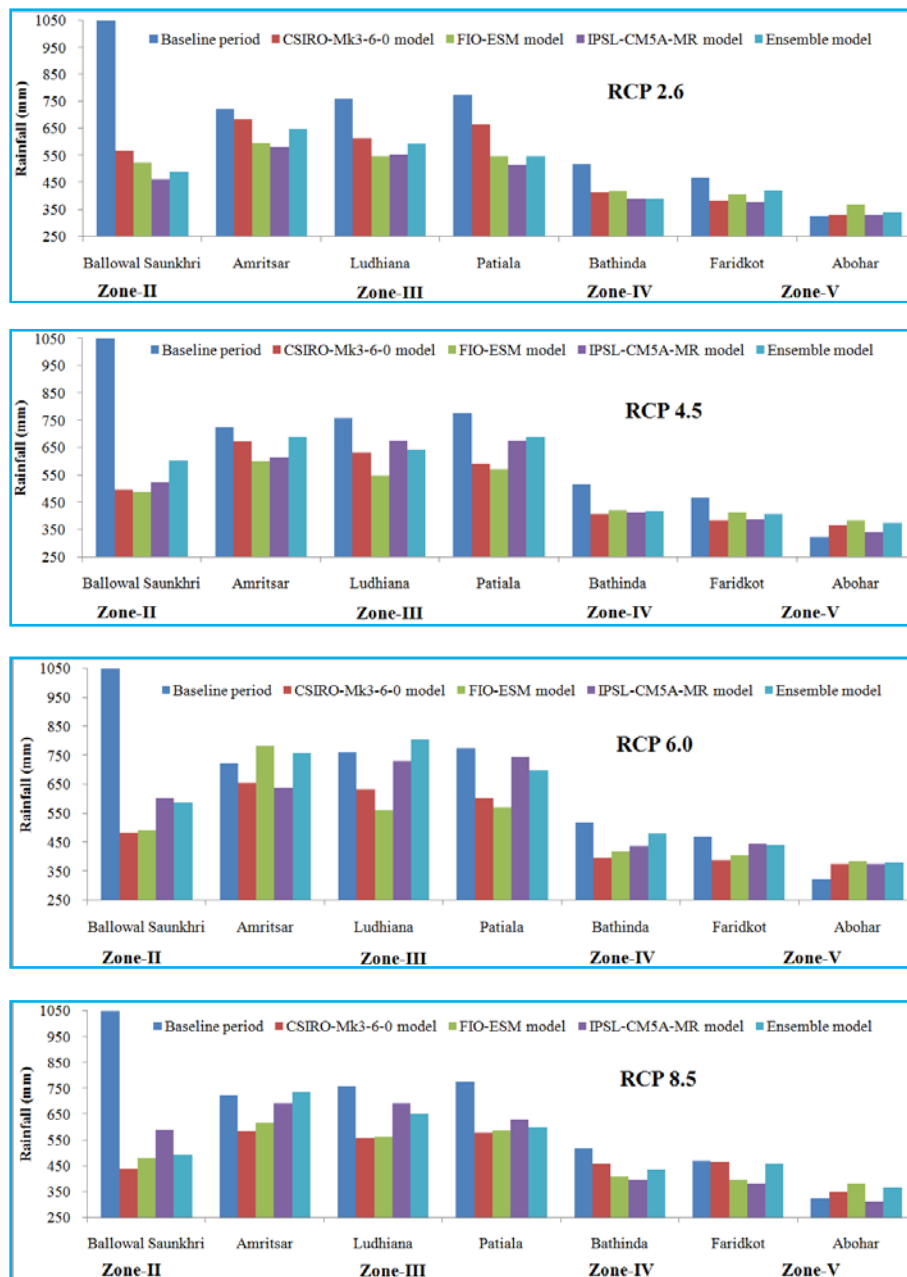
Fig. 6. Annual rainfall (mm) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during end-century (2066-95)

The highest value of annual maximum temperature for both mid-century (2020-2049) as well as end-century (2066-2095) was predicted by CSIRO-Mk3-6-0 model followed by FIO-ESM model for all agro-climatic zones of Punjab. Among different locations, Bathinda (zone-IV) will face the maximum temperature in mid and end century, although, there will be slight variations in the range of maximum temperature depending on location and emission-based scenarios. The stimulated data also revealed that the highest maximum temperature in contrast to baseline temperature will be observed for RCP 8.5 than RCP 2.6, 4.5 and 6.0 scenarios. Jalota *et al.*, (2014) also reported rise in temperature during mid as well as end of 21st century in Punjab.

3.3. *Changes in minimum temperature*

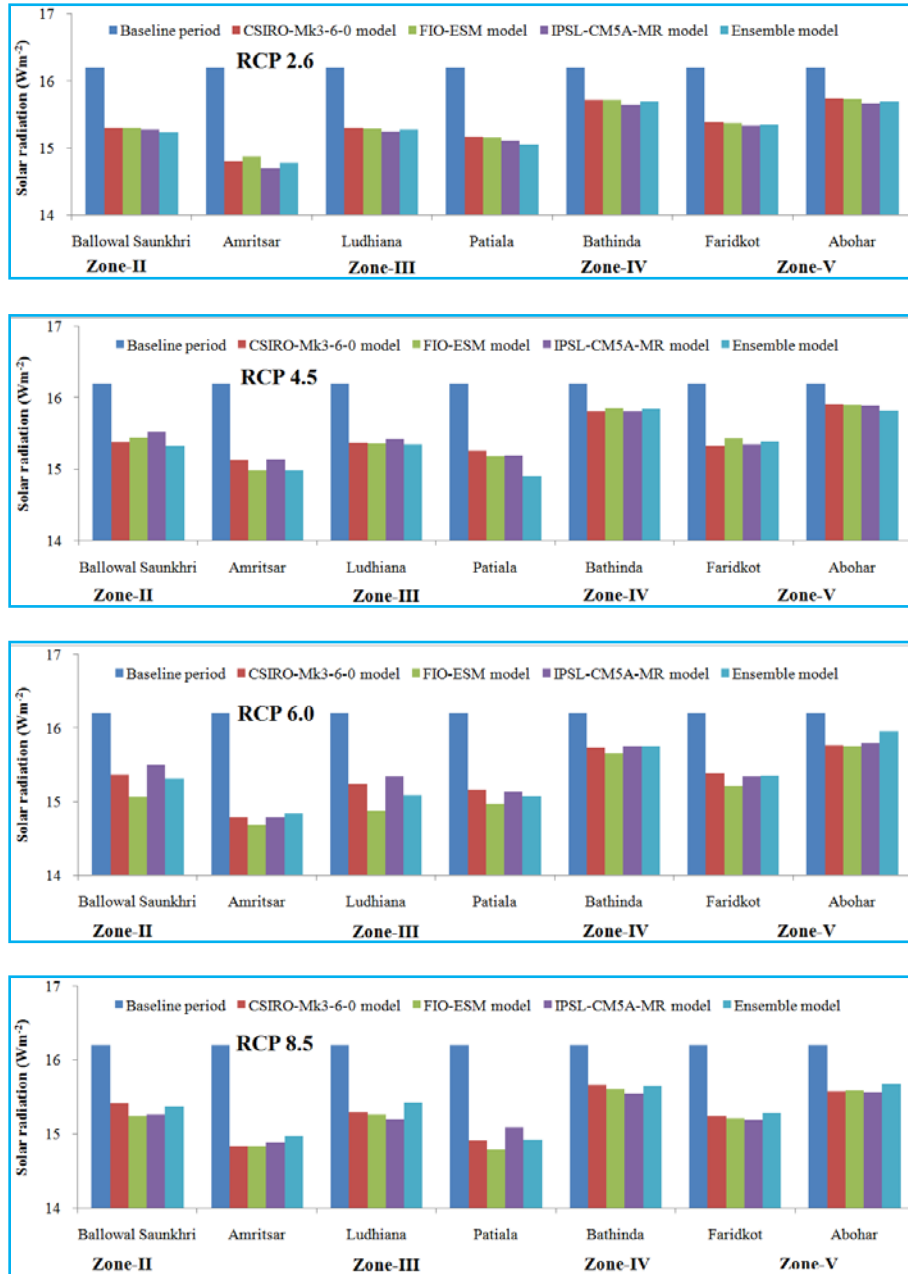The annual minimum temperature will substantially increase from the baseline value for both mid-century

Fig. 7. Annual solar radiation (Wm^{-2}) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during mid-century (2020-49)

(2020-2049) and end-century (2066-2095) as revealed by four models for all scenarios (Figs. 3 and 4).

The highest value of annual minimum temperature for mid-century (2020-2049) was predicted for Ensemble model for all RCP scenarios with the exception of FIO-ESM model for under RCP 6.0 scenario. The highest value of annual minimum temperature for end-century (2066-2095) was predicted for IPSL-CM5A-MR model

for all RCP scenarios with the exception of CSIRO-Mk3-6-0 model under RCP 2.6 scenario. Amongst all the four zones, Patiala (Zone III) will face the highest increase in minimum temperature in both mid-and end-century. Generally, there will be minor variations in the range of minimum temperature depending on location and emission-based scenarios. The stimulated data further revealed that the highest rise in minimum temperature as compared to baseline temperature will be observed for
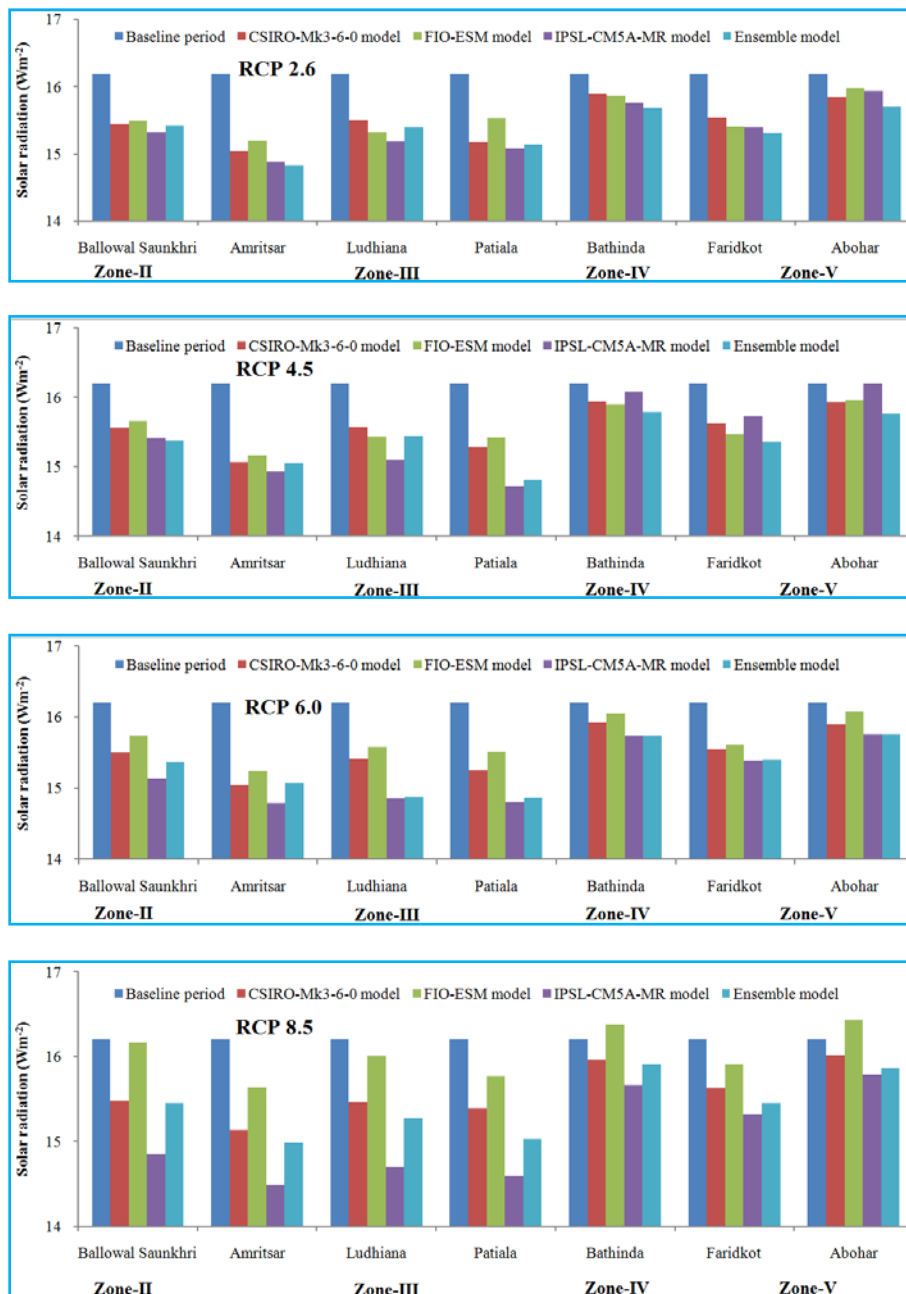
Fig. 8. Annual solar radiation (Wm^{-2}) as simulated by four models under four RCP scenarios at four agro climatic zones in Punjab during end-century (2066-95)

RCP 6.0 for mid-century. While similar response was observed whereas, highest rise in annual minimum temperature for RCP 2.6 scenario for end-century. Overall, rise in minimum temperature will be higher in the end-century in contrast to mid-century. These substantial changes in minimum temperature will affect the crop production. These changes need to be taken in consideration and preventive measures should be taken to combat these climate changes (Naqvi *et al*., 2017; Gul *et al.*, 2019).

3.4. *Changes in rainfall*

The stimulations using all models under different RCP-based conditions revealed that annual rainfall will decrease from the baseline value for both mid-century

TABLE 1

Annual projected changes in climatic parameters from their baseline values under four scenarios during mid and end of 21st century in Punjab

Time period	Baseline period	Representative Concentration Pathways (RCPs)			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Maximum temperature (°C)					
Mid-century (2020-49)	30.2	30.8	31.0	30.7	31.2
End-century (2066-95)		31.0	32.2	32.3	34.2
Minimum temperature (°C)					
Mid-century (2020-49)	17.3	18.9	18.1	19.0	18.6
End-century (2066-95)		18.6	19.9	20.1	22.1
Rainfall (mm)					
Mid-century (2020-49)	659	515	458	487	497
End-century (2066-95)		489	515	544	510
Solar Radiation (Wm^{-2})					
Mid-century (2020-49)	16.2	15.3	15.4	15.3	15.3
End-century (2066-95)		15.4	15.5	15.4	15.5

(2020-2049) and end-century (2066-2095) with the exception for Abohar (Zone V) which shows higher rainfall compared with baseline value (Figs. 5 and 6). An exception was noticed for Abohar under RCP 4.5 and RCP 6.0 which showed an increase in rainfall.

Among the four models, the lowest value of annual rainfall for mid-century (2020-2049) was predicted mostly by FIO-ESM model for all RCP scenarios. Likewise, the lowest value of annual rainfall for end-century (2066-2095) was predicted mostly by IPSL-CM5A-MR model for all RCP scenarios. Abohar (Zone V) will receive rainfall higher than baseline period in both mid- and end-century while there will be slight differences in rainfall due to location and emission-based scenarios. Overall, there will be reduction in rainfall with reference to baseline, and annual rainfall will be lower in end-century as compared to mid-century. The greatest decrease in rainfall was predicted for Ballowal Saunhkri and least decrease in Abohar. These results agree with those reported earlier by Kaur N and Prabhjyot-Kaur (2016). They used PRECIS model and reported a significant increase in maximum and minimum temperature but irregular trend in rainfall. They reported a deficit in rainfall by 78 and 30 % during the winter season under A2 and B2 scenarios for end-century. The reduction in annual rainfall ultimately could affect yield of crops. Therefore,

suitable agronomic management strategies to overcome risk and vulnerabilities need to be considered.

3.5. *Changes in solar radiation*

The simulations revealed that annual solar radiation will decrease from baseline period during the mid-century (2020-49) and end-century (2066-2095). In Figs. 7 and 8 this decline will be more in mid-century (2020-2049) in comparison to end-century (2066-2095). The greatest decrease in solar radiation was predicted by IPSL-CM5A-MR model followed by Ensemble model for all four agro-climatic zones with minor differences due to location and RCP scenarios. The similar trend of decrease in annual solar radiation has been reported by Kingra (2018). They used CROPWAT model for Ludhiana and reported a decreasing trend. The simulated results from our study point to risk and vulnerabilities that might be experienced in future and hence timely planning is envisaged to maintain productivity.

4. Conclusions

In the Punjab state, the maximum temperature on annual basis is predicted to increase from baseline period during mid/end-century by 0.5 to 1.0/0.8 to 4.0 °C and minimum temperature increase by 0.8 to 1.7/1.3 to 4.8 °C

TABLE 2

Variations in observed, modeled and model corrected temperature, rainfall and solar radiation by different methods of bias removal and their statistics for the baseline period (2016-2017)

Parameter	Observed	Modeled	Leander & Buishand Method		Difference Method			Modified Difference Method		
			Monthly	Yearly	Daily	Monthly	Yearly	Daily	Monthly	Yearly
Maximum Temperature (°C)										
Mean	30.37	32.94	29.15	29.84	29.81	29.90	29.81	-	-	-
Standard deviation	7.10	7.93	8.66	8.01	7.24	7.56	7.93	-	-	-
RMSE (%)	-	4.57	4.80	3.80	2.70	3.70	3.82	-	-	-
NRMSE (%)	-	15.04	15.81	12.50	8.90	12.17	12.58	-	-	-
Minimum Temperature (°C)										
Mean	18.33	18.37	18.49	17.75	17.76	17.88	17.76	-	-	-
Standard deviation	7.88	9.52	8.63	9.24	7.90	8.18	9.52	-	-	-
RMSE (%)	-	3.71	3.18	3.59	2.00	3.28	3.75	-	-	-
NRMSE (%)	-	20.23	17.34	19.59	10.92	17.92	20.46	-	-	-
Solar Radiation (Wm^{-2})										
Mean	15.28	18.20	-	-	15.25	15.89	15.33	-	-	-
Standard deviation	5.97	7.67	-	-	4.99	7.56	7.51	-	-	-
RMSE (%)	-	7.28	-	-	3.54	6.62	6.56	-	-	-
NRMSE (%)	-	47.61	-	-	23.17	43.33	42.93	-	-	-
Rainfall (mm/day)										
Mean	1.50	2.14	-	-	1.71	1.60	1.77	2.30	2.51	2.18
Standard deviation	4.81	7.55	-	-	6.53	6.41	7.07	5.21	6.88	7.55
RMSE (%)	-	8.28	-	-	7.56	7.54	7.95	6.79	7.98	8.28
NRMSE (%)	-	1.52	-	-	1.38	1.38	1.46	1.24	1.46	1.52

Bias removal method not applicable

(Table 1) under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. Similarly, the rainfall on annual basis is projected to decrease from baseline period during mid/end-century by 144 to 201/115 to 170 mm and solar radiation decrease by 0.8 to 0.9/0.7 to 0.8 Wm^{-2} during mid/end-century.

The analysis of the predicted data by CSIRO-Mk3-6-0, FIO-ESM, IPSL-CM5A-MR and Ensemble model indicated an appreciable change in temperature, rainfall and solar radiation under RCPs based emission scenarios. The maximum and minimum temperature is projected to increase; and the rainfall and solar radiation are projected to decrease on annual basis under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios by mid and end of 21st century. Projections by these models vary in different agro-climatic zones for these meteorological parameters. Punjab is highly productive from agriculture point of view; hence these changes in meteorological parameters are bound to have direct bearing on the crop production. Kumar *et al.*, (2014) projected that climate change will reduce the wheat yield in India in the range of 6 to 23% by 2050 and 15 to 25% by 2080. Even though the magnitude of the projected impacts is variable, the direction is similar in the climate scenarios of both at global and at regional scale. Negative impacts of climate change are projected to be less severe in low than in high emission scenarios. Thus, in view of the changing climatic conditions, a decrease in

productivity seems imminent due to warming scenarios in future.

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