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Research Article

Climate Change Predictions by Ensemble Model in Different Agro-Climatic Zones of Punjab, India

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ABSTRACT

The projected data on temperature and rainfall derived from Ensemble model based on four RCP (Representative Concentration Pathways) scenarios was analyzed on annual and seasonal (*kharif* : May-October and *rabi* : November-April) basis for four agro-climatic zones of Punjab. In Punjab amongst four agro-climatic zones, the maximum temperature is projected to rise from 29.8-31.3°C (baseline period) to 30.2- 31.3°C (RCP 2.6), 30.8- 31.5°C (RCP 4.5), 30.3- 31.1°C (RCP 6.0) and 30.7- 31.7°C (RCP 8.5) during mid century (2020-2049) and to 30.5-31.6°C (RCP 2.6), 31.8-32.8°C (RCP 4.5), 31.6-32.6°C (RCP 6.0) and 33.6-34.7°C (RCP 8.5) during end century (2066-2095). Similarly, minimum temperature is projected to rise from 15.5-20.3°C (baseline period) to 17.6-18.9°C (RCP 2.6), 17.9-19.2°C (RCP 4.5), 17.7-18.9°C (RCP 6.0) and 18.1-19.4°C (RCP 8.5) during mid-century (2020-2049) and to 17.8-19.1°C (RCP 2.6), 19.0-20.2°C (RCP 4.5), 19.2-20.5°C (RCP 6.0) and 21.1-22.4°C (RCP 8.5) during end century (2066-2095). The rainfall is not only projected to decrease in agro-climatic zone II, III and IV of the state but its distribution may become highly variable.

Key words: Agro-climatic zone, Annual, Ensemble model, Punjab, RCP scenario

Introduction

The term "climatic scenario" is a comprehensible and reliable probable description of a possible future state of the atmospheric conditions. The name "representative concentration pathways - RCP's" are referred to as pathways in order to highlight that their primary purpose is to deliver time-dependent projections of atmospheric greenhouse gases (GHGs) concentrations. It is now an acceptable certainty that anincrease in the concentrations of GHGs and aerosols from human activities will perceptibly alter the Earth's climate during the 21st century (Meehl *et al.,* 2007). The future anthropogenic climate responses have large unpredictability due to uncertainty in the climate sensitivity to the increasing GHGs and the challenge of anticipating future atmospheric compositions and their forcing (Hawkins and Sutton, 2009).At this juncture, multi-GCM (General Circulation Model) ensembles are used as a framework for accommodating probabilistic approaches in interpreting climate predictions for developing climate adaptation plans. Several studies have attempted to quantify these uncertainties with the information of ensemble GCM's and to identify its sources (Doblas-Reyes *et al.,* 2005; Chen and Singh, 2018). An ensemble model approach is used to deal with the uncertainty in climate scenarios because a specific scenario cannot represent all possible future climate conditions (Giorgi and Mearns, 2002; Lee *et al.,* 2016). Most studies have selected appropriate scenarios based on the performance

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in reproducing the historical climate. However, it has the limitation that the performance of a GCM during a historical period cannot guarantee consistent and correct performance during a future period (Rafetry *et al.,* 2005). Therefore, the use of multi-model ensemble (MME) has been increasing to capture the possible climate changes projected by multiple models (Rajagopalan *et al.,* 2002; Raisanen and Palmer, 2001; Berzitis *et al.*, 2014). The advantage of using ensemble output either with GCM model or with emission based RCP scenarios is well known and is applied to eliminate the uncertainties associated with climate change projections (Feng *et al.,* 2010).

To reduce simulation uncertainty and improve GCM predictions, many studies have adopted MME techniques. It is generally accepted that the model uncertainties may be reduced and the model credibility can be improved by employing multi-model ensembles (Krishnamurti *et al.,* 2000; Kumar *et al.,* 2012). Many studies have also simulated historical climate with respect to observations. Generally, the performance of multi-model ensembles is often found to be better than the individual simulation (IPCC, 2001; Tebaldi and Knutti, 2007; Duan and Philips, 2010). A possible explanation is that the multi-model ensemble embraces distinctly different physical parameterizations, thus surmounting the limitations of an overconfident single-model simulation (Duan and Philips, 2010). Hence, ensembles can be used to produce more reliable predictions (Nohara *et al.,* 2006; Tebaldi and Knutti, 2007).

Material and Methods

Site description and model data used

The study was done for four agro-climatic zones of Punjab state, namely Zone II - Undulating plain region (Ballowal Saunkhri 30° 07′ N 76°23′ E 355 a.m.s.l), Zone III - Central plain region (Amritsar 31°37′ N, 74°53′ E 231 a.m.s.l., Ludhiana 30°56′ N 75°48′ E 247 a.m.s.l. and Patiala 30°20′ N, 76°28′ E 251 a.m.s.l.), Zone IV - Western plain region (Bathinda 30°12′ N, 74°57′ E 211 a.m.s.l.) and ZoneV- Western region (Faridkot 30°40′ N, 74°45′ E 204 a.m.s.l. and Abohar 30°58′ N, 74°36′ E 177 a.m.s.l.). The data was analyzed over the annual (January to December) and seasonal (*kharif*: May-October and *rabi*: November-April) basis. The projected data during the mid (2020-2049) and end (2066-2095) of the 21st century under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 was compared with the baseline data for all the respective locations as per the availability of the actual recorded meteorological data. The baseline period used for Ludhiana, Amritsar, Patiala was 1970-2015, for BallowalSaunkhri was 1984-2015, for Bathinda was 1977-2015, for Abohar was 2004-2015 and for Faridkot was 2000-2015.

Retrieval and rectification of climate data

The GCM data for the Ensemble model at daily interval for four RCP scenarios were obtained from the site *http://gismap.ciat.cgiar.org/MarkSimGCM/*. The bias removal in predicted data was done by difference method at daily scale in maximum temperature, at a monthly scale for rainfall. However, no bias removal was done at a minimum temperature.The projected data on temperature, rainfall and solar radiation derived from CSIRO-Mk3-6-0, FIO-ESM, IPSL-CM5A-MR, GISS-E2-R and Ensemble model for four RCP (Representative Concentration Pathways) scenarios was analyzed on annual and seasonal (*kharif* : May-October and *rabi* : November-April) basis for four agro-climatic zones of Punjab. Finally, we selected Ensemble model for futuristic predictions of climate change under four RCP scenarios because this model gave more reliable results after bias removal.

The daily weather data for the past 6 years (2010-2015) on maximum temperature (Tmax), minimum temperature (Tmin) and rainfall (RF) recorded at the ground based agro meteorological observatories were used for bias removal and its validation was done using the 2 years (2016-2017) data. In the differencemethod, the daily difference between modeled data (X_{model}) and observed data (X_{obs}) of meteorological parameter was computed for each Julian day (365 days)andwas then averaged over the 6 years (2010-15). This was considered as the daily correction factor. These correction factors were then subtracted from the modeled uncorrected ($X_{modeluncorr}$) values. The formula for difference method of bias removal was given as under:

$X_{modelcorr} = X_{(model\ uncorr)} - (X_{model} - X_{obs})$

X_{model} = Model data

$X_{modeluncorr}$ = Uncorrected model data

X_{obs} = Observed data

Results and Discussion

The Ensemble model data on temperature and rainfall was analyzed over an annual and seasonal basis as given below:

Agro-climatic zone II - Undulating plain region

Zone II represents about 9% of the land area of Punjab and the maximum temperature on annual, *kharif* and *rabi* season basis is predicted to increase from baseline period by 1.0-1.4, 1.0-1.4 and 0.7-1.3°C, respectively during mid-century (Table 1) and by 1.2-4.4, 1.2-4.1 and 1.1-4.6°C, respectively during end-century (Table 2) under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. Similarly, under the four RCP scenarios, the minimum temperature on annual, *kharif* and *rabi* season may increase from baseline period by 2.2-2.8, 3.8-4.4 and 0.4-0.9°C, respectively during mid-century (Table 3) and by 2.4-5.7, 2.0-7.0 and 0.6-4.1°C, respectively during end-century (Table 4). The rainfall on annual, *kharif* and *rabi* season basis is projected to decrease by 526-594, 425-489, 96-109 mm, respectively during mid-century (Table 5) and by 446-562, 339-456, 104-129 mm, respectively during end-century (Table 6) under the four scenarios.

The standard deviation and coefficient of variation are estimated to be high for both the temperature and rainfall during the mid and end of 21st century and hence the heat wave, extended dry spells and extreme rainfall events are projected to increase in number. This region is the wettest zone of Punjab and rainfall is not only projected to decrease sharply by 40-50% but its distribution over the spatial time scale is also predicted to be alarmingly disturbed (Kaur *et al.,* 2013).

Agro-climatic zone III - Central plain region

This is the biggest zone covering 36% of the land area of the state. In this zone, the maximum temperature on an annual, *kharif* and *rabi* season basis is projected to increase from baseline period by 0.4-1.2, 0.3-1.1 and 0.4-1.2°C, respectively during mid-century (Table 1) and by 0.7-4.5, 0.6-3.7 and 0.7-4.9°C, respectively during end-century (Table 2) under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. Similarly, under the four RCP scenarios the minimum temperature on annual, *kharif* and *rabi* season may increase from baseline period by 1.3-2.3, 2.3-3.7 and 0.3-1.5°C, respectively during mid-century (Table 3) and by 1.5-5.6, 2.5-6.3 and 0.6-4.7°C, respectively during end-century (Table 4). The rainfall in this zone is projected to both increase and decrease from the baseline rainfall on an annual and *kharif* season basis under the four scenarios during the 21st century (Table 5 and 6). However, the *rabi* season rainfall is projected to decrease during the mid and end of the century.

The standard deviation and coefficient of variation are estimated to be high for both the temperature and rainfall during the mid and end of 21st century. Rice and wheat are the main crops grown in this zone and hence the heat wave extended dry spells and extreme rainfall events projected by the model may have adverse effects on the cereal production in the state. Agricultural production is highly vulnerable to these changes and require human interventions to mitigate or adapt to these impacts. Northern part of Indian sub-continent that includes IGP (indo-gangetic plains), has been placed under high risk zone for heat stress risks in future climates (Teixeira *et al.,* 2013). Climatic warming results in enhanced maturity, decrease in grain filling period and hence, reduction in wheat productivity. Similarly, water stress during reproductive growth period of wheat leads to significant reduction in grain yield. Although increase in CO_2 concentration is able to counter balance the negative effect of increase in temperature up to about 1-2°C, but increase in

Table 1. Annual and seasonal variations in maximum temperature during mid-century (2020-2049) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
Ballowal Saunkhri	30.0	0.7	2.4	31.04	6.83	22.00	31.32	6.82	21.78	30.89	6.85	22.17	31.46	6.73	21.41
Zone III : Central plain region															
Ludhiana	29.8	0.5	1.8	30.28	7.46	24.64	30.61	7.46	24.37	30.20	7.49	24.79	30.74	7.38	24.02
Amritsar	30.3	0.6	1.9	30.49	7.18	23.56	30.96	7.20	23.27	30.65	7.18	23.44	31.00	7.11	22.93
Patiala	30.2	0.6	1.9	30.67	7.29	23.77	31.25	7.28	23.29	30.98	7.27	23.46	31.41	7.23	23.01
Zone IV : Western plain region															
Bathinda	31.3	0.7	2.3	31.32	7.91	25.25	31.56	7.93	25.12	31.11	7.88	25.33	31.70	7.88	24.88
Zone V : Western region															
Faridkot	29.9	0.6	2.1	30.52	7.16	23.47	30.81	7.16	23.25	30.37	7.15	23.55	30.95	7.10	22.96
Abohar	30.2	0.8	2.8	30.62	7.59	24.78	30.90	7.60	24.59	30.51	7.60	24.91	31.05	7.54	24.29
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	34.4	0.8	2.4	35.49	3.60	10.15	35.74	3.59	10.04	35.36	3.58	10.13	35.85	3.63	10.13
Zone III : Central plain region															
Ludhiana	34.9	0.6	1.7	35.28	3.78	10.71	35.61	3.77	10.59	35.26	3.71	10.53	35.69	3.77	10.57
Amritsar	35.6	0.7	1.9	35.27	3.58	10.14	35.75	3.63	10.14	35.50	3.44	9.68	35.75	3.52	9.84
Patiala	35.0	0.6	1.8	35.42	3.65	10.31	35.99	3.70	10.28	35.79	3.70	10.34	36.14	3.65	10.11
Zone IV : Western plain region															
Bathinda	36.7	1.0	2.7	36.81	3.90	10.60	37.05	3.93	10.60	36.60	3.90	10.65	37.18	3.93	10.56
Zone V : Western region															
Faridkot	35.1	0.8	2..3	35.32	3.40	9.64	35.60	3.41	9.58	35.17	3.40	9.66	35.72	3.44	9.62
Abohar	35.7	0.5	1.4	36.01	3.63	10.07	36.30	3.64	10.03	35.95	3.58	9.97	36.42	3.64	10.00
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	25.6	0.9	3.6	26.43	6.40	24.23	26.77	6.41	23.94	26.30	6.38	24.25	26.93	6.27	23.28
Zone III : Central plain region															
Ludhiana	24.6	0.8	3.1	25.11	6.87	27.34	25.47	6.84	26.84	25.01	6.83	27.30	25.64	6.77	26.42
Amritsar	24.9	0.8	3.4	25.58	6.67	26.08	26.02	6.67	25.66	25.65	6.64	25.91	26.12	6.59	25.22
Patiala	25.4	0.9	3.4	25.80	6.88	26.66	26.40	6.89	26.09	26.01	6.79	26.10	26.60	6.78	25.50
Zone IV : Western plain region															
Bathinda	25.4	0.9	3.7	25.68	7.00	27.25	25.93	7.03	27.10	25.48	6.94	27.25	26.09	6.94	26.62
Zone V : Western region															
Faridkot	24.5	0.9	3.7	25.59	6.68	26.12	25.90	6.68	25.81	25.43	6.64	26.13	26.07	6.58	25.24
Abohar	24.6	1.4	5.5	25.08	6.57	26.18	25.38	6.58	25.93	24.93	6.54	26.23	25.56	6.49	25.39

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

Table 2. Annual and seasonal variations in maximum temperature during end-century (2066-2095) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
BallowalSaunkhri	30.0	0.7	2.4	31.28	6.77	21.63	32.58	6.68	20.51	32.40	6.67	20.59	34.46	6.52	18.92
Zone III : Central plain region															
Ludhiana	29.8	0.5	1.8	30.54	7.41	24.25	31.87	7.33	22.99	31.63	7.28	23.03	33.69	7.18	21.33
Amritsar	30.3	0.6	1.9	30.74	7.14	23.21	32.29	7.12	22.04	32.26	7.02	21.76	34.08	6.93	20.36
Patiala	30.2	0.6	1.9	30.96	7.27	23.48	32.42	7.17	22.11	32.37	7.10	21.92	34.38	7.00	20.37
Zone IV : Western plain region															
Bathinda	31.3	0.7	2.3	31.60	7.87	24.90	32.83	7.78	23.70	32.62	7.73	23.71	34.74	7.67	22.08
Zone V : Western region															
Faridkot	29.9	0.6	2.1	30.81	7.12	23.10	32.09	7.04	21.95	31.91	6.99	21.92	33.98	6.86	20.19
Abohar	30.2	0.8	2.8	30.94	7.58	24.51	32.17	7.46	23.18	32.04	7.42	23.18	34.08	7.36	21.60
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	34.4	0.8	2.4	35.68	3.62	10.13	36.84	3.67	9.95	36.65	3.58	9.78	38.55	3.66	9.49
Zone III : Central plain region															
Ludhiana	34.9	0.6	1.7	35.52	3.74	10.53	36.73	3.84	10.45	36.40	3.75	10.30	38.31	3.89	10.15
Amritsar	35.6	0.7	1.9	35.52	3.58	10.07	36.97	3.71	10.04	36.92	3.41	9.24	38.57	3.60	9.32
Patiala	35.0	0.6	1.8	35.73	3.65	10.22	36.98	3.73	10.08	36.92	3.62	9.82	38.78	3.73	9.62
Zone IV : Western plain region															
Bathinda	36.7	1.0	2.7	37.05	3.91	10.54	38.14	4.00	10.49	37.92	3.89	10.25	39.93	3.97	9.94
Zone V : Western region															
Faridkot	35.1	0.8	2..3	35.58	3.43	9.63	36.74	3.50	9.52	36.53	3.38	9.25	38.46	3.43	8.91
Abohar	35.7	0.5	1.4	36.34	3.59	9.89	37.43	3.65	9.77	37.28	3.55	9.52	39.21	3.70	9.45
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	25.6	0.9	3.6	26.71	6.33	23.69	28.16	6.33	22.46	28.02	6.33	22.61	30.23	6.18	20.47
Zone III : Central plain region															
Ludhiana	24.6	0.8	3.1	25.39	6.79	26.75	26.85	6.76	25.18	26.72	6.81	25.50	28.92	6.74	23.31
Amritsar	24.9	0.8	3.4	25.80	6.58	25.50	27.46	6.59	23.99	27.44	6.58	24.00	29.46	6.52	22.17
Patiala	25.4	0.9	3.4	26.06	6.82	26.18	27.73	6.84	24.67	27.68	6.80	24.57	29.88	6.74	22.57
Zone IV : Western plain region															
Bathinda	25.4	0.9	3.7	25.99	6.96	26.80	27.36	6.96	25.44	27.17	6.91	25.43	29.40	6.92	23.55
Zone V : Western region															
Faridkot	24.5	0.9	3.7	25.90	6.61	25.54	27.30	6.59	24.14	27.15	6.59	24.28	29.36	6.52	22.21
Abohar	24.6	1.4	5.5	25.38	6.56	25.83	26.77	6.48	24.19	26.65	6.49	24.34	28.82	6.45	22.38

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

Table 3. Annual and seasonal variations in minimum temperature during mid-century (2020-2049) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)	Mean (°C)	S.D. (°C)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
BallowalSaunkhri	16.2	0.5	3.7	18.47	9.37	50.75	18.78	9.36	49.88	18.48	9.41	50.93	19.03	9.35	49.20
Zone III : Central plain region															
Ludhiana	16.7	0.9	5.2	18.52	9.35	50.50	18.84	9.34	49.62	18.55	9.39	50.62	19.06	9.33	49.00
Amritsar	15.5	0.7	4.6	17.61	9.49	53.87	17.98	9.51	52.91	17.71	9.52	53.78	18.19	9.50	52.28
Patiala	17.6	0.5	2.8	18.96	8.90	46.94	19.24	8.87	46.10	18.96	8.90	46.92	19.45	8.86	45.61
Zone IV : Western plain region															
Bathinda	16.9	0.6	3.8	18.35	9.58	52.21	18.64	9.58	51.40	18.30	9.61	52.49	18.84	9.57	50.81
Zone V : Western region															
Faridkot	20.3	2.0	9.8	18.22	9.52	52.26	18.54	9.52	51.38	18.21	9.55	52.44	18.79	9.51	50.63
Abohar	17.6	1.6	8.9	18.48	9.87	53.42	18.77	9.87	52.62	18.45	9.89	53.63	18.99	9.85	51.91
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	22.4	0.5	2.4	26.25	3.46	13.17	26.59	3.38	12.70	26.36	3.39	12.87	26.82	3.40	12.66
Zone III : Central plain region															
Ludhiana	23.3	0.9	4.0	26.30	3.44	13.09	26.65	3.35	12.59	26.41	3.38	12.81	26.84	3.39	12.64
Amritsar	22.5	0.8	3.7	25.58	3.27	12.78	26.00	3.22	12.40	25.74	3.25	12.65	26.22	3.20	12.20
Patiala	23.9	0.6	2.3	26.27	3.33	12.67	26.55	3.26	12.28	26.32	3.29	12.50	26.75	3.27	12.21
Zone IV : Western plain region															
Bathinda	23.9	0.7	3.1	26.40	3.45	13.08	26.70	3.43	12.85	26.37	3.50	13.26	26.91	3.39	12.62
Zone V : Western region															
Faridkot	26.7	1.7	6.4	26.20	3.48	13.27	26.53	3.46	13.03	26.22	3.51	13.40	26.79	3.41	12.75
Abohar	24.0	1.7	7.0	26.80	3.67	13.69	27.09	3.65	13.48	26.77	3.71	13.84	27.31	3.61	13.23
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	10.0	0.8	8.0	10.41	6.29	60.45	10.72	6.25	58.34	10.38	6.25	60.19	10.97	6.23	56.95
Zone III : Central plain region															
Ludhiana	10.0	0.9	8.9	10.48	6.27	59.86	10.80	6.23	57.70	10.47	6.23	59.52	11.03	6.22	56.51
Amritsar	8.4	0.7	8.5	9.43	6.29	66.77	9.78	6.29	64.35	9.50	6.29	66.26	9.99	6.25	62.69
Patiala	11.1	0.6	5.1	11.43	6.16	53.94	11.70	6.10	52.15	11.36	6.06	53.41	11.94	6.10	51.19
Zone IV : Western plain region															
Bathinda	9.9	0.8	8.2	10.07	6.26	62.23	10.36	6.25	60.41	10.00	6.27	62.74	10.56	6.21	58.96
Zone V : Western region															
Faridkot	13.7	2.2	16.2	10.01	6.25	62.47	10.32	6.24	60.50	9.98	6.25	62.69	10.58	6.19	58.67
Abohar	11.0	1.7	15.6	9.92	6.34	63.92	10.21	6.33	62.04	9.88	6.34	64.21	10.44	6.28	60.27

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

Table 4. Annual and seasonal variations in minimum temperature during end-century (2066-2095) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Mean (ºC)	S.D. (ºC)	C.V. (%)	Mean (ºC)	S.D. (ºC)	C.V. (%)	Mean (ºC)	S.D. (ºC)	C.V. (%)	Mean (ºC)	S.D. (ºC)	C.V. (%)	Mean (ºC)	S.D. (ºC)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
BallowalSaunkhri	16.2	0.5	3.7	18.67	9.36	50.13	19.82	9.24	46.59	20.00	9.22	46.12	21.91	8.99	41.08
Zone III : Central plain region															
Ludhiana	16.7	0.9	5.2	18.72	9.34	49.89	19.89	9.21	46.30	20.08	9.20	45.82	21.98	8.96	40.80
Amritsar	15.5	0.7	4.6	17.82	9.50	53.30	19.01	9.38	49.34	19.25	9.37	48.70	21.13	9.16	43.39
Patiala	17.6	0.5	2.8	19.16	8.89	46.38	20.29	8.75	43.12	20.50	8.71	42.48	22.40	8.48	37.90
Zone IV : Western plain region															
Bathinda	16.9	0.6	3.8	18.56	9.58	51.62	19.73	9.47	47.99	19.85	9.44	47.57	21.83	9.20	42.18
Zone V : Western region															
Faridkot	20.3	2.0	9.8	18.43	9.52	51.69	19.60	9.42	48.08	19.75	9.39	47.53	21.78	9.15	42.06
Abohar	17.6	1.6	8.9	18.68	9.89	52.92	19.88	9.78	49.19	20.04	9.73	48.58	22.01	9.49	43.16
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	22.4	0.5	2.4	26.45	3.43	12.97	27.52	3.33	12.09	27.72	3.29	11.87	29.44	3.09	10.50
Zone III : Central plain region															
Ludhiana	23.3	0.9	4.0	26.50	3.41	12.86	27.56	3.32	12.05	27.78	3.28	11.80	29.49	3.09	10.48
Amritsar	22.5	0.8	3.7	25.83	3.23	12.50	26.93	3.17	11.75	27.18	3.13	11.51	28.91	2.92	10.12
Patiala	23.9	0.6	2.3	26.47	3.31	12.49	27.50	3.20	11.63	27.69	3.18	11.50	29.41	2.98	10.13
Zone IV : Western plain region															
Bathinda	23.9	0.7	3.1	26.62	3.43	12.88	27.67	3.41	12.34	27.80	3.34	12.00	29.60	3.11	10.51
Zone V : Western region															
Faridkot	26.7	1.7	6.4	26.42	3.46	13.08	27.53	3.35	12.18	27.65	3.36	12.15	29.50	3.11	10.55
Abohar	24.0	1.7	7.0	27.01	3.65	13.52	28.15	3.55	12.60	28.27	3.53	12.51	30.08	3.26	10.84
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	10.0	0.8	8.0	10.60	6.27	59.16	11.84	6.16	52.05	12.05	6.14	51.03	14.13	6.00	42.57
Zone III : Central plain region															
Ludhiana	10.0	0.9	8.9	10.66	6.24	58.52	11.93	6.14	51.47	12.15	6.12	50.42	14.22	5.97	42.06
Amritsar	8.4	0.7	8.5	9.61	6.28	65.32	10.88	6.17	56.70	11.13	6.16	55.42	13.13	5.98	45.67
Patiala	11.1	0.6	5.1	11.60	6.14	52.88	12.85	6.03	46.92	13.07	5.98	45.74	15.17	5.84	38.58
Zone IV : Western plain region															
Bathinda	9.9	0.8	8.2	10.26	6.26	61.08	11.51	6.20	53.86	11.65	6.14	52.78	13.80	6.00	43.60
Zone V : Western region															
Faridkot	13.7	2.2	16.2	10.19	6.25	61.33	11.42	6.14	53.74	11.62	6.13	52.81	13.80	5.97	43.35
Abohar	11.0	1.7	15.6	10.09	6.35	62.93	11.36	6.23	54.86	11.56	6.22	53.80	13.70	6.04	44.25

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

Table 5. Annual and seasonal variations in rainfall during mid-century (2020-2049) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
BallowalSaunkhri	1049.0	292.2	27.9	463.2	5.0	394.5	487.0	5.1	384.5	455.1	4.9	396.9	523.7	5.8	401.7
Zone III : Central plain region															
Ludhiana	759.0	232.4	30.6	568.4	6.2	396.7	572.4	6.3	401.1	551.7	6.1	403.4	608.8	6.8	408.3
Amritsar	722.0	198.0	27.4	650.3	6.3	355.6	691.1	6.7	354.4	708.5	6.8	351.8	711.1	7.0	357.2
Patiala	774.0	286.2	37.0	543.8	5.3	354.8	590.2	5.7	354.4	539.9	5.5	370.6	614.6	6.0	353.7
Zone IV : Western plain region															
Bathinda	517.0	181.2	35.0	392.7	4.0	374.7	386.3	4.0	374.4	419.0	4.0	352.0	392.8	4.0	373.4
Zone V : Western region															
Faridkot	468.0	169.8	36.3	410.2	4.0	359.5	431.0	4.1	347.9	389.9	3.9	366.4	439.8	4.3	356.7
Abohar	323.0	103.5	32.1	357.9	3.5	356.7	332.7	3.3	366.9	339.4	3.3	359.6	346.2	3.5	364.2
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	888	279.9	31.5	399.3	6.6	305.7	424.1	6.8	297.0	404.8	6.7	303.9	463.5	7.8	309.3
Zone III : Central plain region															
Ludhiana	634	237.8	37.5	497.4	8.3	307.2	510.8	8.5	307.2	505.6	8.3	302.1	541.1	9.1	309.5
Amritsar	579	192.2	33.2	595.4	8.6	264.4	632.0	9.1	264.2	631.2	9.1	265.5	646.4	9.4	267.6
Patiala	649	277.9	42.8	483.6	7.1	269.9	541.8	7.8	263.4	482.0	7.3	279.7	545.4	7.9	268.0
Zone IV : Western plain region															
Bathinda	427	178.4	42.0	371.1	5.5	272.4	348.8	5.3	280.9	369.3	5.4	268.8	357.8	5.4	278.3
Zone V : Western region															
Faridkot	382	134.3	35.1	350.5	5.3	279.4	355.2	5.3	274.8	343.6	5.2	279.6	360.6	5.4	276.4
Abohar	262	95.0	36.3	289.3	4.4	278.4	290.2	4.4	281.0	288.7	4.4	277.9	298.9	4.6	283.0
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	159	85.3	53.6	63.4	1.9	530.8	62.1	1.8	534.5	50.4	1.5	517.8	59.7	1.7	512.5
Zone III : Central plain region															
Ludhiana	126	66.5	52.9	72.4	2.1	495.4	62.0	1.8	513.5	46.5	1.4	570.0	67.1	2.3	584.0
Amritsar	144	78.5	54.3	54.3	1.4	483.5	58.5	1.5	474.6	77.6	2.3	527.2	64.7	1.6	444.0
Patiala	125	85.7	68.8	60.1	1.6	478.1	48.1	1.3	477.1	58.1	1.9	585.4	69.3	2.0	532.5
Zone IV : Western plain region															
Bathinda	90	50.9	56.5	21.3	0.6	492.7	37.4	1.2	559.2	49.7	1.4	487.8	34.5	1.1	550.7
Zone V : Western region															
Faridkot	87	69.0	78.9	60.3	1.6	482.5	75.0	2.0	496.1	46.3	1.3	507.4	78.8	2.5	561.2
Abohar	68	50.7	75.1	68.2	2.1	554.2	42.8	1.3	536.3	50.8	1.5	526.8	47.0	1.3	500.0

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

Table 6. Annual and seasonal variations in rainfall during end-century (2066-2095) as simulated by Ensemble model in Punjab

Season and location	Baseline period			RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)	Total (mm)	S.D. (mm)	C.V. (%)
Annual variations															
Zone II : Undulating plain region															
BallowalSaunkhri	1049.0	292.2	27.9	487.8	5.1	380.3	603.4	6.7	406.4	585.9	6.4	395.8	491.0	5.1	381.7
Zone III : Central plain region															
Ludhiana	759.0	232.4	30.6	593.5	6.8	420.1	642.3	7.0	400.1	803.6	7.7	350.5	650.3	6.5	363.0
Amritsar	722.0	198.0	27.4	647.7	6.1	343.7	688.6	7.7	406.7	757.0	7.9	381.9	735.4	6.9	343.8
Patiala	774.0	286.2	37.0	545.6	5.4	364.1	688.1	6.9	365.1	697.2	6.9	359.0	598.0	6.0	365.1
Zone IV : Western plain region															
Bathinda	517.0	181.2	35.0	388.5	4.0	371.5	418.9	4.1	357.3	478.7	4.9	370.2	433.8	4.3	362.9
Zone V : Western region															
Faridkot	468.0	169.8	36.3	419.3	4.1	353.4	407.2	4.1	365.2	438.1	4.5	375.9	455.4	4.7	379.5
Abohar	323.0	103.5	32.1	338.1	3.3	360.5	375.3	3.8	372.0	379.0	3.9	374.8	366.0	3.7	372.6
***Kharif* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	888	279.9	31.5	432.4	6.8	291.3	549.1	9.1	306.7	538.9	8.6	293.8	461.5	7.0	278.4
Zone III : Central plain region															
Ludhiana	634	237.8	37.5	520.9	9.2	326.3	589.4	9.6	300.3	718.4	10.3	263.4	594.1	8.7	268.8
Amritsar	579	192.2	33.2	588.1	8.2	256.9	634.4	10.5	303.8	700.1	10.8	283.3	681.4	9.4	252.7
Patiala	649	277.9	42.8	483.3	7.3	276.3	626.3	9.3	273.3	637.3	9.2	266.6	547.0	8.1	270.8
Zone IV : Western plain region															
Bathinda	427	178.4	42.0	353.6	5.3	277.6	373.3	5.5	270.3	427.2	6.5	280.0	394.8	5.8	268.8
Zone V : Western region															
Faridkot	382	134.3	35.1	357.1	5.3	273.8	356.9	5.4	280.5	386.4	6.0	286.6	414.9	6.4	284.0
Abohar	262	95.0	36.3	291.5	4.4	278.9	328.8	5.1	287.1	334.0	5.2	285.0	341.3	5.1	273.4
***Rabi* season variation**															
Zone II : Undulating plain region															
BallowalSaunkhri	159	85.3	53.6	54.9	1.4	480.9	54.9	1.5	483.6	46.7	1.4	542.8	29.2	0.9	586.5
Zone III : Central plain region															
Ludhiana	126	66.5	52.9	72.5	2.1	532.5	52.8	1.3	470.7	85.2	2.7	565.0	56.2	1.8	582.3
Amritsar	144	78.5	54.3	58.9	1.6	482.3	54.4	1.5	515.9	57.2	1.5	474.6	53.6	1.5	495.1
Patiala	125	85.7	68.8	62.2	1.9	554.5	62.1	1.7	501.8	59.9	1.8	544.2	51.8	1.6	560.1
Zone IV : Western plain region															
Bathinda	90	50.9	56.5	35.4	1.0	516.8	46.2	1.3	497.1	51.3	1.5	525.3	39.2	1.3	599.3
Zone V : Western region															
Faridkot	87	69.0	78.9	61.0	1.7	500.0	51.0	1.4	488.5	51.7	1.6	542.7	40.5	1.2	554.7
Abohar	68	50.7	75.1	46.6	1.3	522.9	46.7	1.3	483.9	44.6	1.4	574.9	24.7	0.7	541.8

**Baseline period: Ballowal Saunkhri (1984-2015), Ludhiana, Amritsar, Patiala (1970-2015), Bathinda (1977-2015), Faridkot: (2000-2015), Abohar: (2004-2015)

temperature beyond 2°C reported by Kingra *et al.* (2019).

Agro-climatic zone IV–Western plain region

This zone covers about 19% of the land area of the state. In this zone the maximum temperature on annual, *kharif* and *rabi* season basis is projected to increase from baseline period by 0.02-0.4, 0.1-0.4 and 0.2-0.4°C, respectively during mid-century (Table 1) and by 0.3-3.6, 0.3-3.2 and 0.5-4.0°C, respectively during end-century (Table 2) under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. Similarly, under the four RCP scenarios the minimum temperature on annual, *kharif* and *rabi* season may increase from baseline period by 1.4-1.9, 2.5-3.0 and 0.1-1.6°C, respectively during mid-century (Table 3) and by 1.6-4.9, 2.7-5.7 and 0.3-3.9°C, respectively during end-century (Table 4). This is the semi-arid region of the state and the annual rainfall is about 517mm. During the four scenarios, the annual rainfall is projected to decrease by 125-135 mm during mid century by 75-125 mm during the end century (Table 5 and 6). The *rabi* season rainfall which presently is 90 mm projected to decrease by 50-69 mm during the mid century and by 39-60 mm by the end century in this zone.

The standard deviation and coefficient of variation are estimated to be high for both the temperature and rainfall during the mid and end of 21st century. Cotton, rice and wheat are the main crops grown in this zone and hence the heat wave, extended dry spells and extreme rainfall events projected by the model may have adverse effects on the cereal and fibre production in the state reported by Kumar *et al.* (2004). Khan *et al.* (2009) estimated that mean temperature in India is projected to increase by 0.4-2.0°C during *kharif* and 1.1-4.5°C in *rabi* by 2070. Similarly, mean rainfall is projected to increase by up to 10 per cent during *kharif* and *rabi* by 2070. At the same time, there is an increased possibility of climate extremes, such as timing of onset of monsoon, intensities and frequencies of drought and floods. Many studies indicate a probability of 10-40% loss in Indian food grain production because of increase in temperature by 2080–2100 (IPCC, 2007; Fischer *et al.,* 2002).

Agro-climatic zone V - Western region:

The zone V represents about 20% of the land area of Punjab and the maximum temperature on an annual, *kharif* and *rabi* season basis is predicted to increase from baseline period by 0.4-1.0, 0.2-0.7 and 0.5-1.5°C, respectively during mid-century (Table 1) and by 0.7-4.0, 0.4-3.5 and 0.8-5.2°C, respectively during end-century (Table 2) under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. The minimum temperature at the two stations analyzed in this zone revealed an increase in annual and *kharif* season minimum temperature from the baseline at Abohar but a decrease from baseline temperature at Faridkot during the mid century (Table 3). However, during the end century time period,the minimum temperature at Faridkot is predicted to decrease under only under first three scenarios, i.e., RCP 2.6, RCP 4.5 and RCP 6.0 (Table 4).

This zone is the arid region of the state and the annual rainfall during the baseline period is only 325-460 mm. The annual and *kharif* season rainfall at Aboharis projected to increase during mid as well as end-century (Table 5 and 6) under the four scenarios. However, during the *rabi* season, the rainfall is projected to decrease in this zone. Like the other three zones under study, the standard deviation and coefficient of variation are estimated to be high for both the temperature and rainfall during the mid and end of the 21st century. Since this is the driest and arid zone in the state and so the dry spells may require good contingency planning for sustaining the crop production in this region. Prasad *et al.* (2008) reported that high night time temperature adversely affected the phenology of wheat. Although the effect was non-significant upto flag leaf emergence, but high temperature at anthesis and seed setting lead to reduction in period to attain physiological maturity by 10 days and induced spikelet sterility by 26%. Prasad *et al.* (2018) observed decrease in wheat productivity by 9.4 to 33.1% with increase in temperature from 1 to 3°C. Sandhu *et al.* (2019) reported that the seasonal increase (normal + 3.0°C) in temperature may result in reduction in productivity of wheat sown at any time, except in case of late sown wheat at Palampur (northern hill zone) and

Ludhiana (north western plain zone). The decrease in temperature may result in a reduction in productivity of early, timely and late sown wheat at Palampur and at Kanpur. While at Ludhiana productivity of timely and late sown wheat and at Udaipur that of late sown wheat was reduced.

Conclusion

The global climate is altering and agriculture will have to adjust to certify sustainability and survival. Due to the complexity of both agricultural systems and climate change, climate models are often used to understand the impact of climate change on agriculture and to assist in the development of adaptation strategies. The Ensemble model output revealed that in Punjab state the maximum and minimum temperature are projected to increase by 0.4-1.4°C and 1.3-2.8°C, respectively during the mid century and by 1.2-4.4°C and 1.5-5.7°C, respectively during the end century. Hence the increase in minimum temperature is simulated to be more than that in maximum temperature. So the diurnal range of temperature may decrease which is not favourable for good crop production. In the present time scale, the agro-climatic zone II is the wettest zone of the state with annual rainfall of more than 1000mm and during the 21st century it is projected to decrease by more than 45%. However, in the present time scale arid zone (agro-climatic zone V) with annual rainfall 300-400 mm, the rainfall is projected to increase by 30-40 mm. The projected changes in temperature and rainfall may increase the frequency of incidence of extreme weather like dry and wet spells, heat wave etc. The state of Punjab is primarily agrarian and it contributes significantly to the rice and wheat reserve food pool of the country. So to maintain the sustainability of crop production in the state good crop contingency planning would be needed.

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