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Projected changes in temperature and rainfall during 21st century simulated by CSIRO-Mk-3-6-0 model under RCP based scenarios in Punjab

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सार – पंजाब राज्य में 21वीं सदी के दौरान जलवायु मानकों में अनुमानित परिवर्तनों का आकलन करने के लिए एक अध्ययन किया गया। सीएसआईआरओ-एमके 3-6-0 मॉडल सिम्युलेटेड डेटा को चार आरसीपी परिदृश्यों के तहत सात स्थानों के लिए वेबसाइट http://gismap.ciat.cgiar.org/MarkSimGCM/ से डाउनस्केल किया गया। भविष्य की दो अवधियों, यानी मध्य शताब्दी (एमसीः 2020-2049) और शताब्दी के अंत (ईसीः 2066-2095) का मूल्यांकन वार्षिक और ऋतुनिष्ठ (खरीफ और रबी) आधार पर किया गया। शताब्दी की मध्य अवधि के दौरान वार्षिक,खरीफ और रबी मौसम के अधिकतम तापमान में आधारभूत अवधि से क्रमशः 0 से 1.5 °C, 0.3 से 1.5 °C और 0 से 1.6 °C के बीच बढ़ने का अनुमान है; न्यूनतम तापमान क्रमशः 1.1 से 3.1 °C, 0.1 से 4.8 °C और 0.3 से 1.8 °C के बीच बढ़ेगा, लेकिन आधार रेखा की अवधि से वर्षा क्रमशः 33 से 554 मिमी, 20 से 443 मिमी और 20 से 110 मिमी के बीच घटेगी। शताब्दी के अंत के दौरान वार्षिक,खरीफ और रबी मौसम के अधिकतम तापमान में आधारभूत अवधि से क्रमशः 0.8 से 4.4 °C, 0.8 से 4.3 °C और 0.6 से 4.9 °C के बीच बढ़ने का अनुमान है; न्यूनतम तापमान में क्रमशः 0.4 से 6.6 °C, 0.5 से 6.3 °C और 0.0 से 5.5 °C के बीच वृद्धि होगी, लेकिन वर्षा आधार रेखा की अवधि से क्रमशः 3 से 610 मिमी, 14 से 506 मिमी और 17 से 107 मिमी के बीच घटेगी। अबोहर (11-41 मिमी) में बारिश बढ़ने का अनुमान किया गया था, जबकि अमृतसर (49-128 मिमी), बलोवाल सौंखरी (501-554 मिमी), लुधियाना (131-152 मिमी), पटियाला (148-187), बठिंडा (49-82 मिमी) और फरीदकोट (33-67 मिमी) में गिरावट आ सकती है।

ABSTRACT. A study was conducted to assess the projected changes in climatic parameters during 21st century in Punjab state. The CSIRO-Mk 3-6-0 model simulated data was downscaled from the website http://gismap.ciat.cgiar.org/MarkSimGCM/ for seven locations under four RCP scenarios. The two future periods, *i.e*., mid-century (MC: 2020-2049) and end-century (EC: 2066-2095) were assessed on annual and seasonal (*kharif* and *rabi*) basis. During mid-century the annual, *kharif* and *rabi* seasons maximum temperature is projected to increase from baseline period between 0 to 1.5 °C, 0.3 to 1.5 °C and 0 to 1.6 °C, respectively; minimum temperature to increase from baseline period between 1.1 to 3.1 °C, 0.1 to 4.8 °C and 0.3 to 1.8 °C, respectively but the rainfall to decrease from baseline period between 33 to 554 mm, 20 to 443 mm and 20 to 110 mm, respectively. During the end-century the annual, *kharif* and *rabi* seasons maximum temperature is projected to increase from baseline period between 0.8 to 4.4°C, 0.8 to 4.3 °C and 0.6 to 4.9 °C, respectively; minimum temperature to increase from baseline period between 0.4 to 6.6 °C, 0.5 to 6.3 °C and 0.0 to 5.5 °C, respectively but the rainfall to decrease from baseline period between 3 to 610 mm, 14 to 506 mm and 17 to 107 mm, respectively. Rainfall was projected to increase at Abohar (11-41 mm) while it may decline at Amritsar (49-128 mm), Ballowal Saunkhri (501-554 mm), Ludhiana (131-152 mm), Patiala (148-187), Bathinda (49-82 mm) and Faridkot (33-67 mm).

Key words – CSIRO-Mk 3-6-0 model, Temperature, Rainfall, RCP scenario, Punjab.

1. Introduction

Climate change is occurring at a fast pace in recent times and footprints of these changes are becoming visible globally. Though it has been an age old phenomenon but recently due to unprecedented increase in the concentration of greenhouse gases (GHGs) in the atmosphere caused by anthropogenic activities it has gained momentum during 20th century (Khan *et al*., 2009). Climate change has impacted almost all parts of the world, but the Asian continent is considered to be the most vulnerable region to shocks of climate change and climate

TABLE 1

Statistics of temperature and rainfall data simulated by CSIRO-Mk 3-6-0 model before and after bias removal

Statistical parameter	Observed parameter (2016-17)	Uncorrected parameter (2016-17)	Corrected parameter (2016-17)
Maximum temperature (°C)			
Average	30.37	32.94	29.90
SD	7.10	7.93	7.56
C.V. (%)	50.48	62.82	57.09
RMSE (%)	-	4.57	3.70
NRMSE (%)	-	15.04	12.17
Minimum temperature (°C)			
Average	18.33	18.37	17.88
SD	7.88	9.52	8.18
C.V. (%)	62.17	90.72	66.92
RMSE (%)	-	3.71	3.28
NRMSE (%)	-	20.23	17.92
Rainfall (mm/day)			
Average	1.50	18.20	1.60
SD	4.81	7.67	6.41
C.V. (%)	23.13	58.79	41.10
RMSE (%)	-	7.28	7.95
NRMSE (%)	-	47.61	1.46

variability due to various stresses and low adaptive capacity (IPCC : 2013; FAO, 2006). The impacts of climate change on hydrology are evaluated on the basis of climate change projections provided by global (GCM) and regional climate models (RCMs). General circulation models provide large-scale projections for various climate variables (IPCC, 2013). With a variety of numerical formulations and physical parameterization schemes, GCM's provide a range of climate change projections, implying that the uncertainty of the models themselves contributes to overall uncertainty when assessing climate change impacts (Chen *et al*., 2017).

According to IPCC (2014) the downscaled data for temperature and rainfall for the period (1860-2099) based on the multi-model and multi-scenario are now available. In India, during the past few years, several high resolution RCMs have been used by different research groups at a regional scale in climate change analysis. Chaturvedi *et al.* (2012) using the CMIP5 climate projections for India observed great ambiguity in precipitation projections, however, temperature is probably going to increase by 3-4 °C under the RCP 8.5 scenario by the end of 21st century.

A study conducted in Punjab by Prabhjyot-Kaur *et al*. *(*2017) has shown that by the end of 21st century rise in the maximum and minimum temperature and rainfall ranged between 2.0 to 2.2 °C, 3.3 to 5.4 °C and 33 to 66% respectively under different scenarios of climate change in agro-climatic zone II (Ballowal Saunkhri); whereas in agro-climatic zone III (Ludhiana, Amritsar, Patiala and Jalandhar) the values were 0.4 to 5.8 °C, 2.5 to 7.4 °C and 3 to 62% respectively, while and in agro-climatic zone V (Bathinda) the values were 0.5 to 4.0 °C, 4.7 to 7.7 °C and 58 to 69% respectively. Dar *et al.* (2019) used a Global Climate Model HAD GEM2-ES under RCPs 4.5 and 8.5 for climate prediction at Ludhiana in Punjab. This study spanned 46 years of baseline (1970-2015) as well as two future periods, *i.e*., mid-century (2020-2050) and end-century (2060-2090). The outcomes showed that the temperature would increase by 1.56 °C and precipitation would decline by 98 mm in mid-century (2020-2050); and 3.11 °C and 90 mm in end-century (2060-2090),

respectively under RCP 4.5. In RCP 8.5 the increase in temperature and precipitation was 2.75 °C and 153 mm, respectively in mid-century and the corresponding values in end-century were 5.46 °C and 251 mm, respectively.

Currently, several GCMs are available which can be downscaled to the respective grids and ready-to-use information can be accessed on climate change under different RCP scenarios during the near future and end of the 21st century.

Keeping these different scenarios in mind, the results of the general circulation model (CSIRO-Mk 3-6-0) have been presented in our paper under different scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 for the near future and end of 21st century. Such information will guide scientists in planning future research and help policy makers while planning for futuristic agriculture.

2. Materials and method

The study was carried out for Ballowal Saunkhri (30° 07′ N 76° 23′ E 355 a.m.s.l.), Amritsar (31° 37′ N, 74° 53′ E 231 a.m.s.l.), Abohar (30° 58′ N, 74° 36′ E 177 a.m.s.l.), Faridkot (30° 40′ N, 74° 45′ E 204 a.m.s.l.), Jalandhar (31° 19′ N 75° 34′ E 238 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.) and Bathinda (30° 12′ N, 74° 57′ E 211 a.m.s.l.) locations in Punjab state. Data for meteorological parameters like maximum temperature (*T*max), minimum temperature (*T*min) and rainfall (RF) on daily basis was downscaled from General circulation model (CSIRO-Mk3-6-0) available at the website http://gismap.ciat.cgiar. org/MarkSimGCM/ for these locations. The daily weather data for the past 8 years on temperature and rainfall recorded at the agro meteorological observatory was used for calibration (2010-2015) and validation (2016-2017) of the baseline data by developing correction factors using difference method given as under :

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

X_{model} = Model data

$X_{\text{modeluncorr}}$ = Uncorrected model data

X_{obs} = Observed data

The statistical analysis of the model simulated data before and after bias removal along with actual observed data are given in Table 1. The bias correction in the modeled data was done at monthly scale for *T*max and RF, while *T*min data was used without any bias removal. The analysis of the daily data was done on annual and seasonal (*kharif* : May-October and *rabi* : November-April) basis for temperature and rainfall. The statistical analysis of the projected data during the near (2020-2049) and end (2066-2095) of 21st century under four Representative Concentration Pathway (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) scenarios was compared with the climatic normal. The climatic normal were worked from actual available records), *i.e*., 1970-2015 for Ludhiana, Amritsar and Patiala; 1984-2015 for Ballowal Saunkhri; 1977-2015 for Bathinda; 2000-2015 for Faridkot and 2004-2015 for Abohar.

3. Results and discussion

3.1. *Maximum temperature under different RCPs scenarios*

The annual, *kharif* and *rabi* maximum temperature (*T*max) at different locations of Punjab during the baseline period, mid and end 21st century have been presented in Tables 2 and 3. During the mid-century (Table 2), the *T*max is predicted to increase for annual, *kharif* and *rabi*, respectively from baseline period in the range from 1.1 to 1.5 °C, 1.1 to 1.5 °C and 0.9 to 1.4 °C at Ballowal Saunkhri; 0.4 to 1.0 °C, 0.6 to 1.2 °C and 0.2 to 0.7 °C at Amritsar; 0.5 to 1.0 °C, 0.5 to 0.9 °C and 0.6 to 1.0 °C at Ludhiana; 0.9 to 1.0°C, 0.9 to 1.3°C and 0.8 to 1.3°C at Patiala; 0 to 0.5 °C, 0.1 to 0.6 °C and 0 to 0.4 °C at Bathinda; 0.4 to 0.9 °C, 0.3 to 0.8 °C and 0.5 to 1.0 °C at Abohar; 0.6 to 1.1 °C, 0.2 to 0.7 °C and 1.1 to 1.6 °C at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) are respectively, ranged from 6.79 to 6.83 °C and 21.61 to 21.92%, 3.55 to 3.64 °C and 10.0 to 10.13% and 6.29 to 6.35 °C and 23.41 to 23.97% at Ballowal Saunkhri; 7.75 to 7.78 °C and 24.88 to 25.27%, 4.07 to 4.08 °C and 11.07 to 11.27% and 6.64 to 6.69 °C and 25.81 to 26.55% at Amritsar; 7.43 to 7.48 °C and 24.19 to 24.56%, 3.71 to 3.79 °C and 10.45 to 10.60% and 6.74 to 6.79 °C and 26.32 to 26.97% at Ludhiana; 7.20 to 7.26 °C and 22.84 to 23.24%, 3.67 to 3.71 °C and 10.14 to 10.28% and 6.70 to 6.76 °C and 25.81 to 25.83% at Patiala; 7.86 to 7.89 °C and 24.72 to 25.21%, 3.92 to 3.93 °C and 10.55 to 10.63% and 6.91 to 6.98 °C and 26.40 to 26.95% at Bathinda; 7.55 to 7.59 °C and 24.29 to 24.69%, 3.65 to 3.73 °C and 10.12 to 10.31% and 6.47 to 6.52 °C and 25.30 to 25.99% at Abohar; 7.11 to 7.14 °C and 22.93 to 23.35%, 3.44 to 3.48 °C and 9.62 to 9.79% and 6.59 to 6.62 °C and 25.26 to 25.83% at Faridkot, respectively.

During the end-century (Table 3), at different locations of Punjab under study, the Tmax is predicted to increase for three seasons respectively, from baseline

TABLE 2

Annual and seasonal variations in maximum temperature (°C) at different locations during mid-century (2020-2049) as simulated by CSIRO-Mk 3-6-0 model

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															
Ballowal Saunkhri	30.0	0.7	2.4	31.2 (+1.2)	6.83	21.92	31.4 (+1.4)	6.79	21.61	31.1 (+1.1)	6.82	21.97	31.5 (+1.5)	6.81	21.63
Amritsar	30.3	0.6	1.9	30.9 (+0.6)	7.79	25.19	31.2 (+0.9)	7.75	24.88	30.7 (+0.4)	7.77	25.27	31.3 (+1.0)	7.78	24.90
Ludhiana	29.8	0.5	1.8	30.5 (+0.7)	7.48	24.55	30.7 (+0.9)	7.43	24.19	30.3 (+0.5)	7.45	24.56	30.8 (+1.0)	7.46	24.22
Patiala	30.2	0.6	1.9	31.2 (+1)	7.26	23.23	31.5 (+1.3)	7.20	22.85	31.1 (+0.9)	7.23	23.24	31.6 (+1.4)	7.21	22.84
Bathinda	31.3	0.7	2.3	31.5 (+0.2)	7.89	25.09	31.7 (+0.4)	7.87	24.82	31.3 (0)	7.89	25.21	31.8 (+0.5)	7.86	24.72
Abohar	30.2	0.8	2.8	30.8 (+0.6)	7.59	24.65	31.0 (+0.8)	7.55	24.34	30.6 (+0.4)	7.56	24.69	31.1 (+0.9)	7.56	24.29
Faridkot	29.9	0.6	2.1	30.7 (+0.8)	7.14	23.27	30.9 (+1.0)	7.11	22.97	30.5 (+0.6)	7.13	23.35	31.0 (+1.1)	7.11	22.93
Kharif															
Ballowal Saunkhri	34.4	0.8	2.4	35.6 (+1.2)	3.60	10.11	35.9 (+1.5)	3.59	10.02	35.5 (+1.1)	3.55	10.00	35.9 (+1.5)	3.64	10.13
Amritsar	35.6	0.7	1.9	36.4 (+0.8)	4.08	11.22	36.6 (+1.0)	4.08	11.15	36.2 (+0.6)	4.08	11.27	36.8 (+1.2)	4.07	11.07
Ludhiana	34.9	0.6	1.7	35.5 (+0.6)	3.76	10.60	35.8 (+0.9)	3.74	10.45	35.4 (+0.5)	3.71	10.48	35.8 (+0.9)	3.79	10.58
Patiala	35.0	0.6	1.8	36.1 (+1.1)	3.71	10.28	36.3 (+1.3)	3.68	10.14	35.9 (+0.9)	3.67	10.22	36.3 (+1.3)	3.71	10.20
Bathinda	36.7	1.0	2.7	37.0 (+0.3)	3.93	10.63	37.2 (+0.5)	3.94	10.60	36.8 (+0.1)	3.92	10.66	37.3 (+0.6)	3.93	10.55
Abohar	35.7	0.5	1.4	36.2 (+0.5)	3.73	10.31	36.4 (+0.7)	3.69	10.12	36.0 (+0.3)	3.65	10.13	36.5 (+0.8)	3.71	10.15
Faridkot	35.1	0.8	2.3	35.5 (+0.4)	3.48	9.79	35.7 (+0.6)	3.46	9.70	35.3 (+0.2)	3.46	9.79	35.8 (+0.7)	3.44	9.62
Rabi															
Ballowal Saunkhri	25.6	0.9	3.6	26.6 (+1.0)	6.34	23.83	26.9 (+1.3)	6.29	23.41	26.5 (+0.9)	6.35	23.97	27.0 (+1.4)	6.31	23.41
Amritsar	24.9	0.8	3.4	25.3 (+0.4)	6.64	26.27	25.6 (+0.7)	6.69	26.10	25.1 (+0.2)	6.67	26.55	25.6 (+0.7)	6.61	25.81
Ludhiana	24.6	0.8	3.1	25.3 (+0.7)	6.79	26.86	25.6 (+1.0)	6.74	26.36	25.2 (+0.6)	6.79	26.97	25.6 (+1.0)	6.75	26.32
Patiala	25.4	0.9	3.4	26.3 (+0.9)	6.76	25.74	26.6 (+1.2)	6.70	25.21	26.2 (+0.8)	6.76	25.83	26.7 (+1.3)	6.72	25.23
Bathinda	25.8	0.9	3.7	25.8 (+0)	6.96	26.95	26.1 (+0.3)	6.93	26.55	25.7 (-0.1)	6.98	27.20	26.2 (+0.4)	6.91	26.40
Abohar	24.6	1.4	5.5	25.2 (+0.6)	6.51	25.81	25.5 (+0.9)	6.50	25.47	25.1 (+0.5)	6.52	25.99	25.6 (+1.0)	6.47	25.30
Faridkot	24.5	0.9	3.7	25.7 (+1.2)	6.61	25.68	26.0 +(1.5)	6.59	25.31	25.6 (+1.1)	6.62	25.83	26.1 (+1.6)	6.59	25.26

* Figures in the parenthesis denote deviation from the baseline value

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

TABLE 3

Annual and seasonal variations in maximum temperature (°C) at different locations during end-century (2066-2095) as simulated by CSIRO-Mk 3-6-0 model

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															
Ballowal Saunkhri	30.0	0.7	2.4	31.8 (+1.8)	6.72	21.16	33.0 (+3.0)	6.57	19.89	32.8 (+2.8)	6.60	20.10	34.4 (+4.4)	6.54	18.99
Amritsar	30.3	0.6	1.9	31.5 (+1.2)	7.65	24.28	32.8 (+2.5)	7.53	23.00	32.6 (+2.3)	7.56	23.19	34.3 (+4.0)	7.48	21.82
Ludhiana	29.8	0.5	1.8	31.0 (+1.2)	7.36	23.72	32.3 (+2.5)	7.21	22.31	32.1 (+2.3)	7.24	22.55	33.7 (+3.9)	7.21	21.38
Patiala	30.2	0.6	1.9	31.8 (+1.6)	7.10	22.33	33.1 (+2.9)	7.02	21.23	32.9 (+2.7)	7.05	21.45	34.4 (+4.2)	6.97	20.27
Bathinda	31.3	0.7	2.3	32.1 (+0.8)	7.78	24.25	33.4 (+2.1)	7.61	22.82	33.2 (+1.9)	7.65	23.07	34.8 (+3.5)	7.52	21.63
Abohar	30.2	0.8	2.8	31.4 (+1.2)	7.49	23.84	32.7 (+2.5)	7.30	22.33	32.5 (+2.3)	7.34	22.60	34.2 (+4.0)	7.25	21.20
Faridkot	29.9	0.6	2.1	31.3 (+1.4)	7.03	22.46	32.6 (+2.7)	6.87	21.08	32.4 (+2.5)	6.91	21.34	34.0 (+4.1)	6.76	19.88
Kharif															
Ballowal Saunkhri	34.4	0.8	2.4	36.2 (+1.8)	3.50	9.67	37.3 (+2.9)	3.53	9.46	37.1 (+2.7)	3.54	9.54	38.7 (+4.3)	3.62	9.37
Amritsar	35.6	0.7	1.9	36.9 (+1.3)	3.99	10.79	38.1 (+2.5)	3.96	10.40	37.9 (+2.3)	3.97	10.46	39.6 (+4.0)	4.06	10.26
Ludhiana	34.9	0.6	1.7	36.1 (+1.2)	3.67	10.18	37.2 (+2.3)	3.66	9.83	37.0 (+2.1)	3.72	10.06	38.5 (+3.6)	3.80	9.87
Patiala	35.0	0.6	1.8	36.5 (+1.5)	3.60	9.86	37.7 (+2.7)	3.59	9.52	37.5 (+2.5)	3.66	9.75	39.0 (+4.0)	3.76	9.65
Bathinda	36.7	1.0	2.7	37.5 (+0.8)	3.86	10.29	38.6 (+1.9)	3.89	10.06	38.4 (+1.7)	3.94	10.26	40.0 (+3.3)	3.98	9.96
Abohar	35.7	0.5	1.4	36.8 (+1.1)	3.62	9.85	37.9 (+2.2)	3.60	9.48	37.7 (+2.0)	3.60	9.54	39.4 (+3.7)	3.66	9.31
Faridkot	35.1	0.8	2.3	36.1 (+1.0)	3.38	9.37	37.2 (+2.1)	3.36	9.05	37.0 (+1.9)	3.41	9.23	38.6 (+3.5)	3.42	8.88
Rabi															
Ballowal Saunkhri	25.6	0.9	3.6	27.2 (+1.6)	6.21	22.83	28.6 (+3.0)	6.09	21.29	28.4 (+2.8)	6.14	21.62	30.1 (+4.5)	6.05	20.11
Amritsar	24.9	0.8	3.4	25.9 (+1.0)	6.43	24.84	27.3 (+2.4)	6.44	23.58	27.1 (+2.2)	6.44	23.76	28.8 (+3.9)	6.24	21.65
Ludhiana	24.6	0.8	3.1	25.9 (+1.3)	6.65	25.70	27.3 (+2.7)	6.53	23.95	27.1 (+2.5)	6.59	24.34	28.7 (+4.1)	6.50	22.62
Patiala	25.4	0.9	3.4	26.9 (+1.5)	6.61	24.58	28.3 (+2.9)	6.51	23.01	28.1 (+2.7)	6.54	23.27	29.7 (+4.3)	6.46	21.79
Bathinda	25.8	0.9	3.7	26.4 (+0.6)	6.79	25.68	27.9 (+2.1)	6.70	23.98	27.7 (+1.9)	6.73	24.29	29.4 (+3.6)	6.57	22.31
Abohar	24.6	1.4	5.5	25.9 (+1.3)	6.38	24.67	27.3 (+2.7)	6.23	22.81	27.1 (+2.5)	6.29	23.22	28.9 (+4.3)	6.12	21.22
Faridkot	24.5	0.9	3.7	26.4 (+1.9)	6.47	24.55	27.8 (+3.3)	6.37	22.90	27.6 (+3.1)	6.42	23.27	29.4 (+4.9)	6.24	21.25

* Figures in the parenthesis denote deviation from the baseline value

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

period in the range from 1.8 to 4.4 °C, 1.8 to 4.3 °C and 1.6 to 4.5 °C at Ballowal Saunkhri; 1.2 to 4.0 °C , 1.3 to 4.0 °C and 1.0 to 3.9 °C at Amritsar; 1.2 to 3.9 °C, 1.2 to 3.6 °C and 1.3 to 4.1 °C at Ludhiana; 1.6 to 4.2 °C, 1.5 to 4.0 °C and 1.5 to 4.3 °C at Patiala; 0.8 to 3.5 °C, 0.8 to 3.3 °C and 0.6 to 3.6 °C at Bathinda; 1.2 to 4.0 °C, 1.1 to 3.7 °C and 1.3 to 4.3 °C at Abohar; 1.4 to 4.1 °C, 1.0 to 3.5 °C and 1.9 to 4.9 °C at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) ranges from 6.57 to 6.72 °C and 18.99 to 21.16%, 3.50 to 3.62 °C and 9.37 to 9.67% and 6.05 to 6.21 °C and 20.11 to 22.83% at Ballowal Saunkhri; 7.48 to 7.65 °C and 21.82 to 24.28%, 3.96 to 4.06 °C and 10.26 to 10.79% and 6.24 to 6.44 °C and 21.65 to 243.84% at Amritsar; 7.21 to 7.24 °C and 22.31 to 23.72%, 3.66 to 3.80 °C and 9.83 to 10.18% and 6.50 to 6.65 °C and 22.62 to 25.70% at Ludhiana; 6.97 to 7.10 °C and 20.27 to 22.33%, 3.59 to 3.76 °C and 9.52 to 9.86% and 6.46 to 6.61 °C and 21.79 to 24.58% at Patiala; 7.52 to 7.78 °C and 21.63 to 24.25%, 3.86 to 3.98 °C and 9.96 to 10.29% and 6.57 to 6.79 °C and 22.31 to 25.68% at Bathinda; 7.25 to 7.49 °C and 21.20 to 23.84%, 3.60 to 3.66 °C and 9.31 to 9.85% and 6.12 to 6.38 °C and 21.22 to 24.67% at Abohar; 6.76 to 7.03 °C and 19.88 to 22.46%, 3.36 to 3.42 °C and 8.88 to 9.37% and 6.24 to 6.47 °C and 21.25 to 24.55% at Faridkot, respectively.

3.2. *Minimum temperature under different RCPs scenarios*

The annual, *kharif* and *rabi* minimum temperature (*T*min) at different locations during the baseline period, mid and end 21st century have been presented in Tables 4 and 5. During the mid-century (Table 4), the *T*min is predicted to increase for annual, *kharif* and *rabi* respectively, from baseline period in the range from 2.5 to 3.1 °C, 4.2 to 4.8 °C and 0.5 to 1.1 °C at Ballowal Saunkhri; 2.3 to 2.9 °C, 3.4 to 4.0 °C and 1.2 to 1.8 °C at Amritsar; 2.0 to 2.6 °C, 3.4 to 4.0 °C and 0.6 to 1.1 °C at Ludhiana; 1.5 to 2.1 °C, 2.9 to 3.2 °C and 0.3 to 0.9 °C at Patiala; 1.7 to 2.3 °C, 2.8 to 3.4 °C and 0.3 to 1.0 °C at Bathinda; 1.1 to 1.7 °C, 3.1 to 3.7 °C and -0.2 to -0.9 °C at Abohar; 1.2 to 1.9 °C, 0.1 to 0.4 °C and 2.9 to 3.5 °C at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) ranges from 9.50 °C and 49.30 to 50.80%, 3.30 to 3.40 °C and 12.80 to 12.90% and 6.20 to 6.30 °C and 56.20 to 58.00% at Ballowal Saunkhri; 9.50 °C and 51.90 to 52.90%, 3.40 to 3.50 °C and 12.80 to 13.00% and 6.20 °C and 61.10 to 65.70% at Amritsar; 9.50 °C and 49.10 to 50.60%, 3.40 to 3.50 °C and 12.70 to 12.90% and 6.20 °C and 55.70 to 59.10% at Ludhiana; 9.0 °C and 45.80 to 47.00%, 3.30 to 3.40 °C and 12.30 to 12.50% and 6.10 °C and 50.70 to 33.40% at Patiala; 9.60 to 9.70 °C and 50.30 to 52.10%, 3.30 to 3.40 °C and 12.70 to 13.00% and 6.10 °C and 57.50 to 61.50% at Bathinda; 9.90 to 10.0 °C and 51.30 to 53.20%, 3.70 °C and 13.20 to 13.50% and 6.30 to 6.40 °C and 58.70 to 63.10% at Abohar; 9.60 °C and 50.40 to 52.10%, 3.50 °C and 13.00 to 13.50% and 6.20 to 6.30 °C and 57.60 to 61.60% at Faridkot, respectively.

During the end-century (Table 5), at different locations of Punjab under study, the Tmin is predicted to increase for three seasons respectively, from baseline period in the range from 3.2 to 6.6 °C, 4.9 to 6.3 °C and 1.4 to 4.8 °C at Ballowal Saunkhri; 3.1 to 6.5 °C, 4.0 to 5.5 °C and 2.0 to 5.5 °C at Amritsar; 2.8 to 6.1 °C, 4.0 to 5.4 °C and 1.4 to 4.8 °C at Ludhiana; 2.3 to 5.5 °C, 3.4 to 4.7 °C and 1.1 to 4.4 °C at Patiala; 2.5 to 6.1 °C, 3.5 to 4.9 °C and 1.2 to 5.1 °C at Bathinda; 1.9 to 5.6 °C, 3.8 to 5.2 °C and 1.3 to 4.0 °C at Abohar; 0.4 to 2.5 °C, 0.5 to 1.9 °C and -1.0 to -2.6 °C at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) ranges from 9.17 to 9.34 °C and 40.25 to 48.12%, 3.42 to 3.45 °C and 11.30 to 12.66% and 5.78 to 6.14 °C and 39.1 to 54.05% at Ballowal Saunkhri; 9.27 to 9.40 °C and 42.15 to 50.52%, 3.36 to 3.42 °C 11.42 to 12.66% and 5.69 to 6.09 °C and 41.1 to 58.45% at Amritsar; 9.18 to 9.33 °C and 40.24 to 47.90%, 3.41 to 3.46 °C and 11.30 to 12.62% and 5.75 to 6.12 °C and 38.9 to 53.56% at Ludhiana; 8.73 to 8.91 °C and 37.86 to 44.81%, 3.25 to 3.34 °C and 10.84 to 12.25% and 5.69 to 5.99 °C and 36.8 to 48.99% at Patiala; 9.15 to 9.51 °C and 39.93 to 49.11%, 3.33 to 3.47 °C and 10.85 to 12.69% and 5.71 to 6.15 °C and 38.3 to 55.18% at Bathinda; 9.35 to 9.78 °C and 40.28 to 50.12%, 3.49 to 3.68 °C and 11.17 to 12.94% and 5.72 to 6.22 °C and 38.2 to 56.37% at Abohar; 9.15 to 9.45 °C and 40.19 to 49.13%, 3.44 to 3.52 °C and 11.27 to 12.94% and 5.69 to 6.13 °C and 38.5 to 55.28% at Faridkot, respectively.

3.3. *Rainfall under different RCPs scenarios*

The annual, *kharif* and *rabi* rainfall (RF) at different locations of Punjab during the baseline period, mid and end 21st century have been presented in Tables 6 and 7. During mid-century, (Table 6) the rainfall is predicted to increase for annual, *kharif* and *rabi* from baseline period in the range from 501 to 514 mm, 393 to 443 mm and 95 to 110 mm at Ballowal Saunkhri; 49 to 128 mm, 44 to 82 mm and 46 to 72 mm at Amritsar; 133 to 152 mm, 60 to 84 mm and 59 to 74 mm at Ludhiana; 148 to 187 mm, 88 to 128 mm and 57 to 69 mm at Patiala; 49 to 82 mm, 23 to

TABLE 4

Annual and seasonal variations in minimum temperature (°C) at different locations during mid-century (2020-2049) as simulated by CSIRO-Mk 3-6-0 model

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															
Ballowal Saunkhri	16.2	0.5	3.7	18.9 (+2.7)	9.50	50.10	19.0 (+2.8)	9.50	49.90	18.7 (+2.5)	9.50	50.80	19.3 (+3.1)	9.50	49.30
Amritsar	15.5	0.7	4.6	18.1 (+2.6)	9.60	52.90	18.2 (+2.7)	9.60	52.70	17.8 (+2.3)	9.60	53.70	18.4 (+2.9)	9.60	51.90
Ludhiana	16.7	0.9	5.2	19.0 (+2.3)	9.50	49.80	19.1 (+2.4)	9.50	49.70	18.7 (+2.0)	9.50	50.60	19.3 (+2.6)	9.50	49.10
Patiala	17.6	0.5	2.8	19.4 (+1.8)	9.00	46.40	19.5 (+1.9)	9.00	46.30	19.1 (+1.5)	9.00	47.00	19.7 (+2.1)	9.00	45.80
Bathinda	16.9	0.6	3.8	18.8 (+1.9)	9.60	51.20	18.9 (+2.0)	9.70	51.10	18.6 (+1.7)	9.70	52.10	19.2 (+2.3)	9.60	50.30
Abohar	17.6	1.6	8.9	19.0 (+1.4)	9.90	52.40	19.1 (+1.5)	10.00	52.30	18.7 (+1.1)	9.90	53.20	19.3 (+1.7)	9.90	51.30
Faridkot	20.3	2.0	9.8	18.7 (-1.6)	9.60	51.30	18.8 (-1.5)	9.60	51.20	18.4 (-1.9)	9.60	52.10	19.1 (-1.2)	9.60	50.40
Kharif															
Ballowal Saunkhri	22.4	0.5	2.4	26.9 (+4.5)	3.50	12.90	27.0 (+4.6)	3.50	12.80	26.6 (+4.2)	3.40	12.90	27.2 (+4.8)	3.50	12.80
Amritsar	22.5	0.8	3.7	26.2 (+3.7)	3.40	13.00	26.3 (+3.8)	3.40	12.80	25.9 (+3.4)	3.30	12.90	26.5 (+4.0)	3.40	12.80
Ludhiana	23.3	0.9	4.0	26.9 (+3.6)	3.50	12.90	27.1 (+3.8)	3.50	12.80	26.7 (+3.4)	3.40	12.90	27.3 (+4.0)	3.50	12.70
Patiala	23.9	0.6	2.3	26.8 (+2.9)	3.40	12.50	27.0 (+3.1)	3.30	12.40	26.6 (+2.7)	3.30	12.50	27.1 (+3.2)	3.30	12.30
Bathinda	23.9	0.7	3.1	27.0 (+3.1)	3.50	13.00	27.1 (+3.2)	3.50	12.90	26.7 (+2.8)	3.50	12.90	27.3 (+3.4)	3.50	12.70
Abohar	24.0	1.7	7.0	27.4 (+3.4)	3.70	13.50	27.5 (+3.5)	3.70	13.40	27.1 (+3.1)	3.70	13.50	27.7 (+3.7)	3.70	13.20
Faridkot	26.7	1.7	6.4	26.8 (+0.1)	3.50	13.20	26.9 (+0.2)	3.50	13.10	26.5 (-0.2)	3.50	13.20	27.1 (+0.4)	3.50	13.00
Rabi															
Ballowal Saunkhri	10.0	0.8	8.0	10.8 (+0.8)	6.20	58.00	10.9 (+0.9)	6.20	57.60	10.5 (+0.5)	6.30	59.70	11.1 (+1.1)	6.20	56.20
Amritsar	8.4	0.7	8.5	9.8 (+1.4)	6.20	63.60	9.9 (+1.5)	6.20	63.00	9.6 (+1.2)	6.30	65.70	10.2 (+1.8)	6.20	61.10
Ludhiana	10.0	0.9	8.9	10.8 (+0.8)	6.20	57.50	10.9 (+0.9)	6.20	57.00	10.6 (+0.6)	6.20	59.10	11.1 (+1.1)	6.20	55.70
Patiala	11.1	0.6	5.1	11.7 (+0.6)	6.10	52.20	11.8 (+0.7)	6.10	51.80	11.4 (+0.3)	6.10	53.40	12.0 (+0.9)	6.10	50.70
Bathinda	9.9	0.8	8.2	10.5 (+0.6)	6.30	59.80	10.6 (+0.7)	6.30	59.40	10.2 (+0.3)	6.30	61.50	10.9 (+1.0)	6.20	57.50
Abohar	11.0	1.7	15.6	10.4 (-0.6)	6.40	61.30	10.4 (-0.6)	6.40	61.00	10.1 (-0.9)	6.40	63.10	10.8 (-0.2)	6.30	58.70
Faridkot	13.7	2.2	16.2	10.5 (-3.2)	6.30	59.90	10.5 (-3.2)	6.30	59.50	10.2 (-3.5)	6.30	61.60	10.8 (-2.9)	6.20	57.60

* Figures in the parenthesis denote deviation from the baseline value

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

TABLE 5

Annual and seasonal variations in minimum temperature (°C) at different locations during end-century (2066-2095) as simulated by CSIRO-Mk 3-6-0 model

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															
Ballowal Saunkhri	16.2	0.5	3.7	19.4 (+3.2)	9.35	48.12	20.8 (+4.6)	9.24	44.34	20.8 (+4.6)	9.34	44.92	22.8 (+6.6)	9.17	40.25
Amritsar	15.5	0.7	4.6	18.6 (+3.1)	9.40	50.52	20.0 (+4.5)	9.29	46.44	20.0 (+4.5)	9.40	47.06	22.0 (+6.5)	9.27	42.15
Ludhiana	16.7	0.9	5.2	19.5 (+2.8)	9.33	47.90	20.9 (+4.2)	9.23	44.22	20.8 (+4.1)	9.33	44.81	22.8 (+6.1)	9.18	40.24
Patiala	17.6	0.5	2.8	19.9 (+2.3)	8.91	44.81	21.2 (+3.6)	8.78	41.35	21.2 (+3.6)	8.89	42.03	23.1 (+5.5)	8.73	37.86
Bathinda	16.9	0.6	3.8	19.4 (+2.5)	9.51	49.11	20.8 (+3.9)	9.31	44.66	20.8 (+3.9)	9.40	45.22	23.0 (+6.1)	9.15	39.93
Abohar	17.6	1.6	8.9	19.5 (+1.9)	9.78	50.12	21.0 (+3.4)	9.54	45.35	21.0 (+3.4)	9.63	45.86	23.2 (+5.6)	9.35	40.28
Faridkot	20.3	2.0	9.8	19.2 (-1.1)	9.45	49.13	20.7 (+0.4)	9.27	44.81	20.7 (+0.4)	9.38	45.38	22.8 (+2.5)	9.15	40.19
Kharif															
Ballowal Saunkhri	22.4	0.5	2.4	27.3 (+4.9)	3.45	12.66	28.6 (+6.2)	3.42	11.97	28.7 (+6.2)	3.42	11.92	30.6 (+6.3)	3.45	11.30
Amritsar	22.5	0.8	3.7	26.5 (+4.0)	3.36	12.66	27.9 (+5.4)	3.40	12.20	28.0 (+5.4)	3.40	12.16	30.0 (+5.5)	3.42	11.42
Ludhiana	23.3	0.9	4.0	27.3 (+4.0)	3.45	12.62	28.7 (+5.4)	3.42	11.94	28.7 (+5.4)	3.41	11.89	30.6 (+5.4)	3.46	11.30
Patiala	23.9	0.6	2.3	27.3 (+3.4)	3.34	12.25	28.6 (+4.7)	3.25	11.36	28.6 (+4.7)	3.26	11.39	30.4 (+4.7)	3.29	10.84
Bathinda	23.9	0.7	3.1	27.4 (+3.5)	3.47	12.69	28.7 (+4.8)	3.44	11.99	28.8 (+4.8)	3.42	11.90	30.7 (+4.9)	3.33	10.85
Abohar	24.0	1.7	7.0	27.8 (+3.8)	3.68	13.25	29.1 (+5.1)	3.63	12.46	29.2 (+5.1)	3.59	12.31	31.2 (+5.2)	3.49	11.17
Faridkot	26.7	1.7	6.4	27.2 (+0.5)	3.52	12.94	28.5 (+1.8)	3.51	12.31	28.6 (+1.8)	3.50	12.24	30.6 (+1.9)	3.44	11.27
Rabi															
Ballowal Saunkhri	10.0	0.8	8.0	11.4 (+1.4)	6.14	54.05	12.8 (+2.8)	5.94	46.30	12.7 (+2.7)	6.04	47.57	14.8 (+4.8)	5.78	39.1
Amritsar	8.4	0.7	8.5	10.4 (+2.0)	6.09	58.45	11.9 (+3.5)	5.88	49.46	11.8 (+3.4)	5.98	50.88	13.9 (+5.5)	5.69	41.1
Ludhiana	10.0	0.9	8.9	11.4 (+1.4)	6.12	53.56	12.9 (+2.9)	5.92	45.95	12.8 (+2.8)	6.01	47.22	14.8 (+4.8)	5.75	38.9
Patiala	11.1	0.6	5.1	12.2 (+1.1)	5.99	48.99	13.7 (+2.6)	5.79	42.34	13.5 (+2.4)	5.87	43.46	15.5 (+4.4)	5.69	36.8
Bathinda	9.9	0.8	8.2	11.1 (+1.2)	6.15	55.18	12.8 (+2.9)	5.93	46.43	12.7 (+2.8)	6.03	47.73	15.0 (+5.1)	5.71	38.3
Abohar	11.0	1.7	15.6	11.0 (+0.0)	6.22	56.37	12.7 (+1.7)	5.96	46.91	12.6 (+1.6)	6.06	48.20	15.0 (+4.0)	5.72	38.2
Faridkot	13.7	2.2	16.2	11.1 (-2.6)	6.13	55.28	12.7 (-1.0)	5.91	46.62	12.6 (-1.1)	6.01	47.95	14.8 (+1.1)	5.69	38.5

* Figures in the parenthesis denote deviation from the baseline value

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

TABLE 6

Annual and seasonal variations in rainfall (mm) at different locations during mid-century (2020-2049) as simulated by CSIRO-Mk 3-6-0 model

Season and location	Baseline period			RCP 2.6				RCP 4.5				RCP 6.0				RCP 8.5			
	Total (mm)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)
Annual																			
Ballowal Saunkhri	1049.0	292.2	27.9	547.7 (-501)	1.50	5.70	382.3	527.0 (-522)	1.40	5.50	380.7	495.3 (-554)	1.40	5.10	374.7	534.9 (-514)	1.50	5.50	373.5
Amritsar	722.0	198.0	27.4	660.0 (-62)	1.80	6.70	367.7	673.1 (-49)	1.80	6.90	374.7	624.9 (-97)	1.70	5.80	339.3	594.0 (-128)	1.60	5.60	345.7
Ludhiana	759.0	232.4	30.6	628.0 (-131)	1.70	6.90	398.2	613.5 (-146)	1.70	6.70	398.6	607.0 (-152)	1.70	6.80	408.8	626.1 (-133)	1.70	6.60	385.4
Patiala	774.0	286.2	37.0	605.2 (-169)	1.70	6.10	368.7	603.9 (-170)	1.70	6.20	376.9	587.1 (-187)	1.60	5.90	364.4	626.3 (-148)	1.70	6.30	367.6
Bathinda	517..0	181.2	35.0	434.9 (-82)	1.20	4.20	355.2	468.1 (-49)	1.30	4.70	366.1	438.8 (-78)	1.20	4.30	359.4	442.3 (-75)	1.20	4.50	368.2
Abohar	323.0	103.5	32.1	364.3 (+41)	1.00	3.70	370.4	333.6 (+11)	0.90	3.40	368.9	363.2 (+40)	1.00	3.70	368.1	354.0 (+31)	1.00	3.60	369.2
Faridkot	468.0	169.8	36.3	400.9 (-67)	1.10	4.10	377.9	434.8 (-33)	1.20	4.50	378.8	414.9 (-53)	1.10	4.20	370.1	415.4 (-53)	1.10	4.30	379.1
Kharif																			
Ballowal Saunkhri	888	279.9	31.5	495.0 (-393)	2.70	7.80	288.9	477.4 (-411)	2.60	7.40	286.8	445.4 (-443)	2.40	6.90	284.9	471.3 (-417)	2.60	7.30	285.1
Amritsar	579	192.2	33.2	581.4 (+2)	3.20	8.90	281.1	600.3 (+21)	3.30	9.30	285.6	534.8 (-44)	2.90	7.60	262.1	496. (-82)	2.70	7.30	272.5
Ludhiana	634	237.8	37.5	573.7 (-60)	3.10	9.30	299.5	560.6 (-73)	3.00	9.10	298.9	550.3 (-84)	3.00	9.30	309.9	559.5 (-75)	3.00	8.90	293.5
Patiala	649	277.9	42.8	536.7 (-112)	2.90	8.20	281.2	547.3 (-102)	3.00	8.40	283.7	520.8 (-128)	2.80	7.80	275.9	561.5 (-88)	3.10	8.50	278.5
Bathinda	427	179.4	42.0	375.6 (-51)	2.00	5.60	274.1	403.7 (-23)	2.20	6.20	281.6	370.7 (-56)	2.00	5.60	280.6	387.1 (-40)	2.10	5.90	282.9
Abohar	262	95.0	36.3	305.9 (+44)	1.70	4.70	281.3	294.3 (+32)	1.60	4.50	281.7	314.9 (+53)	1.70	4.80	282.3	310.8 (+49)	1.70	4.70	280.4
Faridkot	382	134.3	35.1	339.9 (-42)	1.80	5.50	295.2	388.4 (+6)	2.10	6.10	289.4	362.1 (-20)	2.00	5.60	284.2	367.0 (-15)	2.00	5.80	290.1
Rabi																			
Ballowal Saunkhri	159	85.3	53.6	52.4 (-107)	0.30	1.50	507.0	49.9 (-109)	0.30	1.40	522.8	48.8 (-110)	0.30	1.30	468.4	63.6 (-95)	0.40	1.90	523.9
Amritsar	144	78.5	54.3	78.4 (-66)	0.40	2.20	499.3	72.5 (-72)	0.40	2.00	487.5	91.2 (-53)	0.50	2.50	503.0	98.3 (-46)	0.50	2.60	483.2
Ludhiana	126	66.5	52.9	54.1 (-72)	0.30	1.50	499.4	52.5 (-74)	0.30	1.60	544.0	56.4 (-70)	0.30	1.60	502.5	67.2 (-59)	0.40	1.90	516.8
Patiala	125	85.7	68.8	67.9 (-57)	0.40	1.80	490.9	55.9 (-69)	0.30	1.50	494.1	64.5 (-61)	0.40	1.80	491.0	64.0 (-61)	0.40	1.80	505.5
Bathinda	90	50.9	56.5	59.7 (-30)	0.30	1.70	513.1	63.9 (-26)	0.40	2.00	558.7	67.5 (-23)	0.40	1.90	501.7	55.4 (-35)	0.30	1.50	490.7
Abohar	68	50.7	75.1	32.7 (-35)	0.20	0.90	524.5	38.7 (-29)	0.20	1.20	547.2	48.2 (-20)	0.30	1.40	538.5	43.2 (-25)	0.20	1.30	531.5
Faridkot	87	69.0	78.9	61.3 (-26)	0.30	1.90	548.8	46.6 (-40)	0.30	1.20	463.2	52.7 (-34)	0.30	1.60	537.0	48.8 (-38)	0.30	1.40	522.3

* Figures in the parenthesis denote deviation from the baseline value

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

TABLE 7

Annual and seasonal variations in rainfall (mm) at different locations during end-century (2066-2095) as simulated by CSIRO-Mk 3-6-0 model

Season and location	Baseline period			RCP 2.6				RCP 4.5				RCP 6.0				RCP 8.5			
	Total (mm)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)	Total (mm)	Mean (°C)	S.D. (°C)	C.V. (%)
Annual																			
Ballowal Saunkhri	1049.0	292.2	27.9	565.4 (-484)	1.50	5.90	382.5	495.3 (-554)	1.40	5.10	374.9	482.2 (-567)	1.30	5.00	381.0	439.2 (-610)	1.20	4.60	379.8
Amritsar	722.0	198.0	27.4	684.8 (-37)	1.90	7.70	409.8	671.5 (-51)	1.80	6.60	357.3	653.9 (-68)	1.80	6.70	372.2	583.3 (-139)	1.60	5.70	359.3
Ludhiana	759.0	232.4	30.6	614.6 (-144)	1.70	6.70	400.0	630.4 (-129)	1.70	6.10	354.9	633.6 (-125)	1.70	6.00	347.8	556.0 (-203)	1.50	5.50	359.3
Patiala	774.0	286.2	37.0	661.8 (-112)	1.80	6.90	378.0	591.1 (-183)	1.60	5.90	367.3	602.2 (-172)	1.60	6.00	365.6	577.1 (-197)	1.60	5.50	352.7
Bathinda	517..0	181.2	35.0	412.6 (-104)	1.10	4.10	361.3	406.0 (-111)	1.10	4.00	357.4	396.2 (-121)	1.10	4.00	368.6	454.8 (-62)	1.20	4.80	384.6
Abohar	323.0	103.5	32.1	331.0 (+8)	0.90	3.40	372.3	365.0 (+42)	1.00	3.80	381.5	373.0 (+50)	1.00	3.80	369.1	347.3 (+24)	1.00	3.50	365.4
Faridkot	468.0	169.8	36.3	383.9 (-84)	1.10	3.90	373.8	383.9 (-84)	1.10	3.80	364.5	388.7 (-79)	1.10	3.90	367.7	464.9 (-3)	1.30	5.00	388.3
Kharif																			
Ballowal Saunkhri	888	279.9	31.5	508.9 (-379)	2.80	8.00	288.9	424.8 (-463)	2.30	6.70	289.7	421.8 (-466)	2.30	6.70	293.6	382.1 (-506)	2.10	6.10	292.2
Amritsar	579	192.2	33.2	612.9 (+34)	3.30	10.4	313.2	559.4 (-20)	3.00	8.50	281.9	541.0 (-38)	2.90	8.80	299.1	516.7 (-62)	2.80	7.70	272.5
Ludhiana	634	237.8	37.5	548.8 (-85)	3.00	9.10	306.0	531.6 (-102)	2.90	7.90	272.7	552.2 (-82)	3.00	8.00	267.5	484.3 (-150)	2.60	7.10	271.0
Patiala	649	277.9	42.8	602.5 (-47)	3.30	9.30	283.3	523.7 (-125)	2.80	8.00	280.4	527.6 (-121)	2.90	8.00	279.1	494.4 (-155)	2.70	7.20	270.5
Bathinda	427	179.4	42.0	355.2 (-72)	1.90	5.40	279.3	359.2 (-68)	2.00	5.30	272.0	355.3 (-72)	1.90	5.40	278.7	413.0 (-14)	2.20	6.50	289.1
Abohar	262	95.0	36.3	288.1 (+26)	1.60	4.50	286.7	319.0 (+57)	1.70	5.10	293.2	322.6 (+61)	1.80	5.00	285.5	301.1 (+39)	1.60	4.60	279.9
Faridkot	382	134.3	35.1	340.9 (-41)	1.90	5.30	285.9	338.1 (-44)	1.80	5.10	278.5	335.2 (-47)	1.80	5.20	283.3	411.8 (+30)	2.20	6.60	296.1
Rabi																			
Ballowal Saunkhri	159	85.3	53.6	56.2 (-103)	0.30	1.60	523.2	70.0 (-89)	0.40	2.20	558.9	60.0 (-99)	0.30	1.80	541.7	57.7 (-101)	0.30	1.70	545.1
Amritsar	144	78.5	54.3	71.9 (-72)	0.40	2.00	506.7	112.2 (-32)	0.60	3.10	496.7	113.0 (-31)	0.60	2.90	469.3	65.9 (-78)	0.40	1.90	533.3
Ludhiana	126	66.5	52.9	65.3 (-61)	0.40	1.80	511.2	99.5 (-27)	0.50	2.90	520.7	81.3 (-45)	0.40	2.10	476.0	71.5 (-55)	0.40	2.50	640.8
Patiala	125	85.7	68.8	58.6 (-66)	0.30	1.70	532.7	67.3 (-58)	0.40	1.90	515.4	74.6 (-50)	0.40	2.30	551.5	83.5 (-42)	0.50	2.50	550.4
Bathinda	90	50.9	56.5	57.7 (-32)	0.30	1.60	511.4	47.5 (-43)	0.30	1.30	510.8	41.3 (-49)	0.20	1.20	512.6	42.1 (-48)	0.20	1.20	521.1
Abohar	68	50.7	75.1	44.7 (-23)	0.20	1.30	521.6	46.7 (-21)	0.30	1.40	551.4	50.6 (-17)	0.30	1.40	508.1	46.8 (-21)	0.30	1.40	564.2
Faridkot	87	69.0	78.9	43.1 (-44)	0.20	1.10	468.1	45.7 (-41)	0.30	1.30	516.9	53.2 (-34)	0.30	1.60	519.0	52.5 (-35)	0.30	1.50	510.8

* Figures in the parenthesis denote deviation from the baseline value

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

56 mm and 23 to 35 mm at Bathinda; 11 to 41 mm, 32 to 53 mm and 20 to 35 mm increased at Abohar; 33 to 67 mm, 15 to 42 mm and 26 to 40 mm at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) ranges from 5.10 to 5.70 mm and 373.5 to 382.3%, 6.90 to 7.80 mm and 285.1 to 288.9% and 1.30 to 1.90 mm and 468.4 to 523.9% at Ballowal Saunkhri; 5.60 to 6.90 mm and 339.3 to 374.7%, 7.30 to 9.30 mm and 262.1 to 285.6% and 2.20 to 2.60 mm and 483.2 to 499.3% at Amritsar; 6.60 to 6.90 mm and 385.4 to 398.6%, 8.90 to 9.30 mm and 293.5 to 299.5% and 1.50 to 1.90 mm and 499.4 to 516.8% at Ludhiana; 5.90 to 6.30 mm and 364.4 to 376.9%, 7.80 to 8.50 mm and 275.9 to 281.2% and 1.50 to 1.80 mm and 490.9 to 505.5% at Patiala; 4.20 to 4.70 mm and 355.2 to 368.2%, 5.60 to 6.20 mm and 274.1 to 282.9% and 1.50 to 2.0 mm and 490.7 to 558.7% at Bathinda; 3.40 to 3.70 mm and 368.1 to 370.4%, 4.50 to 4.80 mm and 280.4 to 282.3% and 0.90 to 1.40 mm and 531.5 to 547.2% at Abohar; 4.10 to 4.50 mm and 370.1 to 379.1%, 5.50 to 6.10 mm and 284.2 to 295.2% and 1.20 to 1.90 mm and 463.2 to 548.8% at Faridkot, respectively.

During end-century (Table 7), at all different locations of Punjab under study, the RF is predicted to increase from baseline period in the range from 484 to 610 mm, 379 to 506 mm and 89 to 101 mm at Ballowal Saunkhri; 37 to 139 mm, 20 to 62 mm and 31 to 78 mm at Amritsar; 125 to 203 mm, 82 to 105 mm and 27 to 61 mm at Ludhiana; 112 to 197 mm, 47 to 155 mm and 42 to 66 mm at Patiala; 62 to 121 mm, 14 to 72 mm and 32 to 49 mm at Bathinda; 8 to 50 mm, 26 to 61 mm and 17 to 23 mm increased at Abohar; 3 to 84 mm, 41 to 47 mm and 34 to 44 mm at Faridkot under RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 scenarios.

The value of standard deviation and coefficient of variation (%) ranges from 4.60 to 5.90 mm and 374.9 to 382.5%, 6.10 to 8.0 mm and 288.9 to 293.6% and 1.60 to 2.20 mm and 523.2 to 545.1% at Ballowal Saunkhri; 5.70 to 7.70 mm and 357.3 to 409.8%, 7.70 to 10.4 mm and 272.5 to 313.2% and 1.90 to 3.10 mm and 469.3 to 533.3% at Amritsar; 5.50 to 6.70 mm and 347.8 to 400.0%, 7.10 to 9.10 mm and 267.5 to 306.0% and 1.80 to 2.90 mm and 476.0 to 640.8% at Ludhiana; 5.50 to 6.90 mm and 352.7 to 378.0%, 7.20 to 9.30 mm and 270.5 to 283.3% and 1.70 to 2.50 mm and 515.4 to 551.4% at Patiala, 4.10 to 4.80 mm and 357.4 to 384.6%, 5.30 to 6.50 mm and 272.0 to 289.1% and 1.20 to 1.60 mm and 511.4 to 521.1% at Bathinda; 3.40 to 3.80 mm and 365.4 to 381.5%, 4.50 to 5.10 mm and 279.9 to 273.2% and 1.30 to 1.40 mm and 508.1 to 564.2% increased at Abohar; 364.5 to 388.3 mm and 278.5 to 296.1%, 5.10 to 6.60 mm and 468.0 to 519.0% and 1.10 to 1.60 mm and 57.60 to 61.60% at Faridkot, respectively.

4. Conclusions

The CSIRO-Mk3-6-0 model projections indicate that the climate in Punjab may become hotter and drier during the 21st century. During the mid-century period of 2020-2049, the annual, *kharif* and *rabi* season *T*max is projected to increase from baseline period between 0 to 1.5 °C, 0.3 to 1.5 °C and 0 to 1.6 °C, respectively; *T*min to increase from baseline period between 1.1 to 3.1 °C, 0.1 to 4.8 °C and 0.3 to 1.8 °C, respectively but the rainfall to decrease from baseline period between 33 to 554 mm, 20 to 443 mm and 20 to 110 mm, respectively. The rate of temperature increase is higher during the end-century as compare to mid-century period. Rainfall is also projected to increase at Abohar (11-41 mm) while it may decline at Amritsar (49-128 mm), Ballowal Saunkhri (501-554 mm), Ludhiana (131-152 mm), Patiala (148-187), Bathinda (49-82 mm) and Faridkot (33-67 mm).

Comparison of maximum and minimum temperatures reveals *T*min increase to be more than that in *T*max. This implies that the diurnal range in temperature would decrease which is not favorable for enhancing crop production. Punjab state economy is not only largely dependent on agriculture but it also contributes significantly to rice and wheat reserve pool of the country. In order to maintain the sustainability of crop production and food supply, the state has to evolve suitable crop contingency planning in view of climatic changes.

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Disclaimer

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