**International Journal of Ecology and Environmental Sciences**
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125, Impact Factor: RJIF 5.28
Received: 09-02-2021, Accepted: 12-03-2021, Published: 05-04-2021
Volume 3, Issue 2, 2021, Page No. 16-23

# Comparison of climate change in past versus future as simulated by FIO-ESM model under RCP based emission scenarios at different locations in Punjab

**Jatinder Kaur, Prabhjyot-Kaur***
Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab, India

**Abstract**
The projected data on temperature and rainfall derived from FIO-ESM model based on four RCP (Representative Concentration Pathways) scenarios was analyzed on annual and seasonal (*kharif*: May-October and *rabi*: November-April) basis for seven different locations of Punjab. In Punjab amongst different locations, maximum temperature is projected to rise from 29.8-31.3 ºC (baseline period) to 30.1-31.1ºC (RCP 2.6), 30.2-31.2ºC (RCP 4.5), 30.3-31.3ºC (RCP 6.0) and 30.4-31.4ºC (RCP 8.5) during mid-century (2020-2049) and to 29.7-30.8ºC (RCP 2.6), 30.6-31.7ºC (RCP 4.5), 31.3-32.3ºC (RCP 6.0) and 33.0-34.0ºC (RCP 8.5) during end-century (2066-2095). Similarly, minimum temperature is projected to rise from 15.5-20.3ºC (baseline period) to 17.0-18.5ºC (RCP 2.6), 17.4-18.8ºC (RCP 4.5), 17.2-18.7ºC (RCP 6.0) and 17.5-19.0ºC (RCP 8.5) during mid-century (2020-2049) and to 16.6-18.1ºC (RCP 2.6), 17.6-19.1ºC (RCP 4.5), 18.0-19.5ºC (RCP 6.0) and 19.7-21.3ºC (RCP 8.5) during end- century (2066-2095). The rainfall is not only projected to decrease in different locations but its distribution may become highly variable as indicated by high values of standard deviation and coefficient of variation.

**Keywords:** annual; *RABI*; *Kharif*; Punjab; meteorological parameters; RCPS

## Introduction

In recent years, the phenomenon of global warming has widely been discussed and monitoring and analysis of climatic data have become more important. The agriculture sector in India is highly susceptible tothe frequent and erratic climatic irregularities. The projected changes in the climate due to intensive anthropogenic activities may cause worst conditions. In India, Satyanarayana and Srinivas (2008) [6] studied the variation in amount and duration of Indian monsoon conditions and observed high risk for extreme rainfall events in Indian subcontinent with the change in climate. The average frequency of extreme rainfall events along with the contribution of extreme rainfall events to the seasonal rainfall showed increasing trend during monsoon season and also during June and July months. The increasing trend of contribution from extreme rainfall events is balanced by a decreasing trend in low rainfall events (Pattanaik and Rajeevan, 2010) [5]. India has to face the challenge of sustaining its rapid economic growth in the era of rapidly changing global climate and needs a strong national strategy to adapt to climate change and also to enhance the ecological sustainability. Climate change and its research have gained lot of momentum in recent years and globally it has been scaling down to regional or local concerns. In fact it makes an impetus to our planning and policies on decadal time frame (Li and Calum, 2014) [4]. Thus study of regional climatic variability in decadal time scales do possess an immense potential for planning of socio-economic activities. An effort has been made to study and analyze the change in different weather parameters on the submontane region on the foothills of Shiwalik ranges in Punjab.

According to IPCC (2014) the downscaled data of temperature and rainfall for the period of 1860–2099 is available based on the multi-model and multi-scenario. In India, the temperature rises from 1.7–2°C by the 2030s and 3.3–4.8°C by 2080s under RCP6.0 and RCP8.5 scenarios. Whereas, rainfall increased from 4% to 5% by 2030s and 6% to 14% near the end of the century (2080s) as compared to the baseline (1961–1990) all over India. The projections under RCP 2.6 to RCP 8.5 indicated that rainfall projections in long time period are generally more rapid as compared to short-term period. Region wise analysis of temperature in India (Islam and Sikka, 2010) showed a maximum increase in maximum temperature in the west coast (by 1.2ºC), followed by north-east (by 1.0ºC), western Himalayas (by 0.9ºC), north central (by 0.6ºC), north-west (by 0.6ºC), east coast (by 0.6ºC) and interior peninsula (by 0.5ºC). The region to region variation in climate is driven by the uneven distribution of solar heating, the individual responses of the atmosphere, oceans and land surface, the interactions between these, and the physical characteristics of the regions (Christensen *et al*., 2007). Increasingly reliable regional climate change projections are now available for many regions of the world due to advances in modeling and understanding of the physical processes of the climate system. Keeping these different scenarios in mind, the results of the general circulation model have been presented in this paper under different scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 for the mid and end of 21st century.

## Material and methods

Site description and model data used

The study was done for seven locations of Punjab state, namely Ballowal Saunkhri30° 07′ N 76° 23′ E 355 a.m.s.l, 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., Bathinda 30° 12′ N, 74° 57′ E 211 a.m.s.l., 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 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 periods used for Ludhiana, Amritsar, Patiala was 1970-2015, for Ballowal Saunkhri was 1984-2015, for Bathinda was1977-2015, for Abohar was 2004-2015 and for Faridkot was 2000-2015.

**Retrieval and rectification of climate data**

The GCM data for the FIO-ESM 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 monthly scale in maximum temperature and rainfall, at daily scale for solar radiation. However, no bias removal was done in minimum temperature.

The daily weather data for 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 difference method the daily difference between modeled data ($X_{model}$) and observed data ($X_{obs}$) of meteorological parameter was computed for each Julian day (365 days) and was 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 FIO-ESM model data on temperature and rainfall was analyzed over the annual and seasonal basis as given below:

**Agro-climatic zone II - Undulating plain region**

The 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 0.9-1.2, 1.0-1.1 and 0.5-1.2ºC, respectively during mid-century (Table 1) and by 0.5-3.8, 0.8-3.8and 0.1-3.7ºC, 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 1.8-2.3, 3.4-3.8 and 0.3-0.6ºC, respectively during mid-century (Table 3) and by 1.4-4.6, 3.0-6.0 and 0.6-2.9ºC, respectively during end-century (Table 4). The rainfall on annual, *kharif* and *rabi* season basis is projected to decrease by 546-626, 451-512, 92-118 mm, respectively during mid-century (Table 5) and by 527-567, 419-460, 96-120 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 rise. This region is the wettest zone of Punjab and rainfall is not only projected to decrease sharply but its distribution over the spatial time scale is also predicted to be alarmingly disturbed.

**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 annual, *kharif* and *rabi* season basis is projected to increase from baseline period by 0.2-0.9, 0.4-0.8 and 0.1-1.0ºC, respectively during mid-century (Table 1) and by 0.4-3.6, 0.1-3.4and 0.1-3.6ºC, 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 0.9-2.1, 1.9-3.1 and 0.1-1.0ºC, respectively during mid-century (Table 3) and by 0.5-4.2, 1.5-5.2 and 0.1-3.2ºC, respectively during end-century (Table 4). The rainfall in this zone is projected to both decrease from the baseline rainfall on annual, *kharif* and *rabi* season basis under the four scenarios during the 21st century (Table 5 and 6).

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. The 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.

**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 0.01-0.1, 0.08-0.1 and 0.1-0.5ºC, respectively during mid-century (Table 1) and by 0.4-2.7, 0.5-2.7and 0.6-3.1ºC, 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 0.9-1.4, 2.0-2.4 and 0.01-0.2ºC, respectively during mid-century (Table 3) and by 0.5-3.7, 1.5-4.6 and 0.3-2.6ºC, 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 77-158 mm during mid- century by 96-109mm during end century (Table 5 and 6). The *rabi* season rainfall is projected to decrease by 33-61mm during the mid-century and by 25-49mm 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. The 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.

**Agro-climatic zone V - Western region**

The Agro-climatic zone V represents about 20% 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 0.3-0.8, 0.1-0.3 and 0.2-1.4ºC, respectively during mid-century (Table 1) and by 0.1-3.3, 0.1-3.0and 0.3-4.0ºC, 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 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 323-468mm. The annual and *kharif* season rainfall at Abohar is 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 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 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.

**Table 1:** Annual and seasonal variations in maximum temperature during mid-century (2020-2049) as simulated by FIO-ESM 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 | 30.0 | 0.7 | 2.4 | 30.88 | 6.94 | 22.46 | 31.01 | 6.89 | 22.21 | 31.09 | 6.82 | 21.95 | 31.16 | 6.72 | 21.56 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 29.8 | 0.5 | 1.8 | 30.15 | 7.57 | 25.10 | 30.28 | 7.53 | 24.86 | 30.33 | 7.45 | 24.57 | 30.45 | 7.37 | 24.20 |
| Amritsar | 30.3 | 0.6 | 1.9 | 30.52 | 7.89 | 25.86 | 30.64 | 7.86 | 25.66 | 30.78 | 7.78 | 25.28 | 30.87 | 7.71 | 24.97 |
| Patiala | 30.2 | 0.6 | 1.9 | 30.92 | 7.38 | 23.85 | 30.97 | 7.40 | 23.91 | 31.08 | 7.29 | 23.45 | 31.13 | 7.19 | 23.10 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 31.3 | 0.7 | 2.3 | 31.17 | 8.02 | 25.74 | 31.27 | 7.99 | 25.57 | 31.31 | 7.92 | 25.28 | 31.42 | 7.80 | 24.83 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 29.9 | 0.6 | 2.1 | 30.33 | 7.25 | 23.91 | 30.47 | 7.22 | 23.70 | 30.51 | 7.11 | 23.30 | 30.65 | 7.00 | 22.84 |
| Abohar | 30.2 | 0.8 | 2.8 | 30.47 | 7.67 | 25.18 | 30.50 | 7.69 | 25.23 | 30.62 | 7.59 | 24.79 | 30.72 | 7.50 | 24.41 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 34.4 | 0.8 | 2.4 | 35.44 | 3.58 | 10.10 | 35.50 | 3.56 | 10.04 | 35.53 | 3.61 | 10.16 | 35.49 | 3.58 | 10.10 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 34.9 | 0.6 | 1.7 | 35.27 | 3.73 | 10.58 | 35.31 | 3.78 | 10.70 | 35.34 | 3.77 | 10.68 | 35.34 | 3.81 | 10.77 |
| Amritsar | 35.6 | 0.7 | 1.9 | 36.07 | 4.06 | 11.26 | 36.11 | 4.07 | 11.28 | 36.25 | 4.02 | 11.09 | 36.20 | 4.12 | 11.39 |
| Patiala | 35.0 | 0.6 | 1.8 | 35.78 | 3.54 | 9.88 | 35.76 | 3.64 | 10.19 | 35.81 | 3.62 | 10.10 | 35.71 | 3.71 | 10.38 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 36.7 | 1.0 | 2.7 | 36.78 | 3.92 | 10.65 | 36.83 | 3.92 | 10.64 | 36.79 | 3.94 | 10.71 | 36.78 | 3.96 | 10.77 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 35.1 | 0.8 | 2..3 | 35.22 | 3.40 | 9.64 | 35.32 | 3.43 | 9.72 | 35.27 | 3.42 | 9.70 | 35.28 | 3.42 | 9.68 |
| Abohar | 35.7 | 0.5 | 1.4 | 35.96 | 3.64 | 10.14 | 35.96 | 3.73 | 10.36 | 36.03 | 3.62 | 10.04 | 35.98 | 3.72 | 10.33 |
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 25.6 | 0.9 | 3.6 | 26.15 | 6.50 | 24.84 | 26.35 | 6.50 | 24.66 | 26.50 | 6.40 | 24.16 | 26.75 | 6.32 | 23.62 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 24.6 | 0.8 | 3.1 | 24.84 | 6.95 | 27.96 | 25.08 | 6.98 | 27.83 | 25.17 | 6.86 | 27.26 | 25.45 | 6.78 | 26.66 |
| Amritsar | 24.9 | 0.8 | 3.4 | 24.79 | 6.80 | 27.41 | 25.03 | 6.84 | 27.32 | 25.16 | 6.68 | 26.54 | 25.42 | 6.67 | 26.26 |
| Patiala | 25.4 | 0.9 | 3.4 | 25.93 | 6.97 | 26.87 | 26.05 | 7.09 | 27.23 | 26.22 | 6.94 | 26.45 | 26.42 | 6.89 | 26.10 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 25.4 | 0.9 | 3.7 | 25.40 | 7.07 | 27.84 | 25.53 | 7.12 | 27.89 | 25.67 | 7.02 | 27.37 | 25.92 | 6.96 | 26.86 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 24.5 | 0.9 | 3.7 | 25.29 | 6.75 | 26.68 | 25.46 | 6.76 | 26.53 | 25.61 | 6.63 | 25.89 | 25.87 | 6.62 | 25.58 |
| Abohar | 24.6 | 1.4 | 5.5 | 24.82 | 6.60 | 26.58 | 24.90 | 6.67 | 26.80 | 25.07 | 6.58 | 26.24 | 25.32 | 6.54 | 25.85 |

**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 FIO-ESM 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 | 30.0 | 0.7 | 2.4 | 30.51 | 7.06 | 23.15 | 31.46 | 6.85 | 21.78 | 32.07 | 6.82 | 21.26 | 33.83 | 6.66 | 19.68 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ludhiana | 29.8 | 0.5 | 1.8 | 29.72 | 7.69 | 25.86 | 30.69 | 7.47 | 24.35 | 31.30 | 7.47 | 23.88 | 33.07 | 7.29 | 22.06 |
| Amritsar | 30.3 | 0.6 | 1.9 | 30.09 | 7.97 | 26.51 | 31.04 | 7.75 | 24.97 | 31.75 | 7.79 | 24.55 | 33.46 | 7.60 | 22.72 |
| Patiala | 30.2 | 0.6 | 1.9 | 30.61 | 7.40 | 24.18 | 31.47 | 7.28 | 23.14 | 32.07 | 7.24 | 22.56 | 33.79 | 7.09 | 20.99 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 31.3 | 0.7 | 2.3 | 30.83 | 8.08 | 26.19 | 31.71 | 7.89 | 24.87 | 32.31 | 7.89 | 24.41 | 34.03 | 7.75 | 22.77 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 29.9 | 0.6 | 2.1 | 29.97 | 7.31 | 24.38 | 30.87 | 7.12 | 23.06 | 31.51 | 7.10 | 22.53 | 33.23 | 6.93 | 20.87 |
| Abohar | 30.2 | 0.8 | 2.8 | 30.14 | 7.80 | 25.87 | 30.96 | 7.56 | 24.40 | 31.61 | 7.57 | 23.95 | 33.37 | 7.50 | 22.49 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 34.4 | 0.8 | 2.4 | 35.19 | 3.60 | 10.24 | 35.94 | 3.60 | 10.01 | 36.54 | 3.49 | 9.55 | 38.21 | 3.43 | 8.98 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 34.9 | 0.6 | 1.7 | 34.97 | 3.71 | 10.61 | 35.72 | 3.75 | 10.49 | 36.33 | 3.65 | 10.05 | 37.98 | 3.61 | 9.50 |
| Amritsar | 35.6 | 0.7 | 1.9 | 35.73 | 3.99 | 11.15 | 36.44 | 4.03 | 11.05 | 37.22 | 3.97 | 10.65 | 38.77 | 3.84 | 9.91 |
| Patiala | 35.0 | 0.6 | 1.8 | 35.57 | 3.48 | 9.77 | 36.26 | 3.45 | 9.52 | 36.78 | 3.43 | 9.32 | 38.40 | 3.39 | 8.84 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 36.7 | 1.0 | 2.7 | 36.54 | 3.79 | 10.37 | 37.24 | 3.80 | 10.21 | 37.80 | 3.80 | 10.06 | 39.42 | 3.66 | 9.29 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 35.1 | 0.8 | 2..3 | 34.96 | 3.29 | 9.40 | 35.69 | 3.34 | 9.37 | 36.28 | 3.29 | 9.06 | 37.88 | 3.10 | 8.20 |
| Abohar | 35.7 | 0.5 | 1.4 | 35.78 | 3.54 | 9.89 | 36.36 | 3.59 | 9.86 | 37.03 | 3.51 | 9.47 | 38.72 | 3.44 | 8.89 |
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 25.6 | 0.9 | 3.6 | 25.68 | 6.55 | 25.51 | 26.81 | 6.41 | 23.91 | 27.44 | 6.43 | 23.43 | 29.31 | 6.25 | 21.35 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 24.6 | 0.8 | 3.1 | 24.31 | 7.00 | 28.79 | 25.49 | 6.89 | 27.02 | 26.08 | 6.93 | 26.56 | 27.99 | 6.74 | 24.08 |
| Amritsar | 24.9 | 0.8 | 3.4 | 24.25 | 6.86 | 28.30 | 25.47 | 6.72 | 26.38 | 26.11 | 6.74 | 25.81 | 27.99 | 6.64 | 23.73 |
| Patiala | 25.4 | 0.9 | 3.4 | 25.48 | 6.94 | 27.24 | 26.55 | 6.91 | 26.04 | 27.22 | 6.97 | 25.62 | 29.04 | 6.82 | 23.48 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 25.4 | 0.9 | 3.7 | 24.95 | 7.09 | 28.42 | 26.02 | 6.95 | 26.71 | 26.65 | 7.04 | 26.42 | 28.48 | 6.96 | 24.44 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 24.5 | 0.9 | 3.7 | 24.83 | 6.79 | 27.35 | 25.91 | 6.59 | 25.42 | 26.58 | 6.65 | 25.03 | 28.45 | 6.57 | 23.10 |
| Abohar | 24.6 | 1.4 | 5.5 | 24.31 | 6.67 | 27.43 | 25.40 | 6.49 | 25.56 | 26.03 | 6.56 | 25.19 | 27.87 | 6.53 | 23.45 |

**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 FIO-ESM 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 | 18.03 | 9.37 | 51.99 | 18.35 | 9.35 | 50.96 | 18.22 | 9.31 | 51.09 | 18.50 | 9.34 | 50.48 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 16.7 | 0.9 | 5.2 | 18.09 | 9.34 | 51.65 | 18.42 | 9.32 | 50.60 | 18.29 | 9.28 | 50.74 | 18.57 | 9.30 | 50.09 |
| Amritsar | 15.5 | 0.7 | 4.6 | 17.09 | 9.56 | 55.93 | 17.40 | 9.55 | 54.86 | 17.29 | 9.48 | 54.83 | 17.56 | 9.52 | 54.22 |
| Patiala | 17.6 | 0.5 | 2.8 | 18.55 | 8.86 | 47.77 | 18.87 | 8.83 | 46.80 | 18.74 | 8.81 | 47.01 | 19.04 | 8.81 | 46.29 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 16.9 | 0.6 | 3.8 | 17.83 | 9.61 | 53.89 | 18.17 | 9.57 | 52.68 | 18.05 | 9.52 | 52.75 | 18.33 | 9.54 | 52.07 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 20.3 | 2.0 | 9.8 | 17.71 | 9.56 | 53.95 | 18.05 | 9.53 | 52.79 | 17.93 | 9.47 | 52.84 | 18.21 | 9.49 | 52.15 |
| Abohar | 17.6 | 1.6 | 8.9 | 17.92 | 9.91 | 55.27 | 18.24 | 9.88 | 54.16 | 18.16 | 9.82 | 54.06 | 18.44 | 9.83 | 53.32 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 22.4 | 0.5 | 2.4 | 25.78 | 3.48 | 13.50 | 26.11 | 3.49 | 13.38 | 25.92 | 3.51 | 13.54 | 26.21 | 3.50 | 13.34 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 23.3 | 0.9 | 4.0 | 25.83 | 3.45 | 13.37 | 26.15 | 3.48 | 13.29 | 25.96 | 3.48 | 13.39 | 26.25 | 3.47 | 13.23 |
| Amritsar | 22.5 | 0.8 | 3.7 | 25.11 | 3.27 | 13.01 | 25.42 | 3.32 | 13.05 | 25.24 | 3.32 | 13.15 | 25.55 | 3.29 | 12.86 |
| Patiala | 23.9 | 0.6 | 2.3 | 25.78 | 3.34 | 12.95 | 26.07 | 3.40 | 13.06 | 25.89 | 3.40 | 13.14 | 26.18 | 3.40 | 12.97 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 23.9 | 0.7 | 3.1 | 25.88 | 3.53 | 13.64 | 26.17 | 3.61 | 13.80 | 25.99 | 3.61 | 13.91 | 26.28 | 3.59 | 13.66 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 26.7 | 1.7 | 6.4 | 25.70 | 3.54 | 13.78 | 25.99 | 3.61 | 13.90 | 25.82 | 3.61 | 13.98 | 26.10 | 3.59 | 13.77 |
| Abohar | 24.0 | 1.7 | 7.0 | 26.24 | 3.76 | 14.33 | 26.52 | 3.82 | 14.41 | 26.37 | 3.82 | 14.50 | 26.66 | 3.81 | 14.29 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 10.0 | 0.8 | 8.0 | 9.98 | 6.36 | 63.72 | 10.32 | 6.28 | 60.85 | 10.26 | 6.31 | 61.54 | 10.57 | 6.36 | 60.32 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 10.0 | 0.9 | 8.9 | 10.08 | 6.35 | 62.95 | 10.41 | 6.26 | 60.11 | 10.34 | 6.28 | 60.78 | 10.66 | 6.34 | 59.53 |
| Amritsar | 8.4 | 0.7 | 8.5 | 8.87 | 6.42 | 72.31 | 9.17 | 6.34 | 69.17 | 9.14 | 6.34 | 69.34 | 9.36 | 6.35 | 67.87 |
| Patiala | 11.1 | 0.6 | 5.1 | 11.07 | 6.22 | 56.17 | 11.44 | 6.17 | 53.89 | 11.35 | 6.20 | 54.66 | 11.68 | 6.21 | 53.30 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 9.9 | 0.8 | 8.2 | 9.53 | 6.32 | 66.27 | 9.91 | 6.28 | 63.37 | 9.86 | 6.29 | 63.80 | 10.12 | 6.30 | 62.35 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 13.7 | 2.2 | 16.2 | 9.48 | 6.32 | 66.64 | 9.84 | 6.27 | 63.73 | 9.79 | 6.27 | 64.06 | 10.06 | 6.29 | 62.67 |
| Abohar | 11.0 | 1.7 | 15.6 | 9.35 | 6.40 | 68.40 | 9.70 | 6.35 | 65.53 | 9.69 | 6.34 | 65.50 | 9.96 | 6.36 | 63.96 |

**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 FIO-ESM 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 | 17.59 | 9.38 | 53.31 | 18.60 | 9.27 | 49.82 | 19.03 | 9.25 | 48.60 | 20.78 | 9.11 | 43.86 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 16.7 | 0.9 | 5.2 | 17.63 | 9.36 | 53.09 | 18.67 | 9.23 | 49.43 | 19.10 | 9.21 | 48.19 | 20.86 | 9.06 | 43.45 |
| Amritsar | 15.5 | 0.7 | 4.6 | 16.63 | 9.49 | 57.08 | 17.62 | 9.47 | 53.73 | 18.04 | 9.49 | 52.63 | 19.72 | 9.45 | 47.93 |
| Patiala | 17.6 | 0.5 | 2.8 | 18.10 | 8.89 | 49.13 | 19.14 | 8.73 | 45.61 | 19.58 | 8.69 | 44.36 | 21.39 | 8.48 | 39.68 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 16.9 | 0.6 | 3.8 | 17.39 | 9.61 | 55.29 | 18.40 | 9.50 | 51.64 | 18.84 | 9.48 | 50.32 | 20.61 | 9.35 | 45.39 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 20.3 | 2.0 | 9.8 | 17.26 | 9.55 | 55.31 | 18.27 | 9.45 | 51.74 | 18.70 | 9.45 | 50.50 | 20.46 | 9.33 | 45.62 |
| Abohar | 17.6 | 1.6 | 8.9 | 17.46 | 9.92 | 56.81 | 18.50 | 9.80 | 52.94 | 18.93 | 9.80 | 51.74 | 20.74 | 9.64 | 46.51 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 22.4 | 0.5 | 2.4 | 25.36 | 3.50 | 13.81 | 26.29 | 3.50 | 13.32 | 26.70 | 3.45 | 12.92 | 28.38 | 3.36 | 11.84 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 23.3 | 0.9 | 4.0 | 25.39 | 3.47 | 13.65 | 26.33 | 3.48 | 13.21 | 26.74 | 3.42 | 12.80 | 28.41 | 3.33 | 11.74 |
| Amritsar | 22.5 | 0.8 | 3.7 | 24.57 | 3.34 | 13.61 | 25.59 | 3.30 | 12.88 | 26.02 | 3.28 | 12.62 | 27.71 | 3.16 | 11.39 |
| Patiala | 23.9 | 0.6 | 2.3 | 25.36 | 3.37 | 13.29 | 26.29 | 3.35 | 12.75 | 26.64 | 3.36 | 12.62 | 28.33 | 3.26 | 11.50 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 23.9 | 0.7 | 3.1 | 25.42 | 3.62 | 14.24 | 26.38 | 3.57 | 13.55 | 26.75 | 3.60 | 13.45 | 28.47 | 3.46 | 12.16 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 26.7 | 1.7 | 6.4 | 25.22 | 3.62 | 14.36 | 26.20 | 3.56 | 13.58 | 26.60 | 3.57 | 13.41 | 28.31 | 3.44 | 12.15 |
| Abohar | 24.0 | 1.7 | 7.0 | 25.76 | 3.84 | 14.89 | 26.75 | 3.78 | 14.12 | 27.16 | 3.77 | 13.89 | 28.88 | 3.66 | 12.66 |
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 10.0 | 0.8 | 8.0 | 9.56 | 6.35 | 66.41 | 10.62 | 6.19 | 58.22 | 11.08 | 6.22 | 56.14 | 12.92 | 6.06 | 46.95 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 10.0 | 0.9 | 8.9 | 9.62 | 6.34 | 65.92 | 10.73 | 6.17 | 57.52 | 11.19 | 6.19 | 55.36 | 13.04 | 6.03 | 46.29 |
| Amritsar | 8.4 | 0.7 | 8.5 | 8.50 | 6.39 | 75.19 | 9.44 | 6.24 | 66.04 | 9.84 | 6.30 | 64.06 | 11.54 | 6.22 | 54.01 |
| Patiala | 11.1 | 0.6 | 5.1 | 10.56 | 6.21 | 58.78 | 11.76 | 6.05 | 51.44 | 12.28 | 6.09 | 49.58 | 14.22 | 5.87 | 41.31 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 9.9 | 0.8 | 8.2 | 9.11 | 6.32 | 69.42 | 10.17 | 6.15 | 60.43 | 10.64 | 6.21 | 58.36 | 12.49 | 6.04 | 48.40 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 13.7 | 2.2 | 16.2 | 9.07 | 6.31 | 69.68 | 10.11 | 6.14 | 60.76 | 10.55 | 6.19 | 58.74 | 12.37 | 6.04 | 48.88 |
| Abohar | 11.0 | 1.7 | 15.6 | 8.90 | 6.40 | 71.97 | 10.00 | 6.21 | 62.10 | 10.44 | 6.26 | 59.99 | 12.35 | 6.08 | 49.33 |

**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 FIO-ESM model inPunjab

| 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 | 447.8 | 4.7 | 382.0 | 502.2 | 5.3 | 386.3 | 435.7 | 4.7 | 392.1 | 422.3 | 4.5 | 388.6 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 759.0 | 232.4 | 30.6 | 580.3 | 6.0 | 375.6 | 586.0 | 5.9 | 370.3 | 543.0 | 5.9 | 395.2 | 587.1 | 6.5 | 404.0 |
| Amritsar | 722.0 | 198.0 | 27.4 | 614.1 | 6.2 | 366.5 | 601.8 | 6.1 | 368.5 | 595.0 | 6.2 | 379.3 | 619.5 | 6.3 | 373.1 |
| Patiala | 774.0 | 286.2 | 37.0 | 481.8 | 4.9 | 374.7 | 494.7 | 4.9 | 364.8 | 479.4 | 5.0 | 377.9 | 538.2 | 5.3 | 360.3 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 517.0 | 181.2 | 35.0 | 367.1 | 3.7 | 366.5 | 359.0 | 3.6 | 365.3 | 383.7 | 4.0 | 382.0 | 439.4 | 4.4 | 367.3 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 468.0 | 169.8 | 36.3 | 362.2 | 3.6 | 364.9 | 357.4 | 3.6 | 370.3 | 367.3 | 3.6 | 362.6 | 390.4 | 3.9 | 360.8 |
| Abohar | 323.0 | 103.5 | 32.1 | 298.6 | 3.4 | 410.5 | 289.3 | 3.1 | 386.8 | 317.3 | 3.5 | 401.3 | 373.2 | 3.8 | 370.2 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 888 | 279.9 | 31.5 | 406.1 | 6.3 | 286.4 | 436.1 | 7.0 | 295.7 | 391.0 | 6.2 | 294.4 | 375.3 | 6.1 | 297.7 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 634 | 237.8 | 37.5 | 525.4 | 8.0 | 279.0 | 519.8 | 7.9 | 282.3 | 507.2 | 8.0 | 291.3 | 534.1 | 8.8 | 305.4 |
| Amritsar | 579 | 192.2 | 33.2 | 558.9 | 8.3 | 273.6 | 530.1 | 8.1 | 283.0 | 534.5 | 8.3 | 286.3 | 541.6 | 8.5 | 287.6 |
| Patiala | 649 | 277.9 | 42.8 | 449.0 | 6.7 | 274.3 | 420.6 | 6.5 | 286.1 | 429.6 | 6.7 | 287.0 | 480.4 | 7.1 | 273.7 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 427 | 178.4 | 42.0 | 324.4 | 4.9 | 278.5 | 308.3 | 4.8 | 284.9 | 355.0 | 5.4 | 282.3 | 381.8 | 5.9 | 284.4 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 382 | 134.3 | 35.1 | 311.2 | 4.8 | 283.6 | 303.0 | 4.8 | 288.8 | 318.1 | 4.8 | 280.4 | 339.6 | 5.1 | 277.2 |
| Abohar | 262 | 95.0 | 36.3 | 280.0 | 4.5 | 298.4 | 250.2 | 4.1 | 301.4 | 283.0 | 4.7 | 304.3 | 321.1 | 5.0 | 283.8 |
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 159 | 85.3 | 53.6 | 40.9 | 1.3 | 563.0 | 66.3 | 2.2 | 587.3 | 44.1 | 1.5 | 623.8 | 47.5 | 1.3 | 500.3 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 126 | 66.5 | 52.9 | 54.6 | 1.8 | 607.1 | 66.3 | 1.9 | 526.9 | 35.9 | 1.0 | 505.4 | 52.5 | 1.4 | 494.1 |
| Amritsar | 144 | 78.5 | 54.3 | 54.5 | 1.6 | 539.2 | 73.1 | 1.9 | 486.5 | 60.9 | 1.9 | 565.4 | 79.6 | 2.2 | 507.9 |
| Patiala | 125 | 85.7 | 68.8 | 32.3 | 1.0 | 577.5 | 73.2 | 1.8 | 451.8 | 50.1 | 1.4 | 517.4 | 57.9 | 1.6 | 485.7 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 90 | 50.9 | 56.5 | 43.1 | 1.3 | 564.7 | 51.5 | 1.4 | 490.8 | 28.7 | 0.9 | 584.0 | 56.9 | 1.6 | 498.7 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 87 | 69.0 | 78.9 | 50.9 | 1.4 | 508.2 | 54.2 | 1.6 | 518.6 | 48.6 | 1.3 | 511.2 | 50.6 | 1.5 | 529.8 |
| Abohar | 68 | 50.7 | 75.1 | 18.5 | 0.9 | 909.3 | 38.8 | 1.1 | 518.6 | 34.2 | 1.1 | 610.3 | 52.7 | 1.7 | 598.6 |

**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 FIO-ESM 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 | 521.7 | 5.5 | 384.9 | 487.7 | 5.1 | 380.5 | 489.5 | 5.3 | 395.0 | 481.7 | 5.4 | 407.7 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 759.0 | 232.4 | 30.6 | 546.6 | 5.9 | 396.0 | 548.3 | 5.5 | 364.7 | 558.7 | 6.0 | 391.3 | 561.8 | 5.8 | 374.2 |
| Amritsar | 722.0 | 198.0 | 27.4 | 596.4 | 5.7 | 350.8 | 600.5 | 5.9 | 359.5 | 781.2 | 6.9 | 320.5 | 615.8 | 5.8 | 344.1 |
| Patiala | 774.0 | 286.2 | 37.0 | 546.2 | 5.3 | 354.7 | 569.9 | 5.9 | 379.5 | 570.3 | 5.8 | 371.4 | 587.2 | 6.1 | 382.3 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 517.0 | 181.2 | 35.0 | 416.6 | 4.1 | 359.5 | 420.4 | 4.3 | 372.7 | 417.9 | 4.1 | 360.8 | 407.5 | 4.2 | 374.9 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 468.0 | 169.8 | 36.3 | 406.2 | 4.0 | 360.2 | 411.3 | 4.1 | 364.7 | 404.6 | 4.0 | 364.4 | 395.9 | 4.0 | 372.3 |
| Abohar | 323.0 | 103.5 | 32.1 | 367.6 | 3.7 | 370.4 | 384.5 | 4.0 | 379.2 | 384.3 | 4.0 | 376.1 | 380.8 | 4.0 | 383.2 |
| *Kharif* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 888 | 279.9 | 31.5 | 469.0 | 7.5 | 293.3 | 429.4 | 6.8 | 292.2 | 427.3 | 7.1 | 306.4 | 441.1 | 7.3 | 304.1 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 634 | 237.8 | 37.5 | 494.7 | 8.0 | 299.1 | 471.0 | 7.3 | 284.6 | 487.4 | 8.0 | 303.7 | 493.2 | 7.7 | 288.2 |
| Amritsar | 579 | 192.2 | 33.2 | 505.8 | 7.5 | 273.3 | 498.3 | 7.7 | 285.3 | 662.2 | 8.9 | 248.1 | 529.2 | 7.7 | 267.1 |
| Patiala | 649 | 277.9 | 42.8 | 464.8 | 7.0 | 276.6 | 507.1 | 8.0 | 288.5 | 493.6 | 7.7 | 287.6 | 492.4 | 7.9 | 295.1 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 427 | 178.4 | 42.0 | 351.8 | 5.4 | 281.4 | 373.9 | 5.7 | 282.7 | 360.2 | 5.5 | 279.0 | 366.9 | 5.6 | 282.9 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 382 | 134.3 | 35.1 | 347.2 | 5.3 | 279.4 | 353.6 | 5.4 | 281.7 | 349.2 | 5.4 | 282.6 | 353.7 | 5.4 | 283.2 |
| Abohar | 262 | 95.0 | 36.3 | 326.9 | 5.0 | 279.1 | 344.9 | 5.4 | 286.0 | 334.5 | 5.2 | 287.8 | 347.2 | 5.4 | 286.7 |
| *Rabi* season variation | | | | | | | | | | | | | | | |
| *Zone II: Undulating plain region* | | | | | | | | | | | | | | | |
| BallowalSaunkhri | 159 | 85.3 | 53.6 | 51.8 | 1.3 | 469.7 | 59.1 | 1.7 | 510.0 | 62.1 | 1.8 | 515.4 | 39.0 | 1.3 | 589.7 |
| Zone III: Central plain region | | | | | | | | | | | | | | | |
| Ludhiana | 126 | 66.5 | 52.9 | 51.8 | 1.5 | 528.4 | 76.5 | 2.0 | 476.0 | 70.5 | 2.0 | 503.6 | 69.6 | 1.9 | 500.6 |
| Amritsar | 144 | 78.5 | 54.3 | 90.6 | 2.5 | 507.8 | 103.2 | 2.8 | 493.2 | 116.8 | 2.9 | 441.4 | 85.7 | 2.2 | 460.5 |
| Patiala | 125 | 85.7 | 68.8 | 81.8 | 2.2 | 489.5 | 63.3 | 1.9 | 549.4 | 77.3 | 2.1 | 495.2 | 93.3 | 3.0 | 579.6 |
| Zone IV: Western plain region | | | | | | | | | | | | | | | |
| Bathinda | 90 | 50.9 | 56.5 | 64.6 | 1.8 | 491.9 | 46.1 | 1.3 | 492.3 | 57.2 | 1.6 | 502.3 | 40.6 | 1.1 | 483.3 |
| Zone V: Western region | | | | | | | | | | | | | | | |
| Faridkot | 87 | 69.0 | 78.9 | 58.2 | 1.7 | 519.7 | 57.6 | 1.7 | 515.7 | 54.7 | 1.5 | 495.6 | 42.3 | 1.1 | 466.3 |
| Abohar | 68 | 50.7 | 75.1 | 41.1 | 1.3 | 596.6 | 39.6 | 1.2 | 554.9 | 49.8 | 1.6 | 564.7 | 33.0 | 1.0 | 557.7 |

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

## Conclusions

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 FIO-ESM model output revealed that in Punjab state the maximum and minimum temperature are projected to increase by 0.4-1.4$^{o}$C and 0.01-3.8$^{o}$C, respectively during mid-century and by 0.1-4.0$^{o}$C and 0.1-6.0$^{o}$C, respectively during 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 more than 1000mm and during the 21$^{st}$ 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 300-400mm, the rainfall is projected to increase by 30-40mm. 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 state and it contributes significantly to 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.

## Acknowledgements

This study was carried out for Ph.D research work in Department of Climate Change and Agricultural Meteorology at Punjab Agricultural University, Ludhiana. The simulated GCM data used in this work was obtained from site *http://gismap.ciat.cgiar.org/MarkSimGCM/* at daily interval under RCP scenarios for Ludhiana.

## References

1. Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I. 'Regional Climate Projections. In: *Climate Change 2007*: The PhysicalScience Basis. Contribution of Working Group I to theFourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon,S., Qin, D., Manning,M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.)].Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.
2. IPCC Summary for Policymakers. In: Climate Change: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Field, C.B., Barros, V.R., Dokken,D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., Mac, C.S., Mastrandrea, P.R., White, L.L.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, 1-32.
3. Islam A, Sikka AK. Climate change and water resources in India: Impact assessment and adptation strategies. *In* "Natural and anthropogenic disasters- Vulner*abi*lity, preparedness and mitigation" (Jha MK ed.), 386-413. Capital Publishing Company, New Delhi and Springer, The Netherlands.
4. Li Z, Calum GT. 'Climate change, adaptation and China's grain production.' *china economic review*, 2014:28:72-89.
5. Pattanaik DR, Rajeevan M. 'Variability of extreme rainfall events over India during south west monsoon season.'*Meteorological Applications*,2010:17:88-104.
6. Satyanarayana P, Srinivas VV. 'Regional frequency analysis of precipitation using large scale atmospheric variables.'

Journal of Geophysical Research 2008, 113. DOI:10.1029/2008JD010412. ISSN, 0148–0227.