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PRECIS-model simulated changes in climatic parameters under various scenarios in different agro-climatic zones of Punjab

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सार – इस अध्ययन में पंजाब के विभिन्न कृषि जलवायविक जोनों क्षेत्रों जैसे जोन II (बलोवाल सौंखटी) जोन III (लुधियाना, अमृतसर, पटियाला और जालंधर) और जोन V (भटिंडा) के लिए 21वीं शताब्दी के लिए भविष्य के अनुकारी जलवायविक आंकड़ों (तापमान और वर्षा) को प्रादेशिक जलवायु मॉडल नामत: PRECIS मॉडल (इम्पैक्ट अध्ययन के लिए प्रादेशिक जलवायु उपलब्ध कराना) का उपयोग करके डाउनस्केल किय गया। अधिकतम और न्यूनतम तापमान तथा वर्षा का निर्धारण करने के लिए वार्षिक और मौसमी आधार पर संशोधित अनुकारी आंकड़ो को पुन: विश्लेषित किया गया। अध्ययन से पता चला कि जलवायु परिवर्तन के विभिन्न परिदृश्यों में पंजाब राज्य के विभिन्न स्थानों में अधिकतम और न्यूनतम तापमान तथा वर्षा 21 वीं शताब्दी के अंत तक कृषि जलवायविक जोन II में क्रमश: 2.0 से 2.2 ºC, 3.3 से 5.4 ºC और 33 से 66% तक; कृषि जलवायविक जोन III में क्रमश 0.4 से 5.8 ºC, 2.5 से 7.4 ºC और 3 से 62% तथा कृषि जल-वायविक जोन V में क्रमश 0.5 से 4.0 ºC, 4.7 से 7.7 ºC और 58 से 69% तक वृद्धि होने की संभावना है। इन प्राचलों के प्रवृत्ति विश्लेषण से पंजाब राज्य में विभिन्न परिदृश्यों के अंतर्गत सकारात्मक रैखिक वृद्धि की प्रवृत्ति का पता चला है।

ABSTRACT. In this study,the future simulated climatic data (temperature and rainfall) for the 21st century were downscaled using the regional climate model, *viz*., PRECIS model (Providing Regional Climates for Impact Studies) for different agro-climatic zones, *i.e*., Zone II (Ballowal Saunkhri), Zone III (Ludhiana, Amritsar, Patiala and Jalandhar) and Zone V (Bathinda) of Punjab. The corrected simulated data were then analyzed on the annual and seasonal basis to quantify the changes in maximum and minimum temperature and rainfall. The study showed that the maximum and minimum temperature and rainfall by the end of 21st century are likely to increase by 2.0 to 2.2 °C, 3.3 to 5.4 °C and 33 to 66% respectively in agro-climatic zone II; by 0.4 to 5.8 °C, 2.5 to 7.4 °C and 3 to 62% respectively in agro-climatic zone III and by 0.5 to 4.0 °C, 4.7 to 7.7 °C and 58 to 69% respectively in agro-climatic zone V at different locations of Punjab state under various scenarios of climate change. The trend analysis of these parameters revealed there is positive linear increasing trend under different scenarios in the Punjab state.

Key words – Climate change, PRECIS model, SRES scenarios, A1B scenario, A2 scenario, B2 scenario, Punjab.

1. Introduction

Climate change is one of the most important global environmental challenges facing humanity with implications for food production, natural ecosystems, freshwater supply, health, *etc*. According to the latest scientific assessment, the earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era. Further evidence shows that most of the warming (of 0.1 °C per decade) observed over the last 50 years, is attributable to human activities (Gautam *et al*., 2013). The Intergovernmental Panel on Climate Change (IPCC) projects that the global mean temperature may increase between 1.4 and 5.8 degree Celsius (°C) by 2100 (Gautam *et al*., 2013). This unprecedented increase is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production and related processes. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India.

Climate change has been observed at global, regional, and local scales (IPCC, 2007; IPCC, 2014; Fitzpatrick *et al*., 2008) and is simulated to impact precipitation and temperature patterns to varying degrees in different parts of the world (Root *et al*., 2005; William *et al*., 2007). Differences in both the seasonal distribution and annual total accumulations of precipitation, or mean monthly temperature patterns and variation may impact the local and regional environment, and the welfare of both humans and biodiversity within that environment. Changes in temperature could yield similarly disruptive

impacts such as increased droughts as a result of higher temperatures (Sheffield and Wood, 2008).

The climate change uncertainties are due to two main reasons, firstly the future factors that may influence climate such as emissions of greenhouse gases, volcanic eruptions, and changing solar activity are uncertain; and secondly the knowledge of how strongly the climate system responds to external influences, particularly increases in greenhouse gases, is incomplete. There is still considerable uncertainty about the rates of change that can be expected, but it is clear that these changes will be increasingly manifested in important and tangible ways, such as changes in extremes of temperature and precipitation, decreases in seasonal and perennial snow and ice extent, and sea level rise (Karl and Trenberth, 2003). IPCC has given different scenarios in its Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al*., 2006). The A1B scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter and the rapid introduction of new and more efficient technologies. There would be the balanced use of all the fossil and non-fossil energy resources. The A2 scenario describes a very heterogeneous world with continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other scenarios. The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change. The scenario is also oriented toward environmental protection and social equity and it focuses on local and regional levels.

Researchers have applied GCM outputs to assess potential climate impacts in a variety of areas. Developing high resolution models on a global scale is not only expensive for climate change simulations, but also suffers from errors due to inadequate representation of climate processes worldwide. Rupakumar *et al*. (2006) simulated the regional climate of India by using PRECIS for the baseline 1961-1990 as well as 2071-2100 under the SRES scenarios A2 and B2. Krishnakumar *et al*. (2011) also used PRECIS model for India for the period 1961-2098 using SRES scenario A1B.

In the present study, the outputs for IPCC SRES scenarios, *i.e*., A1B, A2 and B2 in Punjab state were analyzed. The regional scale analyses are necessary to identify the range of changes that may occur in different areas with respect to temperature and precipitation. Also, while multiple climate change-related studies have been performed at the global and national scale, the literature for the regional scale is more limited. Therefore we planned to analyze the simulated changes in the temperature and precipitation using outputs from the PRECIS model for precipitation and temperature for mid and end of the 21st century for the different zones of Indian Punjab.

2. Materials and method

The daily climatic data for the past 30 years (1970-1990) on maximum and minimum temperature and rainfall were used in this study for Ballowal Saunkhri (31° 6′ 5″ N, 76° 23′ 26″ E), Amritsar (31° 31′ 56″ N, 74° 52′ 25″ E), Jalandhar (31° 31′ 50″ N, 75° 34′ 25″ E), Ludhiana, (30° 75′ 48″ N, 75° 48′ 30″ E), Patiala (30° 19′ 38″ N, 76° 24′ 00″ E) and Bathinda (30° 12′ 32″ N, 74° 57′ 09″ E) under different agro-climatic regions of Punjab state. The baseline (1961-1990) and simulated (2021-2100) climatic data for different agro-climatic region of the Punjab was downscaled using PRECIS (Providing Regional Climates for Impact Studies) model prepared by IITM, Pune. The daily data for maximum temperature, minimum temperature and rainfall for the baseline period (1961-1990) and simulated data under A1B scenario for mid century (2021-2050) and under A1B, A2 and B2 scenarios for the end of 21st century (2071-2100) were downscaled using PRECIS model. Thereafter the biases in the modeled data were minimized by applying different method correction functions developed from observed and modeled data and further the simulated weather data for the mid and end century was corrected by applying correction factor. Then the corrected futuristic daily weather data was analyzed on annual, *kharif* season (May-October), and *rabi* season (November-April) basis to quantify the changes in maximum temperature (°C), minimum temperature (°C) and rainfall (mm) from the baseline period. The trend analysis of the baseline and simulated data were done by calculating their respective annual linear average which was then regressed against time to obtain their regression coefficients. The *F* values (observed) were calculated using the formula as given below:

$$F = \frac{R^2}{1-R^2}\,\frac{n-p-1}{p}$$

where, R^2 is regression coefficient, n is number of observations, p is the number of independent variable whose value for linear regression is one. This calculated value of F was compared with tabulated value of F (p, n-p-1) at 1% level of significance to test the significance of the regression coefficient.

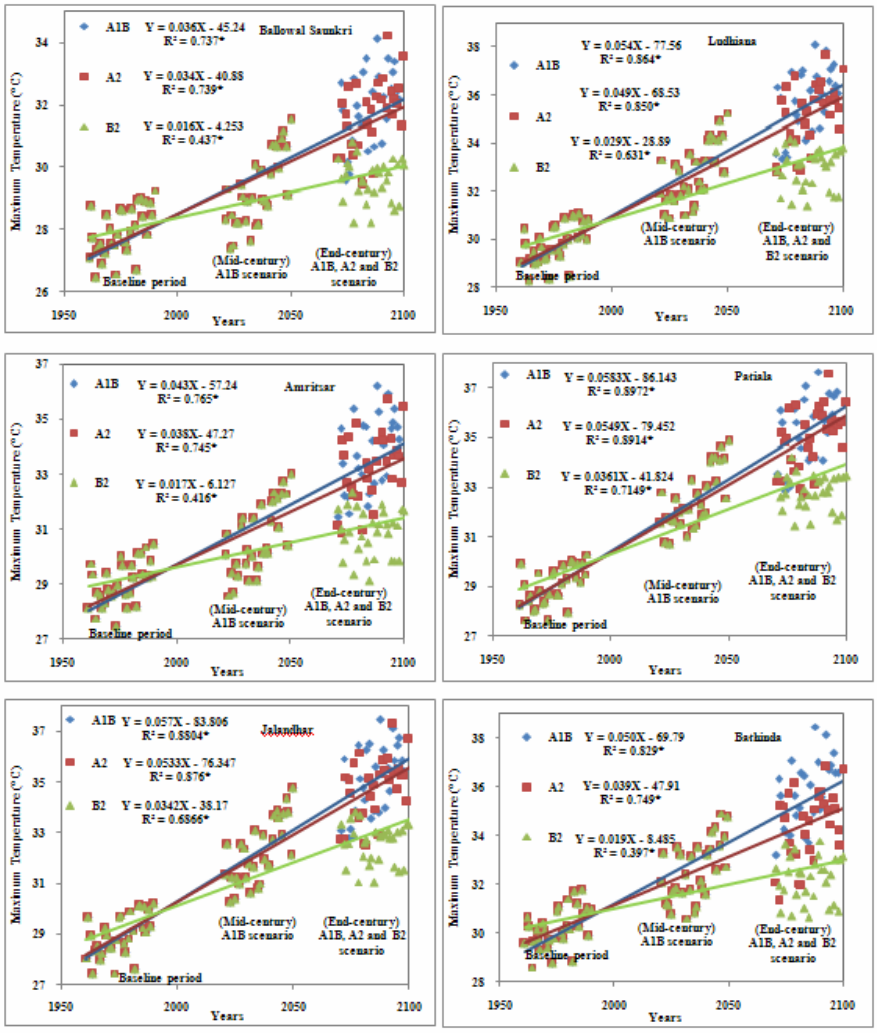

Fig. 1. PRECIS-model simulated changes in maximum temperature under different scenarios of climate change in Punjab State. Significant at 1% level of significance

3. Results and discussion

3.1 *Changes in maximum temperature*

The annual and seasonal maximum temperature at different locations of Punjab during the baseline period, mid and end 21st century have been presented in Table 1. The trend analysis of maximum temperature revealed that by the end of 21st century, the maximum temperature has been predicted to increase at the rate of 0.03 to 0.05 °C/year under AIB and A2 scenarios and 0.01 to 0.03 °C/year under B2 scenario at all the locations under different agro-climatic regions of Punjab state (Fig. 1).

The maximum temperature is expected to increase during the mid century in all the zones under study except Zone II (Ballowal Saunkhri). In the Zone II, the annual and *kharif* season maximum temperature may decrease by 0.4 and 0.9 °C (under the A1B scenario) as compared to the baseline temperature, whereas, there is no change in the maximum temperature for the *rabi* season. By the end of the century, the annual maximum temperature may increase by the 2.2 °C and 2.0 °C under the A1B and A2 scenario, respectively; however, it is expected to decrease by 0.1 °C during the end of the 21st century under B2 scenario. The *kharif* maximum temperature may increase by 1.8 °C under A1B scenario, whereas, for A2 and B2 scenario, it is expected to decrease by 0.3 and 1.7 °C, respectively. The *rabi* season maximum temperature is expected to increase by 1.4 to 4.3 °C during the end of century under different climate change scenarios.

TABLE 1

PRECIS model simulated changes in maximum temperature for the mid and end century for different scenarios and their deviation from baseline period in Punjab

Time period	Baseline period	Mid century (2021-2050)	End century (2071-2100)		
		A1B	A1B	A2	B2
Zone II North-eastern zone (Ballowal Saunkhri)					
Annual	29.7	29.3 (-0.4)*	31.9 (+2.2)	31.7 (+2.0)	29.6 (-0.1)
Kharif	34.0	33.1 (-0.9)	35.8 (+1.8)	33.7 (-0.3)	32.3 (-1.7)
Rabi	25.3	25.3 (0.0)	27.9 (+2.6)	29.6 (+4.3)	26.7 (+1.4)
Zone III Central plain zone					
Amritsar					
Annual	30.4	30.7 (+0.3)	33.7 (+3.3)	33.2 (+2.8)	30.8 (+0.4)
Kharif	35.7	35.7 (0.0)	39.1 (+3.4)	36.3 (+0.6)	34.5 (-1.2)
Rabi	25.0	25.5 (+0.5)	28.3 (+3.3)	30.0 (+5.0)	27.0 (+2.0)
Jalandhar					
Annual	29.8	32.2 (+2.4)	35.1 (+5.3)	34.7 (+4.9)	32.6 (+2.8)
Kharif	35.0	38.8 (+3.8)	41.8 (+6.8)	39.4 (+4.4)	37.9 (+2.9)
Rabi	24.6	25.5 (+0.9)	28.3 (+3.7)	30.1 (+5.5)	27.0 (+2.4)
Ludhiana					
Annual	29.8	32.7 (+2.9)*	35.6 (+5.8)	35.2 (+5.4)	32.9 (+3.1)
Kharif	35.1	37.3 (+2.2)	40.4 (+5.3)	38.0 (+2.9)	36.4 (+1.3)
Rabi	24.5	28.0 (+3.5)	30.9 (+6.4)	32.4 (+7.9)	29.3 (+4.8)
Patiala					
Annual	30.1	32.5 (+2.4)	35.3 (+5.2)	35.0 (+4.9)	32.8 (+2.7)
Kharif	34.9	38.1 (+3.2)	40.8 (+5.9)	38.8 (+3.9)	37.5 (+2.6)
Rabi	25.2	26.8 (+1.6)	29.6 (+4.4)	31.1 (+5.9)	28.0 (+2.8)
Zone V South-western zone (Bathinda)					
Annual	31.7	32.6 (+0.9)	35.7 (+4.0)	34.4 (+2.7)	32.2 (+0.5)
Kharif	37.2	37.2 (0.0)	40.6 (+3.4)	37.1 (-0.1)	35.4 (-1.8)
Rabi	26.1	27.7 (+1.6)	30.7 (+4.6)	31.8 (+5.7)	28.8 (+2.7)

* Figures in the parenthesis denote deviation from the baseline value

**Baseline period for Ballowal Saunkhri 1984-90, for Amritsar, Jalandhar, Ludhiana and Patiala (1971-90) and for Bathinda (1977-90)

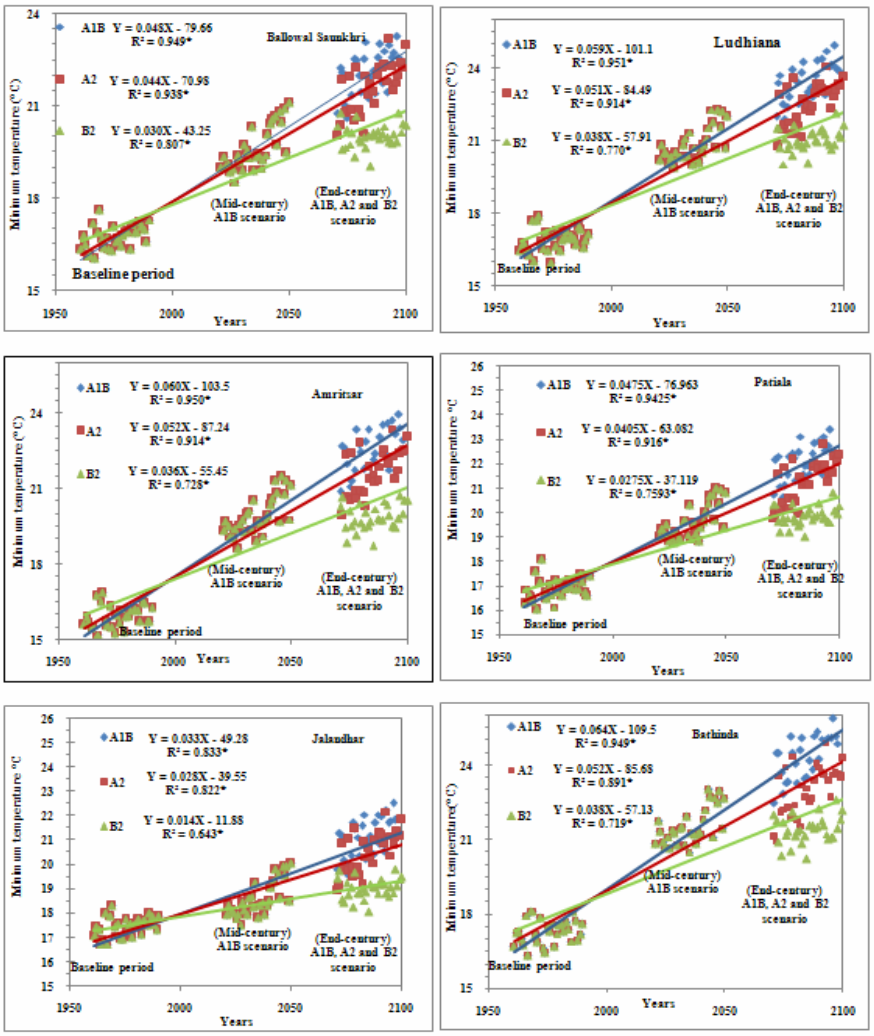

Fig. 2. PRECIS - model simulated changes in minimum temperature under different scenarios of climate change in Punjab state. Significant at 1% level of significance

All the districts in the Zone III, *i.e.*, central plain zone are predicted to have an increase in maximum temperature during mid and end of the 21st century as compared to the baseline period. The deviation in the maximum temperature from the baseline would be lower in Amritsar district as compared to other districts in the Central plain zone. The deviation in maximum temperature from the baseline on annual, *kharif* and *rabi* basis by the end of 21st century is expected to be 0.4 to 3.3 °C, -1.2 to 3.4 °C and 2.0 to 5.0 °C, respectively for Amritsar, 2.8 to 5.3 °C, 2.9 to 6.8 °C and 2.4 to 3.7 °C, respectively for Jalandhar; 3.1 to 5.8 °C, 1.3 to 5.3 °C and 4.8 to 7.9 °C, respectively for Ludhiana and 2.7 to 5.2 °C, 2.6 to 5.9 °C and 2.8 to 5.9 °C, respectively for Patiala under different scenarios.

The temperature data for south western zone (Zone V) also shows warming trends. The PRECIS model projects a temperature rise of 0.9 °C and 1.6 °C annually and *rabi* season, respectively, under the A1B scenario for 2020-2050s compared to the baseline. By end of 21st century, under different scenarios, the deviation in maximum temperature from the baseline on annual, *kharif* and *rabi* basis is expected to be 4.4 to 7.7 °C, 6.1 to 9.6 °C and 3.3 to 5.7 °C, respectively for Bathinda. A mean temperature rise of 2.9-4.1 °C for India under B2 and A2 scenario in 2080's relative to 1970's was reported by Rupakumar *et al.* (2006). Similarly, a warming of 3.5-4.3 °C over the same period for A1B scenario has been reported by Krishankumar *et al.* (2011).

3.2 *Changes in minimum temperature*

The annual and seasonal minimum temperature at different locations of Punjab during the baseline period, mid and end 21st century have been presented in Table 2.

TABLE 2

PRECIS model simulated changes in minimum temperature for the mid and end century for different scenarios and their deviation from baseline period in Punjab

Time period	Baseline period	Mid century (2021-2050)	End century (2071-2100)		
		A1B	A1B	A2	B2
Zone II North-eastern zone (Ballowal Saunkhri)					
Annual	16.7	19.6 (+2.9)*	22.1 (+5.4)	21.6 (+4.9)	20.0 (+3.3)
Kharif	22.8	26.8 (+4.0)	29.3 (+6.5)	28.3 (+5.5)	27.1 (+4.3)
Rabi	10.6	12.3 (+1.7)	14.8 (+4.2)	14.8 (+4.2)	12.8 (+2.2)
Zone III Central plain zone					
Amritsar					
Annual	15.4	19.9 (+4.5)	22.6 (+7.2)	21.7 (+6.3)	19.9 (+4.5)
Kharif	22.3	29.0 (+6.7)	31.9 (+9.6)	30.6 (+8.3)	29.9 (+7.6)
Rabi	8.3	10.7 (+2.4)	13.1 (+4.8)	12.6 (+4.3)	10.5 (+2.2)
Jalandhar					
Annual	16.0	18.6 (+2.6)	21.1 (+5.1)	20.6 (+4.6)	19.0 (+3.0)
Kharif	22.8	25.3 (+2.5)	27.9 (+5.1)	26.8 (+4.0)	25.5 (+2.7)
Rabi	9.0	11.8 (+2.8)	14.3 (+5.3)	14.3 (+5.3)	12.3 (+3.3)
Ludhiana					
Annual	16.0	20.9 (+4.9)*	23.4 (+7.4)	22.5 (+6.5)	21.0 (+5.0)
Kharif	22.6	30.0 (+7.4)	32.7 (+10.1)	31.6 (+9.0)	30.2 (+7.6)
Rabi	9.3	11.6 (+2.3)	14.0 (+4.7)	13.4 (+4.1)	11.6 (+2.3)
Patiala					
Annual	17.3	19.6 (+2.3)	22.1 (+4.8)	21.3 (+4.0)	19.8 (+2.5)
Kharif	23.6	25.9 (+2.3)	28.4 (+4.8)	27.3 (+3.7)	26.2 (+2.6)
Rabi	10.9	13.2 (+2.3)	15.7 (+4.8)	15.2 (+4.3)	13.4 (+2.5)
Zone V South-western zone (Bathinda)					
Annual	16.7	21.5 (+4.8)	24.4 (+7.7)	23.0 (+6.3)	21.4 (+4.4)
Kharif	23.8	30.3 (+6.5)	33.4 (+9.6)	31.3 (+7.5)	29.9 (+6.1)
Rabi	9.5	12.6 (+3.1)	15.2 (+5.7)	14.6 (+5.1)	12.8 (+3.3)

*Figures in the parenthesis denote deviation from the baseline value

**Baseline period for Ballowal Saunkhri 1984-90, for Amritsar, Jalandhar, Ludhiana and Patiala (1971-90) and for Bathinda (1977-90)

TABLE 3

PRECIS model simulated changes in rainfall for the mid and end century for different scenarios and their deviation from baseline period in Punjab

Time period	Baseline (1961-1990)	Mid century (2021-2050)	End century (2071-2100)		
		A1B	A1B	A2	B2
Zone II North-eastern zone (BallowalSaunkhri)					
Annual	1173	1601 (+429)*	1950 (+777)	1621 (+449)	1627 (+454)
Kharif	1004	1371 (+367)	1690 (+685)	1518 (+513)	1488 (+483)
Rabi	169	233 (+64)	254 (+85)	105 (-64)	142 (-27)
Zone III Central plain zone					
Amritsar					
Annual	743	1050 (+307)	1079 (+336)	1041 (+298)	1056 (+313)
Kharif	590	872 (+282)	892 (+302)	979 (+389)	965 (+375)
Rabi	154	180 (+26)	180 (+26)	63 (-91)	93 (-60)
Jalandhar					
Annual	771	819 (+48)	983 (+212)	794 (+23)	882 (+111)
Kharif	615	563 (-52)	707 (+92)	651 (+36)	704 (+89)
Rabi	158	258 (+100)	270 (+112)	143 (-15)	180 (+22)
Ludhiana					
Annual	741	1075 (+334)*	1204 (+463)	1066 (+325)	1131 (+390)
Kharif	614	912 (+298)	1027 (+413)	995 (+381)	1035 (+421)
Rabi	128	165 (+37)	172 (+44)	72 (-56)	98 (-30)
Patiala					
Annual	778	1000 (+222)	1245 (+467)	953 (+175)	997 (+219)
Kharif	646	783 (+137)	1007 (+361)	832 (+186)	840 (+194)
Rabi	138	219 (+81)	233 (+95)	122 (-16)	158 (+20)
Zone V South-western zone (Bathinda)					
Annual	560	860 (+300)	882 (+322)	903 (+343)	949 (+389)
Kharif	457	737 (+281)	761 (+304)	849 (+393)	878 (+421)
Rabi	104	124 (+20)	119 (+15)	54 (-50)	73 (-31)

* Figures in the parenthesis denote deviation from the baseline value

**Baseline period for Ballowal Saunkhri 1984-90, for Amritsar, Jalandhar, Ludhiana and Patiala (1971-90) and for Bathinda (1977-90)

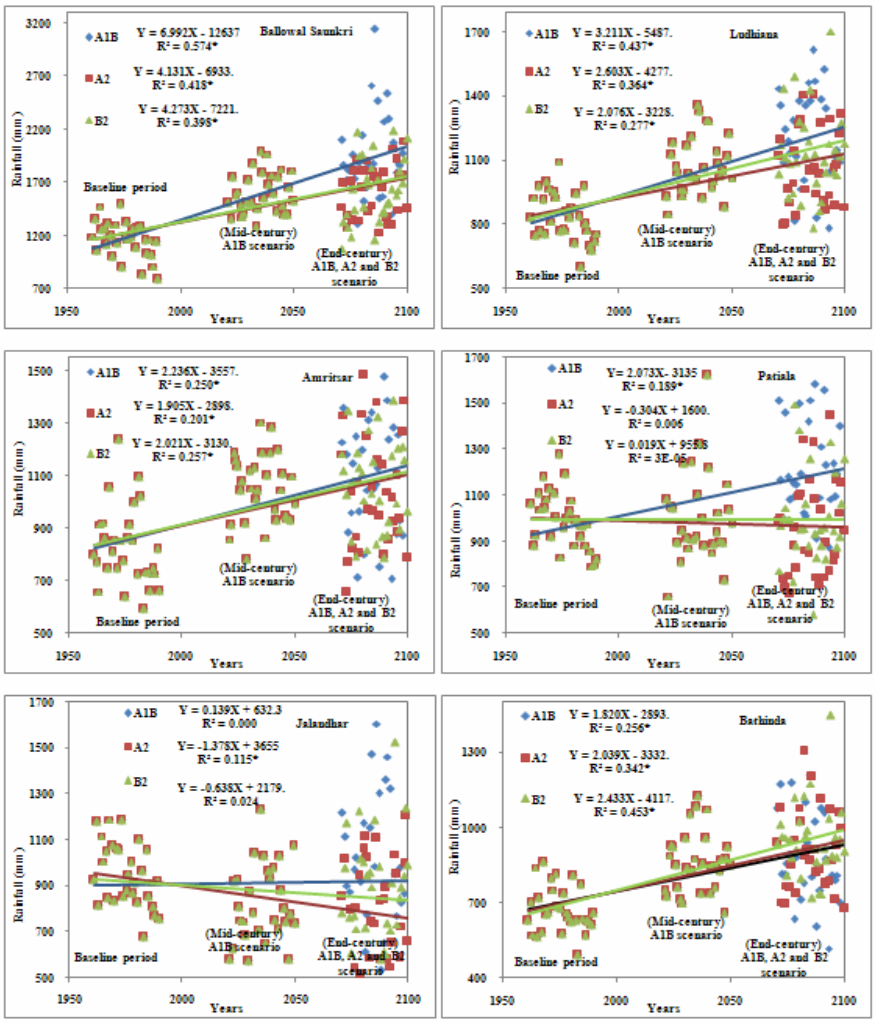

Fig. 3. PRECIS - model simulated changes in rainfall under different scenarios of climate change in Punjab state. Significant at 1% level of significance

The trend analysis of minimum temperature revealed that by the end of 21st century, the minimum temperature has been projected to increase by 0.03 to 0.06 °C/year, 0.02 to 0.05 °C/year and 0.01 to 0.03 °C/year under AIB, A2 and B2 scenarios respectively at all the stations under different agro-climatic regions of Punjab state (Fig. 2.).

The analysis of data reveals overall increasing trend in the minimum temperature in all the zones of Punjab state under different climate change scenarios. At Ballowal Saunkhri, representing the North-eastern zone, the minimum temperature during the mid of 21st century is expected to increase by 2.9 °C annually, 4.0 °C for the *kharif* season and 1.7 °C for the *rabi* season than the baselines of 16.7, 22.6 and 10.8 °C, respectively. By the end century, the minimum temperature on annual, *kharif* and *rabi* basis may range from 20.0 to 22.1 °C, 27.1 to 29.3 °C and 12.8 to 14.8 °C, respectively, under different climate change scenarios.

In the Central plain zone (Zone III), by the end of 21st century, the deviation from the baseline in minimum temperature on annual, *kharif* and *rabi* basis is expected to be 4.5 to 7.2 °C, 4.6 to 9.6 °C and 2.2 to 4.8 °C, respectively for Amritsar, 3.0 to 5.1 °C, 2.7 to 5.1 °C and 3.3 to 5.3 °C, respectively for Jalandhar; 5.0 to 7.4 °C, 7.6 to 10.1 °C and 2.3 to 4.7 °C, respectively for Ludhiana and 2.5 to 4.8 °C, 2.6 to 4.8 °C and 2.5 to 4.8 °C, respectively for Patiala under different scenarios. The minimum temperature data for Bathinda lying in South-western zone (Zone V) of Punjab also shows increasing trends. The projections reveal that the annual, *kharif* and *rabi* minimum temperature under different scenarios during the period 2070-2100 at Bathinda district may

increase by 4.4 to 7.7 °C, 6.1 to 9.6 °C and 3.3 to 5.7 °C, respectively than that of baseline.

3.3 *Changes in rainfall*

The annual and seasonal rainfall at different locations of Punjab during the baseline period, mid and end 21st century have been presented in Table 3. The trend analysis of rainfall revealed that by the end of 21st century, the rainfall has been projected to increase by 0.13 to 6.99 mm/year, 1.90 to 4.13 mm/year and 0.01 to 4.27 mm/year under A1B, A2 and B2 scenarios respectively at all the stations under different agro-climatic regions of Punjab state (Fig. 3.). The decreasing trend predict a fall in rainfall by the end of 21st century at the rate of 1.37 and 0.63 mm/year under A2 and B2 scenario, respectively at Jalandhar; and 0.30 mm/year under A2 scenario at Patiala.

The PRECIS-model predictions indicate that by 2050s and 2099, rainfall over the different zones of Indian Punjab may increase and extreme rainfall events would rise sharply. The annual, *kharif* and *rabi* rainfall over the North eastern zone during the mid of 21st century is expected to increase by about 36, 37 and 39%, respectively as compared to the baseline. By the end of the century (2071-2100), this increase may range from 33 to 66%, 48 to 68% and -16 to 50% on annual, *kharif* and *rabi* season basis, respectively. The extremes events with 30-65% (2086 under A1B scenario; 2082 and 2086 under A2 scenario and 2094 under B2 scenario) or less (2078, 2088 and 2093 2086 under A1B scenario) rainfall than the normal rainfall of end century may occur.

In the Zone III, the annual, *kharif* and *rabi* rainfall for Amritsar district during mid century is expected to increase by about 41, 47 and 17% as compared to the baseline (743, 590 and 154 mm) respectively. The deviation in rainfall from the baseline on annual, *kharif* and *rabi* basis is expected to be 40 to 45%, 51 to 66% and -59 to 17%, respectively for Amritsar, 3 to 27%, 6 to 15% and -9.0 to 71%, respectively for Jalandhar; 44 to 62%, 62 to 69% and -44 to 38%, respectively for Ludhiana and 22 to 60%, 29 to 56% and -14 to 69% respectively for Patiala under different scenarios.

For Amritsar, the extreme rainfall events with ≥30% less rainfall than normal rainfall for end century are expected during years 2078, 2088 and 2093 under A1B scenario; whereas year 2090 with 37% more rainfall than normal. Similarly, under A2 scenario, the year 2073 with about 36% less rainfall, and the years 2081, 2086 and 2089 with >30% rainfall as compared to the normal (1041 mm) are predicted. The year 2094 with 31% higher rainfall than normal (1056 mm) has been predicted under the B2 scenario.

For Jalandhar, the years 2029, 2078, 2081, 2088, 2089 and 2093 with 30-58% decreased rainfall, and years 2035, 2049, 2084, 2086 and 2091 with 31-50% increased rainfall than normal (982 mm) rainfall of end century are predicted under A1B scenario. The years 2073-74, 2076, 2079, 2083, 2088, 2091-93, 2096-97 and 2100 with about 30 to 57% reduced rainfall than normal (794 mm) rainfall of end century under the A2 scenario are predicted. The years 2075, 2077, 2081, 2086, 2088-89, 2090-92 and 2094-95 may receive about 30 to 56% reduced rainfall as compared to normal (882 mm) rainfall of end century under the B2 scenario, respectively.

The PRECIS model projections for Ludhiana indicate that 30% higher rainfall than the normal rainfall of end century (983, 794 and 882 mm for A1B, A2 and B2 scenario respectively) may occur during the year 2086 under A1B scenario, during the year 2082 and 2086 under A2 scenario and during the year 2073, 2078, 2085 and 2094 under B2 scenario. Similarly, there are possibilities of 30% lower rainfall than the normal during the years 2078, 2088, 2093 under A1B scenario.

For Patiala district, during the mid century, the year 2022 may have 33% less rainfall; whereas, the years 2036 and 2039 with 32-62% higher rainfall respectively than the normal rainfall (1000 mm) of mid century are predicted. The year 2086 of end century under the A1B scenario; years 2082, 2086 and 2094 under the A2 scenario; and years 2078, 2080 and 2094 under B2 scenario may have the extreme high rainfall (33 to 62%) events than normal (1244, 953 and 997mm for A1B, A2 and B2 scenario, respectively) rainfall of end century. The year 2086 under the B2 scenario may have 42% less rainfall than the normal (997 mm) rainfall of end century under B2 scenario.

At the mid of the 21st century, the Zone V (South-western zone) is predicted to receive about 54, 61 and 19% higher rainfall than the baseline rainfall on annual, *kharif* and *rabi* basis, respectively. The model predictions for Bathinda district indicate that the annual, *kharif* and *rabi* rainfall during the end of century may range from 58 to 69%, 67 to 92% and -48 to 14% respectively, under the different climate change scenarios. The events of 30 to 33% less rainfall than the normal (1079, 1041 and 1056 mm for A1B, A2 and B2 scenario, respectively) rainfall of end century may occur during the year 2078 under the A1B scenario; year 2073, 2088 and 2092-93 under A2 scenario; and year 2071 under B2 scenario. The high rainfall event of 30 to 61% rainfall may occur during the year 2084, 2086 and 2091 under A1B scenario; 2094

and 2099 under A2 scenario; and 2078 and 2094 under the B2 scenario. Rajendran and Kitoh, (2008) also simulated high rainfall events by the end of century. The trends of heavy (Palmer *et al*., 2002; Goswami *et al*., 2006) or in some places reduced precipitation (Kitoh *et al*., 2008) have also been observed in some other studies. Precipitation is simulated to increase from 4 to 5% by 2030's and 6 to 14% towards end of century (2080's) (Chaturvedi *et al*., 2012).

4. Conclusion

The results of the present study, as predicted by PRECIS model under the A1B, A2 and B2 scenario, indicate more increase in minimum temperature as compared to increase in maximum temperature during the mid and end 21st century in the Indian Punjab. This means that increase in night time temperature will be more than increase in daytime temperature, thereby decreasing the diurnal range of temperature. This will directly hamper the net photosynthesis rate as the respiratory losses will be more due to higher night time temperatures. Coupled with the decrease in diurnal range of temperature, the extremes of the rainfall with +30% rainfall from the normal have also been predicted to increase in future in the study area. These simulated changes may have implications for agricultural production in the state.

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