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ISSN: 0974-4908
Res. Environ. Life Sci.
9(1) 100-104 (2016)

Possible futuristic rainfall and temperature variability trend in central Indian Punjab

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(Received: May 16, 2015; Revised received: November 19, 2015; Accepted: November 22, 2015)

Abstract: Rainfall and temperature are two important parameters among the climate change variables which can affect agricultural production through their direct as well as indirect effect. An important link between climate change and agricultural productivity is an essential pre-requisite to generate variable predictions about impact of climate change and variability. In this study, MarkSim DSSAT weather file generator was used to predict the rainfall and temperature data on daily basis for SRES emission scenarios (A1B, A2 and B1) under the ECHam5 model for 80 years (2011-2090). The mean decadal rainfall decreases is decreasing in trend (approximately 13.2 percent) from 2011 to 2090 showing higher reduction from mid to end of 21st century. The mean decadal annual rainfall is likely to be maximum during 2011-20 (774.8 mm) followed by 2021-30 (767.3 mm) and minimum during 2081-90 (672.4 mm) being statistically similar among the three scenarios and different among the decades. The decadal maximum temperature is likely to rise by 18.6, 9.3, 10.4 and 13.0 percent under the four respective quarters of the year with an average rise of 12.8 percent. However, the decadal minimum temperature is expected to rise by 50.9, 15.2, 15.7 and 34.6 percent under the four respective quarters of the year with an average rise of 29.1 percent. The rise of temperature is likely to be greater in case of minimum temperature especially in first and fourth quarters respectively.

Key Words: MarkSim, ECHam5 model, climate change, rainfall, temperature

Introduction

Climate change is any significant long-term change in the expected patterns of average weather of a region over a significant period of time under the influences of human practices on climate. Any change in climatic factors such as rainfall and temperature is bound to have a significant impact on crop growth and production as the climate change is one of the main determinants of agricultural production. Studies have shown a significant effect of climate change on five year average crop yield (Cline 2007; Seo and Mendelsohn 2008). The climatic change and carbon-dioxide level can affect the yields of rice and wheat through their direct effect as well as indirect effect such as weather induced changes in incidence of pests and dieses and requirement or availability of irrigation water (Timsina and Humphreys; 2003). Hundal *et al.* (1997) have reported an increasing trend over normal for both annual as well as kharif season rainfall in the past 30 years at Ludhiana. Whereas, Gill *et al.* (2010) have reported rainfall below normal for 24 years for Ludhiana being highest (1334 mm) during 1988 and lowest (379.6 mm) during 1974 showing a rainfall variability having standard deviation of 227.07 and coefficient of variation of 30.14 percent. Further, from the rainfall data analysis collected from different locations in Punjab has reported that five yearly moving five year average trend in annual rainfall showed an overall increase of about 120 mm at Amritsar, 150 mm at Ludhiana, 150 mm at Patiala and 140 mm at Bathinda during past 30 years (Hundal and Prabhjyot-Kaur, 2002b). The global five year average surface temperature increment of about 0.6°C has been reported during the 20th century and an increment between 1.4 and 5.8°C has been reported from the present to 2100 (IPCC, 2001). However, the recent modeling work indicates that the temperature increases by 2100 may be larger than those estimated in 2001 (Stainforth et al., 2005). A gradual increase in minimum temperature of 0.07 °C per year has been reported over the past 30 years at Ludhiana district of Punjab state (Hundal and Prabhjyot-Kaur, 2002a). Developing countries are generally considered most vulnerable to the effects of climate change than more developed countries mainly because of their often limited capacity to adapt (Thomas and Twyman, 2005). Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes particularly temperature increases (IPCC, 2007). The globally increased five year average temperature since the mid 20th century is very likely due to the increased in anthropogenic greenhouse gas concentrations (IPCC, 2007).

The important links between climate and agricultural productivity is an essential pre-requisite to generate variable predictions about of impact of climate change and variability. The emissions scenarios (SRES) have been developed and subsequently widely used to drive climate models and determine the impacts of climate change (IPCC). The SRES scenarios have subsequently been used as inputs to climate change experiments conducted by several modeling groups (Noda *et al.,* 2001; Nozawa *et al.,* 2001; Johns *et al.,* 2003). The numerical weather models (GCMs) have become an integral tool in meteorological research and help scientists simulate future climates in line with IPCC emission scenarios (SRES). In the present study, an attempt has been made to identify the possible futuristic variability trend in rainfall and temperature of Ludhiana district. In this study, MarkSim DSSAT weather file generator was used to predict the climatic data of rainfall, maximum and minimum temperatures for the SRES emission scenarios (A1b, A2 and B1) under the ECHam5 model, a most commonly used model by IPCC community.

Materials and Methods

In this study, MarkSim DSSAT weather file generator was used to predict the rainfall, maximum and minimum temperature data on daily basis for 80 years (2011-2090) for the SRES emission scenario (A1B, A2 and B1) under the ECHam5 model. The data is generated on daily basis for 80 years (2011-2090). The data was first converted to monthly basis and then divided quarterly (January-March, April-June, July-September and October-December).

Study site: Ludhiana district falls in central part of Indian Punjab and is bounded between latitude 30°33`` to 31°01``N and longitude 75°25`` to 76°27``E having geographical area of 3767 km^2. The climate of Ludhiana district can be classified as tropical steppe, hot and semi-arid which is mainly dry with very hot summer and cold winter except during monsoon season. The normal annual rainfall of the district is 680 mm with uneven distribution. The south west monsoon sets in from last week of June and withdraws in end of September, contributes about 70-80% of annual rainfall with July and August being the wettest months. The district has four sub-divisions viz-Ludhiana, Khanna, Samrala and Jagraon and eleven development blocks. In terms of ground water resources in the district, the overall stage of ground water development in the district is of the order of 144 % (CGWB, 2007). The ground water development in all the blocks of the district have been categorized as over exploited except Doraha block where it is critical.

MarkSim-DSSAT weather file generator: MarkSim is a third-order Markov rainfall generator (Jones and Thornton, 1997; 2000; Jones *et al.,* 2002) which has been developed in the 1980s and 1990s to simulate weather from known sources of monthly climate data from around the world (Jones and Thornton 1999; 2000). The model can be fitted to any monthly climate data record by determining to which cluster it belongs and using the relevant regression equations. MarkSim estimates daily maximum and minimum air temperatures values from monthly means of these variables (Richardson, 1981). A central part of MarkSim is the concept of a climate record. This is independent of the scale of the data, but is constant in its form and acceptability to the rest of the MarkSim software. It includes the temporal phase angle that is the degree by which the climate record is rotated in date. This rotation is done to eliminate timing differences in climate events, such as the seasons in the northern and southern hemispheres, so that analysis can be done on standardized climate data. The climate record is rotated to a standard date, using the 12-point Fast Fourier transform, on the basis of the first phase angle calculated using both rainfall and temperature. In MarkSim, almost all operations are done in rotated date space. The estimated GCM differential values are added to the rotated record. The models divide the atmosphere into boxes, where each meteorological variable is represented by one value. The equations of motion are then discretized over these boxes and solved processes that occur at a scale smaller than the box size are represented implicitly. The performance of GCMs follows the technological evolution of supercomputers, leading in particular to more and smaller boxes.

SRES emission scenario (A1B, A2 and B1): The A1 storyline and scenario family, describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter and in several variations of it, the rapid introduction of new and more efficient technologies. Major underlying themes are convergence between regions, capacity-building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. A1 is subdivided into A1FI (fossil intensive) A1T (high-technology) and A1B (balanced) (Nakicenovic *et al.,* 2000). The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines (Nakicenovic *et al.,* 2000). The B1 storyline and scenario family describes a convergent world with the

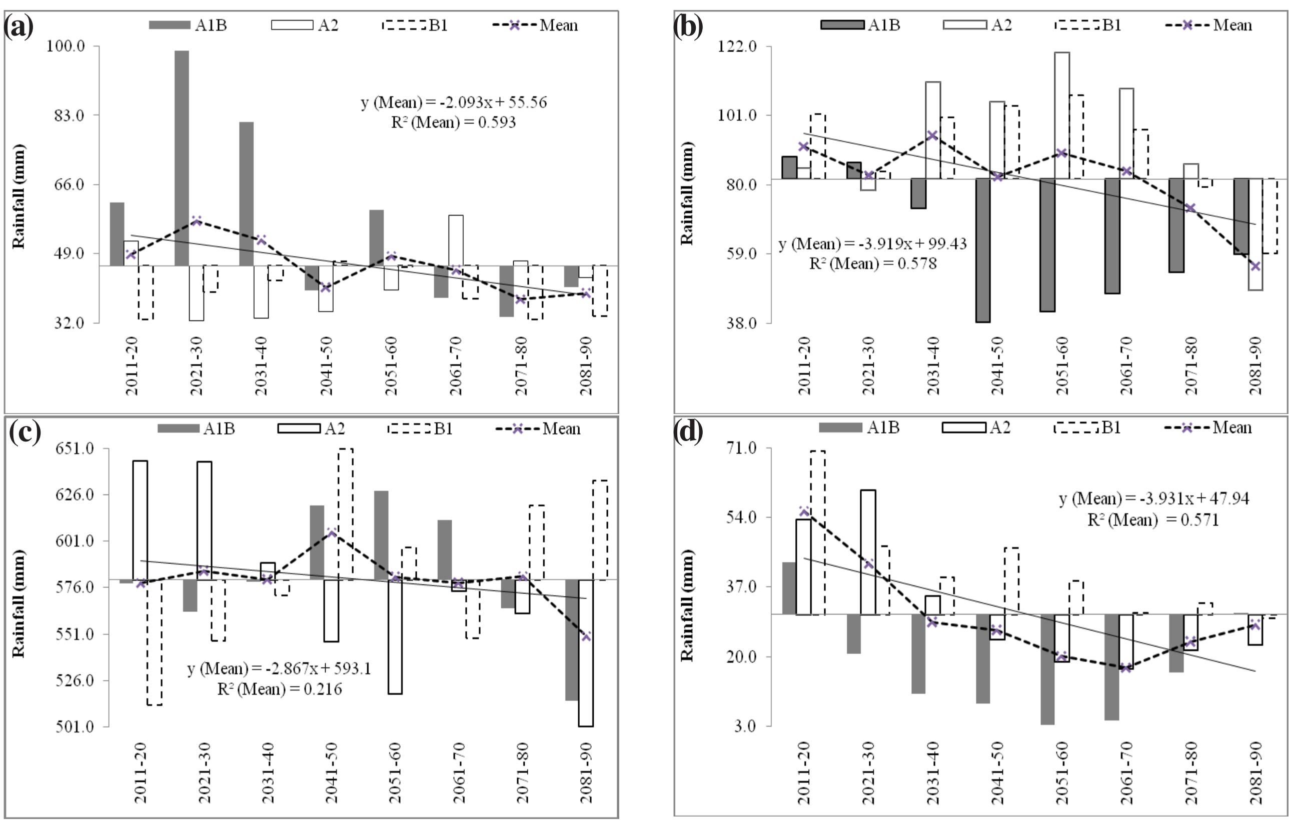

Fig.1: Rainfall (10 year average) variation during a) Quarter-I, b) Quarter-II, c) Quarter-III, d) Quarter-IV and annual rainfall for the period under study (2011-2090)

same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives (Nakicenovic *et al.,* 2000).

Result and Discussion

Rainfall (mm): The study reveals that the mean decadal rainfall is continuously decreasing in trend among all the three scenarios for the period under study under all the four quarters during a year. The rainfall is expected to decrease by 2.5 percent from 2011-20 to mid 21st century (2041-50) and 13.2% from 2011-20 to end century (2081-90) respectively, showing higher reduction from mid to end century.The mean decadal annual rainfall is highest (774.8 mm) during 2011-20 followed by 767.3 mm during 2021-30 and lowest (672.4 mm) during 2081-90. The rainfall is highest and lowest under A2 and A1B scenarios repectively being statistically similar among the three scenarios (A1B, A2 and B1) and different among the decades.

Quarter-I: The decadal rainfall is decreasing in trend under all the three scenarios throughout the study period from 2011 to 2090 with correlation coefficient (R^2) value of 0.593 (Fig. 1a). In the first quarter, the mean decadal rainfall is 46.1mm being highest (56.8 mm) and lowest (39.0 mm) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 26.2 % being highest (41.2%) and lowest (14.7 %) under A1B and B1 scenarios respectively. The decadal rainfall is expected to decrease by 16.2 % from 2011 to 2090, the decrease being highest (33.7%) under A1B scenario.

Quarter-II: The decadal rainfall is decreasing in trend under all the three scenarios for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.578 (Fig. 1b). In the second quarter, the mean decadal rainfall is 81.8 mm being highest (92.9 mm) and lowest (60.9 mm) under A2 and A1B scenarios respectively. The mean decadal cofficient of variation is 25.1% being highest (32.3%) and lowest (17.8%) under A1B and B1 scenarios respectively. The decadal rainfall is expected to decrease by 39.6 % from 2011 to 2090, the decrease being highest (43.6%) under A2 scenario.

Quarter-III: The decadal rainfall is decreasing in trend under all the three scenarios for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.216 (Fig. 1c). In the third quarter, the mean decadal rainfall is 580.3 mm being highest (585.4 mm) and lowest (572.6 mm) under B1 and A2 scenarios respectively. The mean decadal cofficient of variation is 7.9% being highest (9.1%) and lowest (6.4%) under A2 and A1B scenarios respectively. The decadal rainfall is expected to decrease by 3.2% from 2011 to 2090, the decrease being highest (22.1%) under A2 scenario.

Quarter-IV: The decadal rainfall is decreasing in trend under all the three scenarios for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.571(Fig. 1d). In the third quarter, the mean decadal rainfall is 30.3 mm being highest (41.9 mm) and lowest (17.2 mm) under B1 and A1B scenarios respectively. The mean decadal cofficient of variation is 54.8% being highest (80.3%) and lowest (31.6%) under A1B and B1 scenarios respectively. The decadal rainfall is expected to decrease by 47.9% from 2011 to 2090, the decrease being highest (58.1%) under B1 scenario.

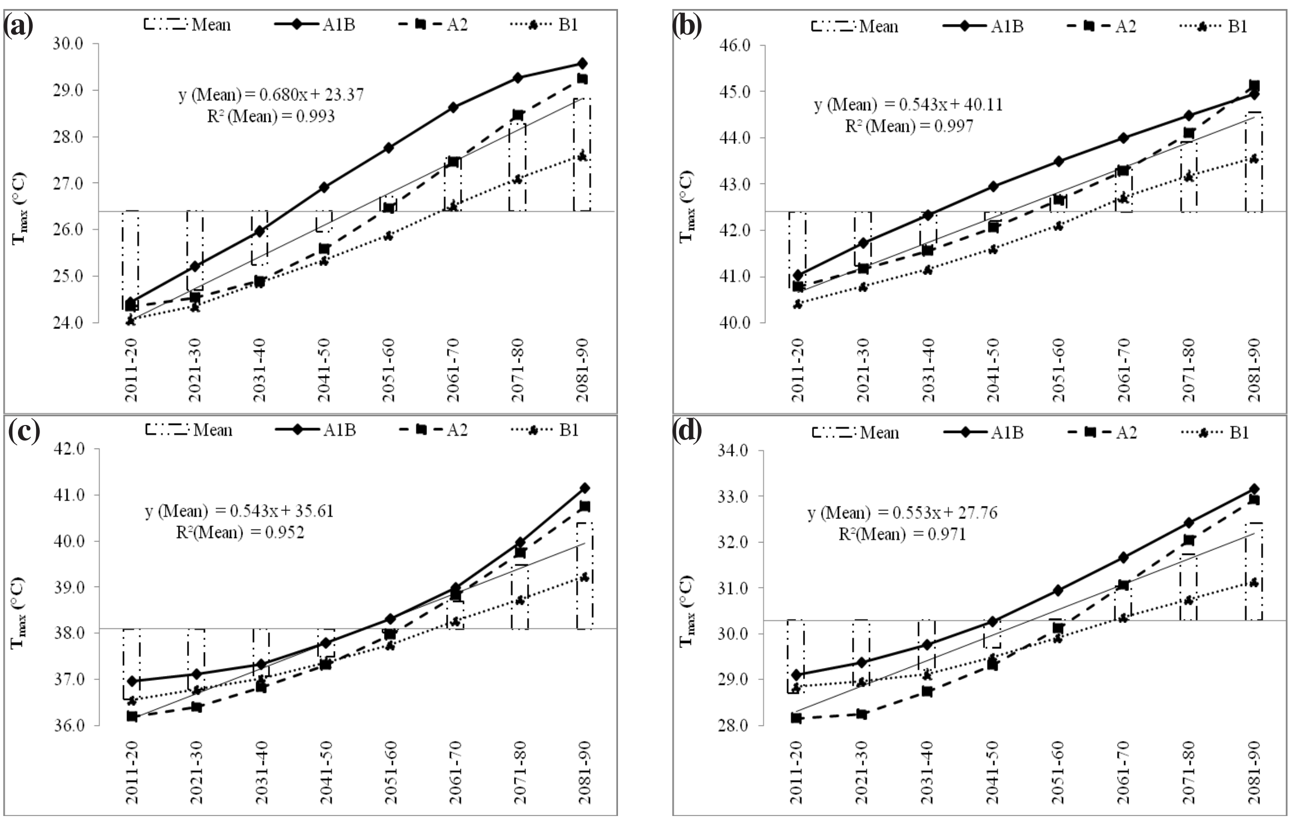

Fig.2: Maximum temperature (10 year average) variation during a) Quarter-I, b) Quarter-I I, c) Quarter-III and d) Quarter-IV for the period under study (2011-2090)

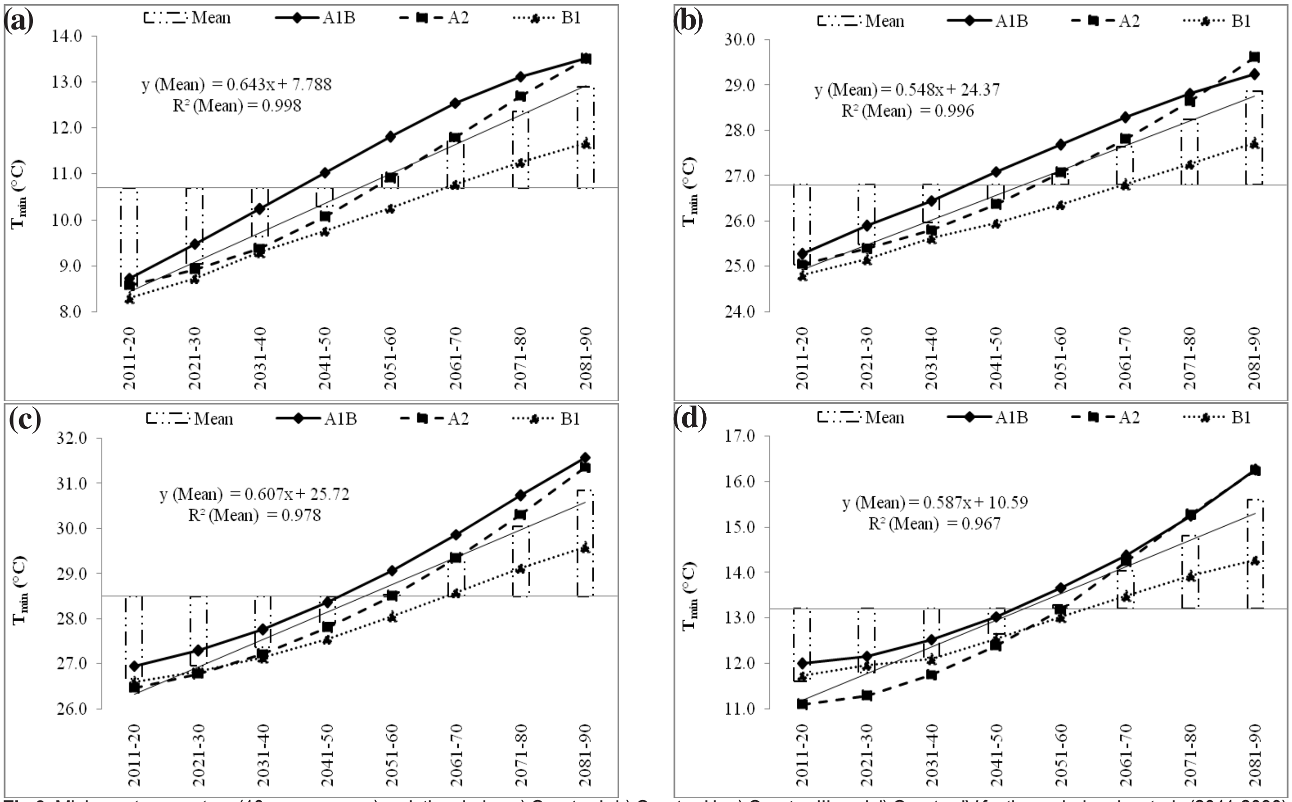

Fig.3: Minimum temperature (10 year average) variation during a) Quarter-I, b) Quarter-II, c) Quarter-III and d) Quarter-IV for the period under study (2011-2090)

Temperature - Maximum temperature (T_{max}): The mean decadal T_{max} is increasing in trend among all the three scenarios throughout the year for the period under study with correlation coefficient (R^2) values of 0.993, 0.997, 0.952 and 0.971 respectively under the four respective quarters. The mean decadal T_{max} is expected to rise by 18.6, 9.3, 10.4 and 13.0% under four rspective quarters, the rise being more from mid towards the end of century (2051-2090).

Quarter-I: The mean decadal T_{max} is increasing in trend under all the three scenarios during quarter-I for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.993 (Fig. 2a). In the first quarter, the mean decadal T_{max} is 26.4°C being highest (27.2°C) and lowest (25.7°C) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 6.3 percent being highest (7.0%) and lowest (5.0%) under A1B and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 18.6%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (21.0%) and lowest (14.7%) under A1B and B1 scenarios recpectively.

Quarter-II: The mean decadal maximum temperature is increasing in trend under all the three scenarios during quarter-II for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.997 (Fig. 2b). In the first quarter, the mean decadal T_{max} is 42.6°C being highest (43.1°C) and lowest (42.6°C) under A1B and A2 scenarios respectively. The decadal cofficient of variation is 3.1 percent being highest (3.5%) and lowest (2.7%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 9.3%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (10.7%) and lowest (7.8%) under A2 and B1 scenarios recpectively.

Quarter-III: The mean decadal T_{max} is increasing in trend under all the three scenarios during quarter-III for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.952 (Fig. 2c). In the first quarter, the mean decadal T_{max} is 38.1°C being highest (38.5°C) and lowest (38.0°C) under A1B and A2 scenarios respectively. The mean decadal cofficient of variation is 3.6% being highest (4.3%) and lowest (2.6%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 10.4%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (12.6%) and lowest (7.3%) under A2 and B1 scenarios recpectively.

Quarter-IV: The mean decadal T_{max} is increasing in trend under all the three scenarios during quarter-IV for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.971 (Fig. 2d). In the first quarter, the mean decadal T_{max} is 30.3°C being highest (30.8°C) and lowest (30.1°C) under A1B and A2 scenarios respectively. The mean decadal cofficient of variation is 4.5% being highest (5.9%) and lowest (2.9%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 13.0%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (17.0%) and lowest (7.9%) under A2 and B1 scenarios recpectively.

Minimum temperature (T_{min}): The mean decadal T_{min} is increasing in trend among all the three scenarios throughout the year for the period under study with correlation coefficient (R^2) values of 0.998, 0.996, 0.978 and 0.967 respectively under the four respective quarters. The mean decadal T_{min} is expected to rise by 50.9, 15.2, 15.7 and 34.6% under four rspective quarters, the rise being more from mid towards the end of century (2051-2090).

Quarter-I: The mean decadal T_{min} is increasing in trend under all the three scenarios during quarter-I for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.998 (Fig. 3a). In the first quarter, the mean decadal T_{max} is 10.7°C being highest (11.3°C) and lowest (10.0°C) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 14.7% being highest (16.9%) and lowest (12.0%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 50.9%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (57.4%) and lowest (40.6%) under A2 and B1 scenarios recpectively.

Quarter-II: The mean decadal T_{min} is increasing in trend under all the three scenarios during quarter-II for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.996 (Fig 3b). In the first quarter, the mean decadal T_{max} is 26.8°C being highest (27.3°C) and lowest (26.2°C) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 5.0% being highest (6.0%) and lowest (3.9%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 15.2%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (18.2%) and lowest (11.8%) under A2 and B1 scenarios recpectively.

Quarter-III: The mean decadal T_{min} is increasing in trend under all the three scenarios during quarter-III for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.978 (Fig 3c). In the first quarter, the mean decadal T_{max} is 28.5°C being highest (29.0°C) and lowest (27.9°C) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 5.3% being highest (6.2%) and lowest (3.9%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 15.7%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (18.5%) and lowest (11.2%) under A2 and B1 scenarios recpectively.

Quarter-IV: The mean decadal T_{min} is increasing in trend under all the three scenarios during quarter-IV for the period under study from 2011 to 2090 with correlation coefficient (R^2) value of 0.967 (Fig 3d). In the first quarter, the mean decadal T_{max} is 13.2°C being highest (13.7°C) and lowest (12.9°C) under A1B and B1 scenarios respectively. The mean decadal cofficient of variation is 11.0% being highest (14.5%) and lowest (7.4%) under A2 and B1 scenarios respectively. The mean decadal T_{max} is expected to rise by 34.6%, the rise being more from mid towards the end of century (2051-2090). The rise in temperature is highest (46.6%) and lowest (21.8%) under A2 and B1 scenarios recpectively.

The decadal rainfall decreases significantly among the eight decades from 2011-2090, showing the decrease more from mid to end of 21st century. The annual rainfall is expected to be highest (774.8 mm) during 2011-20 followed by 2021-30 (767.3 mm) and lowest during 2081-90 (672.4 mm). The decadal maximum and minimum temperatures are expected to rise by 18.6, 9.3, 10.4 and 13.0% and 50.9, 15.2, 15.7 and 34.6% respectively under the four rspective quarters, showing more increment in T_{min} from mid to end century (highest under first quarter followed by fourth and minimum under second quarter). This type of studies could be helpful in planning the cropping pattern and water resource management to mitigate the impact of climate change and variability during the 21st century, particularly in central Indian Punjab.

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